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THE UNIVERSITY OF WARWICK

Nitrogen UK

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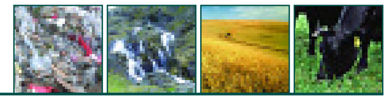

Biffaward Programme on Sustainable Resource Use

Objectives
This report forms part of the Biffaward programme on sustainable resource use. The aim of this programme is to provide accessible, well researched information about the flows of different resources through the UK economy based either singly, or on a combination of regions, material streams or industry sectors.

Background
Information about material resource flows through the UK economy is of fundamental importance to the cost-effective management of resource flows, especially at the stage when resources become 'waste'. In order to maximise the programmes full potential, data will be generated and classified in ways that are both consistent with each other, and with the methodologies of the other generators of resource flow/waste management data. In addition to the projects having their own means of dissemination to their own constituencies, their data and information will be gathered together in a common format to facilitate policy making at corporate, regional and national levels.

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Project Team
This project was primarily funded by Biffaward under the Landfill Tax Credit Scheme, with additional contributions from the Department for Environment, Food and Rural Affairs (Defra).

Acknowledgments
Throughout the project, the team was assisted by a variety of stakeholders who raised issues and gave feedback, enabling real issues to be highlighted and practical solutions to be proposed. In particular, we would like to thank the following individuals:
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* Conor Linstead, Forum for the Future
* Peter Costigan, Defra
* Nina Sweet, Environment Agency
* Keir McAndrew, Scottish Environment Protection Agency
* Ann Morton, HRI Wellesbourne

Many other stakeholders also contributed. Although too many to mention by name, their cooperation was gratefully received.

Biffaward investing in the environment

Nitrogen Mass Balance Foreword
The concept of developing an understanding of material resource flows through our complex economy - in terms of inputs, intermediate processes and outputs might at first seem, to the uninitiated, an arcane and pointless exercise. The reality is that for many of us we are more accustomed to being exposed to the financial flows of costs, income and sales values rather than the issues that surround the corresponding environmental costs.

Indicative data from research establishments around the world, however, suggest that for every tonne of consumed output there is an embedded (or hidden) trail of between 10 and 20 tonnes which creates the unseen "baggage" of pollution which it is thought is now resulting in radical changes to the geomorphology and biosphere of space ship earth.

This study into nitrogen is one of around 40 similar snapshot approaches to the nature of those resource flows in terms of UK regions, industry sectors and - in this case - specific materials. As such, nitrogen joins complementary studies into carbon and methane (a full listing of other studies is contained in this volume). The comment "we are fertilizing the earth on a global scale and in a largely uncontrolled experiment" in the early pages of this volume sums up the specifics of this particular study. CO^2 in comparison could be relatively uncomplicated. We are on the threshold of understanding the potential destructive power of just under 5 million tonnes of reactive nitrogen produced by our economy each year - and more significantly how those destructive reagent properties impact not just the atmosphere, but also groundwater, the oceans, the troposphere and a broad range of other media.

Much of those impacts are in turn created by our species' need for electrical energy, heat and the ability to feed ourselves. In reality, our route to nitrogen to satisfy those requirements could be radically different - but substantial structural shifts need to occur in relation to the interaction between the way we sequester and modify carbon in our environment. We in the waste industry increasingly recognise the challenge of those shifts - particularly in relation to the use of bio-organic systems to convert waste into renewable energy and fertilizers. This study forms a key part in highlighting where opportunities exit to accelerate that process through the use of policy, regulatory and fiscal instruments. Much of this thinking is still in its infancy but it is to be hoped that nitrogen producing sectors come to terms with the scale of their impacts and the opportunity for their amelioration at a time of mounting concern that the loading factors for these substances are now reaching critical levels.

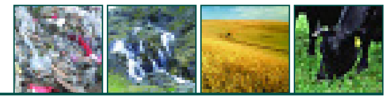
These studies were originally funded through the Biffaward Programme on Sustainable Resource Use - a framework that eventually committed around £8m to underlining the value of this process. Regrettably, changes in 2003 to the rules governing the awards of such funds were altered with the result that this suite of work could - at worst - be left to moulder on recipients' book shelves.

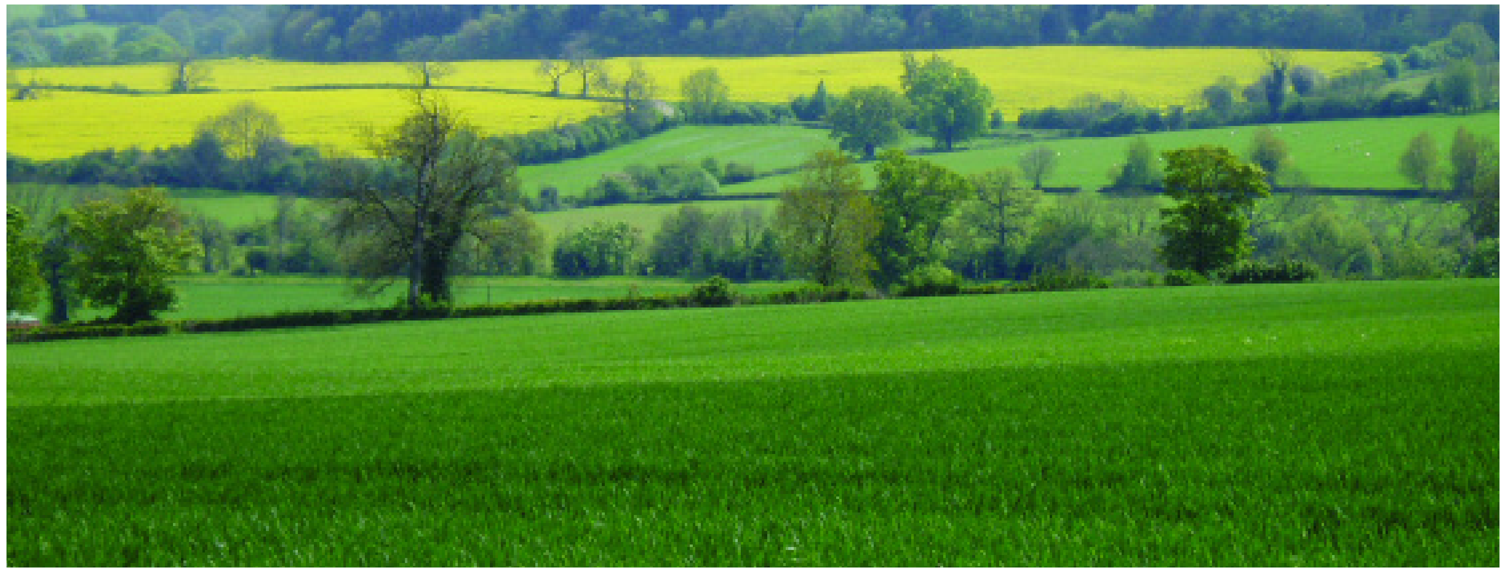
It is hoped that you - the reader - will take on board the need to move this work forward within a cohesive national framework. As this report is being released - in 2005 - the government is at an early stage in consulting on the development of a national waste data framework. Such a step is an important first stage in developing a national resource flow database. It is a mammoth undertaking but one which future generations will thank us for as an important pre-requisite in improving the quality, range and depth of our environmental policy making. Information gives wisdom, authority and control. Let us hope that those with the ability to take this initiative forward can exercise each on behalf of those future generations.

Peter Jones
Director - Development and External Relations
Biffa Ltd

0 Contents

1 Introduction





1.1 Why nitrogen?

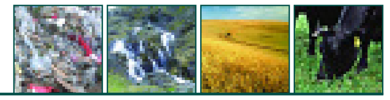
"There is an emerging recognition that there is a global nitrogen problem, with some areas receiving nitrogen compounds in quantities that lead to unwanted ecosystem changes, such as excessive plant growth. Human activities now contribute more to the global supply of fixed nitrogen than do natural processes. We are fertilizing the Earth on a global scale and in a largely uncontrolled experiment". Global Environment Outlook, UNEP (1999).

Nitrogen is an essential element. It is essential for plant growth and therefore it is also essential for human survival, since plants underpin our food chain. It is essential because it forms part of the structure of deoxyribonucleic acid (DNA), ribonucleic acid (RNA) and proteins and is therefore an integral part of all plants and animals. Although nitrogen surrounds us, the air we breathe is mainly nitrogen, this form is unavailable to most plants and animals, including humans, so we must obtain our nitrogen through the food we eat.

However, nitrogen is also a pollutant. Nitrate from agriculture and sewage promotes eutrophication while the gaseous products, nitrogen and nitrous oxides from combustion contribute to global warming. The goal for nitrogen management should be to strike a balance between what is essential for human maintenance but avoiding the pollution caused by excess.

Eutrophication

Eutrophication is the production of abundant organic matter, sometimes called algal blooms, in inland and marine waters; caused by an excess of nitrates and phosphates. These algal blooms exhaust the water's oxygen content resulting in a loss of animal and plant life and subsequent reduction in organism diversity



1.2 The nitrogen cycle

The nitrogen cycle (Figure 1) is one of the more complex of the natural elementary cycles. Nitrogen is incorporated within many different compounds and can follow many pathways. The biggest reservoir of nitrogen is the atmosphere which contains 78% di-nitrogen (N_2), this is an non-reactive gas. The biggest primary users of nitrogen are plants, however they require a reactive compound, either ammonium (NH_4) or nitrate (NO_3). N_2 can be converted into these compounds via nitrogen fixing bacteria, lightning strikes and to a lesser extent, forest fires. Soil processes and manures produce nitrous oxide (N_2O) and ammonia (NH_3), and combustion, nitrogen oxides (NO_x). Denitrification back into N_2 occurs in both soil and water. Historically the natural nitrogen cycle has been in balance, with nitrification being matched by denitrification.

The natural nitrogen cycle has been augmented by humans. Industrialisation throughout the last two centuries has introduced two new major sources of reactive nitrogen. The first is combustion, where nitrogen in fuel and also in the air combines to produce the nitrogen oxides, NO and NO_2, collectively known as NO_x. Secondly, the demand for food and the need for fertilizer led in 1913 to the introduction of the Haber-Bosch process where ammonia, synthesised from atmospheric N_2 and natural gas, is converted into inorganic nitrogen fertilizer. These two processes have resulted in a doubling of the reactive nitrogen within the biosphere.

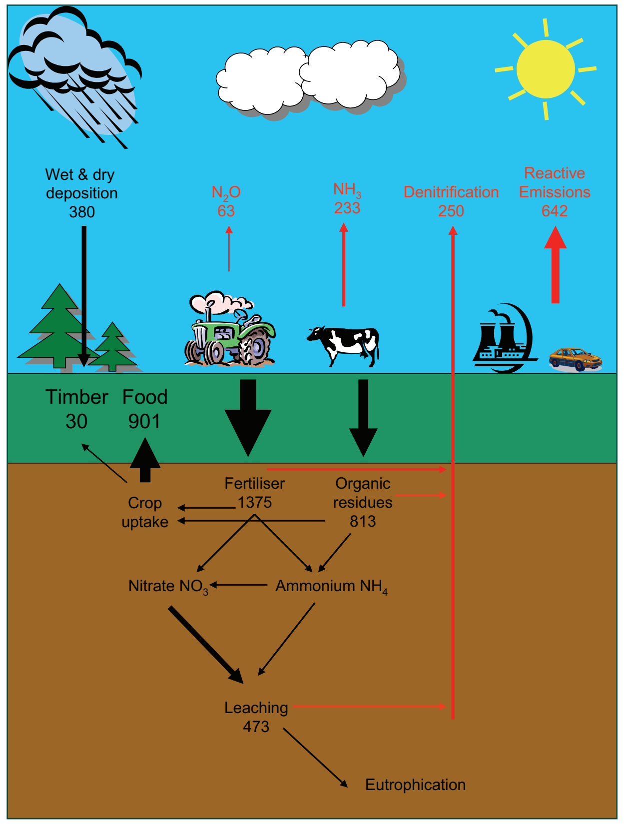


Figure 1. The nitrogen cycle.

The Harber-Bosch Process

This chemical process produces ammonia by combining nitrogen from the air with hydrogen under extremely high pressures and moderately high temperatures. The source of hydrogen is normally natural gas. The lower the temperature and the higher the pressure used, the greater the proportion of ammonia yielded in the mixture. For commercial production, the reaction is carried out at pressures ranging from 200 to 400 atmospheres and at temperatures ranging from 400 to 650 C (750 to 1200 F).

1.3 The problem with nitrogen

In the last ten years, the global scientific community has started to recognise the problems brought about by the increased use of nitrogen fertilizer. Research is underway to understand the effects and to reduce the impact of the ever increasing demand. The GANE project suggests that "whereas the global carbon cycle is being perturbed by less than 10%, the global reactive N cycle is being perturbed by over 90%". Galloway (1998) suggests that global biological nitrogen fixation, that is the natural nitrogen cycle, fixes about 90-130 million tonnes of nitrogen per annum. In addition, human activities through combustion of fossil fuels, fertilizer production and the cultivation of legume crops add another 150 million tonnes nitrogen.

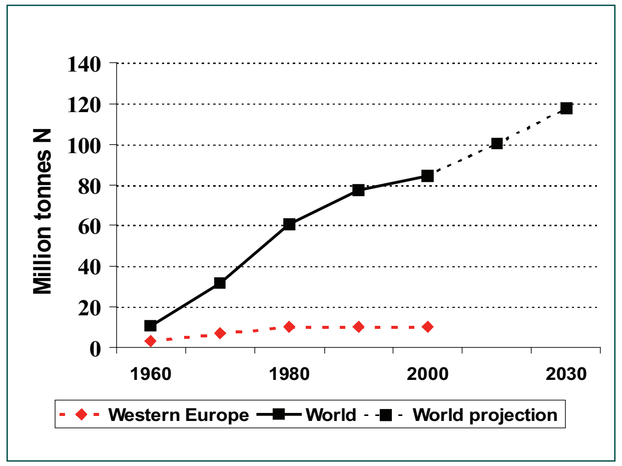


Figure 2. World consumption of nitrogen fertilizer in the last 40 years

The GANE thematic programme aims to study the problems arising from nitrogen enrichment of our environment. The programme is centred around three themes which will attempt to answer questions concerning:

Theme 1:
the transformation and pathways of reactive N

Theme 2:
quantify N fluxes at large temporal and spatial scales,

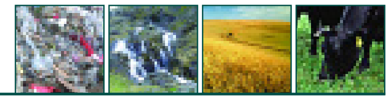
Theme 3:
on N-sensitive semi-natural ecosystems and coastal waters

The global demand for food will continue to drive the use of ever increasing amounts of inorganic nitrogen fertilizer (Figure 2). A major limitation to crop growth and the cause of excessive reactive nitrogen in the environment is that plants use nitrogen fertilizer inefficiently. Only half of the nitrogen fertilizer applied is taken up by the growing crop, the other half is lost to the environment. Even the half used by growing plants is eventually returned to the environment, either as the product of bacterial decomposition, animal manures or human sewage. This increased enrichment of our biosphere has been going on since 1910 and has resulted in greater concentrations of nitrogen within our soils, oceans and atmosphere. The enrichment is most easily seen in the increasing levels of eutrophication in inland and marine waters caused mainly by the leaching and run-off of agricultural nitrates (MacGarvin 2001, Scottish Executive 2001)

Global warming is normally associated with the increasing level of carbon dioxide (CO_2) in the atmosphere. However nitrous oxide (N_2O) is also a very long lived, >100 years, greenhouse gas. Soil acidification and loss of plant diversity are caused by aerial deposition of nitrogen, principally as the gases nitrogen oxide, nitrogen dioxide and ammonia.

Aerial deposition

Aerial deposition is the total of wet and dry deposition. Dry deposition occurs when a nitrogen compound is removed from the atmosphere by contact with the surface of the land or an aerial-borne particle that subsequently falls to the ground. Wet deposition occurs when a nitrogen compound is dissolved into water vapour and is returned to the land surface as rain.



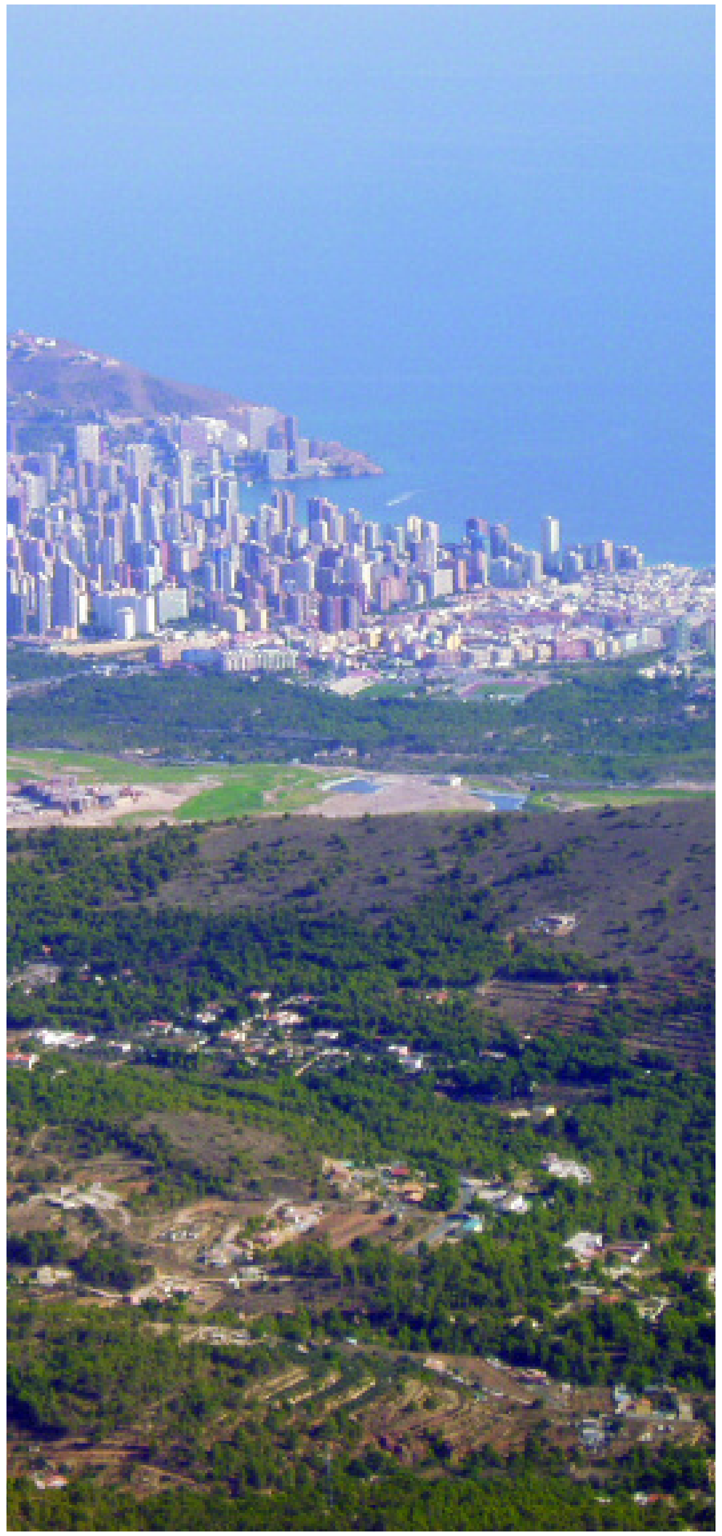
1.4 The mass balance concept

The aim of this project is to prepare a nitrogen mass balance for the United Kingdom. The first law of thermodynamics states that matter is neither created nor destroyed by any physical transformation process. When this principle is applied to an economy, it means that inputs, outputs and accumulations should balance. This mass balance will quantify all the nitrogen products and compounds within these three categories, enabling sources, sinks and flows to be identified. This approach should yield a clear picture of what is happening to nitrogen within the UK. Once this has been established, informed decisions can be made about how effectively nitrogen is being utilised within the economy.

1.5 Project boundaries

Linstead and Ekins (2001) state in 'Mass Balance UK' that "the flow of mass within the natural environment is not of direct interest" and that "the mass of inputs, mass of outputs and the change in mass within the system should balance". Unfortunately, nitrogen by its very nature makes it almost impossible to adhere to these statements. There are examples, notably the combustion of petrol, where the end product, NO_x, contains nitrogen from both fuel and the atmosphere. Equally, it is difficult to ascertain whether the nitrate found in our rivers originated from nitrogen fertilizer or a natural soil process.

Unlike, for example, an industrial mass balance where discrete product is counted, there are many instances where nitrogen cannot be compartmentalised and the flow between input and output is continuous. So, this report cannot be considered a mass balance as envisaged by Linstead and Ekins since the flow of nitrogen between the anthroposphere and the natural environment is un-preventable, bi-directional and difficult to assess. Bearing in mind the large atmospheric pool of nitrogen that exists, these relationships are complex and therefore difficult to measure. We have attempted to quantify the nitrogen content of the UK economy, be it a resource or product, as far as available information will allow. This still leaves areas of uncertainty that are due to examples of double accounting and lack of data in the natural and man-made nitrogen cycles.



Anthroposphere

The anthroposphere (from 'anthrop' meaning human) is defined as that part of the biosphere which is affected by humans, their activities, and the products they make by transforming and recombining the biosphere's natural resources.

The geographical area covered in the report is the United Kingdom, that is England, Wales, Scotland and Northern Ireland, but excluding the Isle of Man and the Channel Islands. Data was collected for 1998 to coincide with the publication by The Environment Agency of The Strategic Waste Management Reports for that year.

In the introduction to Chapter 3, we have estimated nitrogen contained within the UK environment, that is the atmosphere, soils, marine waters and non-agricultural biomass; this is to give scale to the rest of the report.

For the sake of clarity, mass balance studies normally restrict their data collection and activities to an industrial sector, such as construction, chemical, foundry, or discrete region, such as the Isle of Wight or south-east. This study is different; nitrogen is a natural element that is present in many industries and in many forms. In solid form, e.g. fertilizer, the nitrogen is easily quantifiable but in other forms, e.g. aqueous or gaseous, it is not since it moves freely within the biosphere. For this reason some assumptions have had to be made in order that we can present the overall picture; these will be remarked upon in the appropriate sections.

1.6 Sources of information

This study is largely based on publicly available statistics. Extensive use has been made of internet-based resources from the Department for Environment, Food and Rural Affairs (Defra), The Office for National Statistics (ONS), The Environment Agency (EA) and The Department for Trade and Industry (DTI). These have been supplemented by consultation with over 80 organisations and individuals. A review of the scientific literature and UK and EC legislation was undertaken. Prior to publication a review group was convened to assess progress and a draft report circulated to stakeholders for comments. A full reference list and webliography for all text and tables is included at the end of this report.

The collection of information and data within the UK is complicated by the fact that for some sectors the four home countries report separately while for other data is combined into a UK report. For example, Defra report agricultural statistics for the UK. However, the three environmental departments covering the same area, The Environment Agency (EA), Scottish Environment Protection Agency (SEPA) and Environment and Heritage Service (EHS) of Northern Ireland report separately.

1.7 Funding

The Landfill Tax Credit Scheme, through Biffaward, provided 90% of the funding with Defra providing the remaining 10%. The Royal Society of Wildlife Trusts (RSWT) and Forum for the Future managed the project. The project was initiated in October 2001.

2 Nitrogen, forms and processes

N_2 NO_2 NO_3 NH_4

2.1 Forms

Di-nitrogen (N_2) is a gas and the most abundant form of nitrogen, comprising 78% of our atmosphere, and is the reservoir at the heart of the nitrogen cycle. Nitrogen in this form is a triple bonded molecule, and as such is practically inert.

Nitrate

Nitrate (NO_3^-) and nitrite (NO_2^-) ions are oxidised compounds of nitrogen and are highly mobile. Nitrate is the product of the biochemical oxidation of ammonium using nitrite as an intermediary (nitrification) or can be supplied in ionic form such as ammonium nitrate (NH_4NO_3) fertilizer. Nitrate is commonly found in soil and water and is one of the main forms by which plants obtain their nitrogen. In excess, nitrate can also be responsible for eutrophication.

Ammonia

Ammonia (NH_3) and the reduced ammonium ion (NH_4^+) can be found in water, soil and air in aqueous or gaseous form. Ammonia is released during the breakdown of organic matter; ammonia can also be released during combustion. Like nitrate, ammonium is used by plants as a source of nitrogen. Industrial synthesis of ammonia by the Haber-Bosch process is the basis of all nitrogen fertilizers. Ammonia, either through direct deposition or in rain to semi-natural (not agricultural) land causes acidification of soils and water and leads to a change in the mix of plant species. This loss of bio-diversity is a serious problem in some areas, particularly in ecosystems that are naturally low in available nitrogen.

Organic nitrogen

Nitrogen is a component of all amino acids, which are the building blocks of proteins, and proteins are found in all organic material. Organic nitrogen is found in both living and decomposing organic matter, in all biomass, soil and water. Soils contain large amounts of organic nitrogen resulting from the breakdown of plant roots, leaves and other plant materials, in addition to dead animals, insects, microorganisms and manures. Soil microbes convert this organic nitrogen into inorganic forms that plants can use. Water also contains large amounts of organic nitrogen, mainly resulting from the excess nitrogen contained within the human diet which enters the water supply via the sewage system.

Nitrogen oxides (NO_x)

Nitrogen oxides is the generic name for nitrogen oxide (NO) and nitrogen dioxide (NO_2). These gases are produced by soil bacteria and also the combustion of fuels. They are implicated in global warming, acid rain and nitrogen deposition, and in the formation of precursor pollutants including ozone (O_3).

Nitrous oxide (N_2O)

Nitrous oxide is a gas released from the soil during the breakdown of organic matter and nitrogen fertilizers. It is also produced in some industrial processes such as the production of nylon. N_2O has a global warming potential over 200 times greater than that of CO_2.

2.2 Processes

Nitrogen Fixation

Atmospheric nitrogen (N_2) can be fixed, that is converted into other nitrogen compounds, by two main methods in the natural world. Bacteria in the soil can convert atmospheric nitrogen into ammonia and lightning strikes can convert it into nitrogen oxides. A very small amount is fixed during forest fires but at the same time, previously fixed nitrogen is also lost in this process. In the UK, conversion by lightning strikes is insignificant. However, bacterial fixation is in the region of 200,000 to 400,000 tonnes per annum. In aquatic environments, blue-green algae have the ability to fix dissolved nitrogen. Nitrogen is also fixed industrially by the Haber-Bosch process.

Mineralization

The microbial breakdown of organic matter, mainly in soil, to produce ammonia.

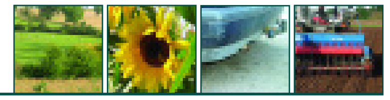
Nitrification

The bacterial conversion of ammonia to nitrate. There are a number of eventual pathways associated with fixed nitrogen. Some are converted back to N_2 gas thus escaping into the atmosphere, whist some is emitted as N_2O or NH_3 gas.

Denitrification

The bacterial conversion of nitrates and nitrites to atmospheric nitrogen, and to nitrous oxide. Denitrification of 'reactive' nitrogen back to N_2 occurs mainly in power generation with smaller amounts occurring naturally in the environment. Denitrification cannot easily be measured, but is assumed to be the difference between input and output.

3 Nitrogen in the UK economy



As was stated in the introduction, the aim of this project is to quantify the total nitrogen content and nitrogen flow through the UK economy and to place this information against the wider backdrop of nitrogen in the natural environment. The amount of nitrogen in, above, below and surrounding the UK is vast. In order to understand the role and importance that reactive nitrogen plays in the UK economy, it is first of all necessary to gain an idea of the relative proportion of natural to reactive nitrogen. This is shown in Figure 3, which is not to scale.

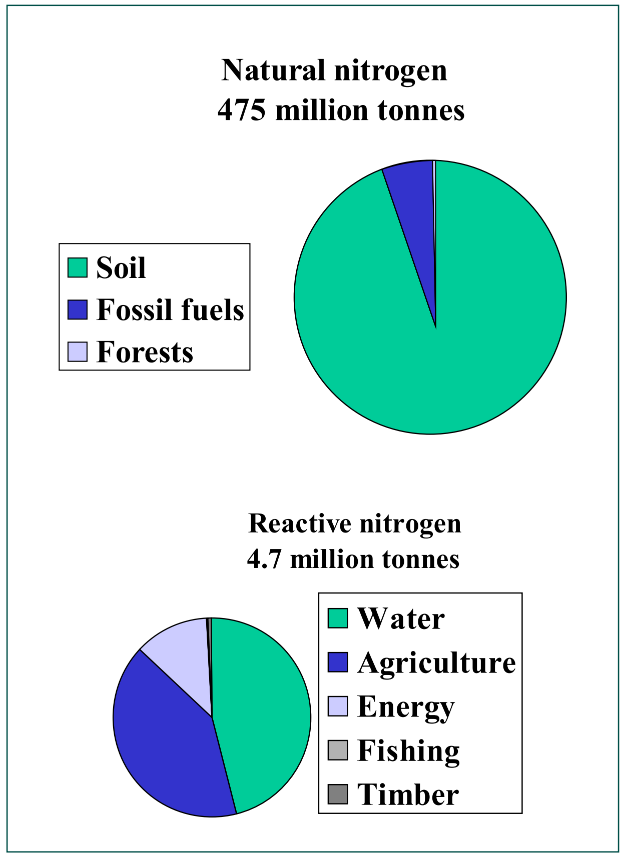


Figure 3. Natural versus reactive nitrogen in the UK

Figure 3 does not include the biggest reservoir of nitrogen in the UK which is the atmosphere which contains 78% nitrogen in the inert N_2 form, meaning that the skies above the UK contain a staggering 200 billion tonnes. The Royal Society (1983), in their report, 'The Nitrogen Cycle of the UK' suggest that UK soils contain approximately 450 million tonnes nitrogen. Reserves of fossil fuels hold approximately 24 million tonnes and a further one million tonnes are held in the 2.8 million ha of UK woodlands.

In contrast, the overall quantities of reactive nitrogen are small. Reactive nitrogen in the natural environment is mainly nitrate, ammonia, ammonium, and various types of nitrogen oxides. The total amount of reactive nitrogen circulating within the UK economy is approximately five million tonnes per annum. Whilst this appears small in comparison to the reservoir of natural nitrogen in the atmosphere and soils, its impact is significant and has far reaching consequences on the environment.

3.1 Introduction

Every year, just over two and half million tonnes of 'new' nitrogen is introduced into the UK economy. Over half of this is contained within agricultural fertilizers, while the rest is divided between fossil fuels and timber. Of course the nitrogen isn't really new, merely converted by industrial or natural processes from the natural pool to the reactive. This is shown in Figure 4. The input is made up of 'natural' nitrogen contained in fossil fuels and timber, and 'reactive' nitrogen contained in fertilizers. However, the output contains only reactive nitrogen. We assume that the difference in totals between the input and output could be attributed to denitrification to N_2 although we were unable to find data to support this view.

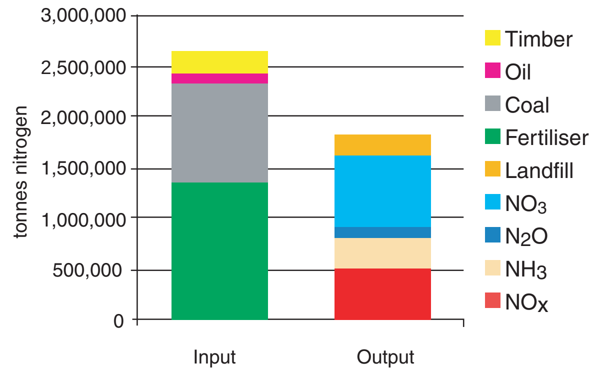
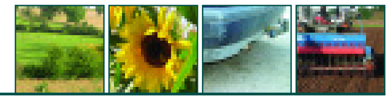


Figure 4. Annual input and output of new nitrogen in the UK economy



Chapters 1 and 2 have illustrated the diversity, and some of the difficulties, in drawing up a nitrogen mass balance. In order to simplify the approach and to make best use of the mass balance reports available from other industrial sectors we have categorised the nitrogen in the UK economy using the standard industrial classification codes (SIC).

Table 1 contains an overview of the industrial sectors and our estimation of the annual nitrogen content within those sectors. Each sector will be considered in greater detail later in this chapter. In additional to the sectors listed in Table 3 there are sections on gaseous output and water which do not fall into any single SIC code.

Table 1. UK sector (natural & industrial) and nitrogen content ('000 tonnes)

SIC Code	Sector	Sector contains	Annual input	Annual output
	Atmosphere	200,000,000	n/a	n/a
	Soils	450,000	2,998	1,718
	Fresh Water	~1,000	~500	420
0100	Agriculture, hunting and forestry	~5,000	3,584	2,735
0500	Fishing	n/a	12	21
1000	Mining and quarrying	24,000	1,074	544
1500	Food products	n/a	1,138	962
1600	Tabacco	n/a	10	10
1700	Textiles and textile products	n/a	10	10
1900	Leather and leather products	n/a	10	10
2000	Wood and wood products	~1,000	48	35
2100	Pulp, paper and products	?	13	13
2400	Chemical products and man-made fibres	n/a	?	1,500-3000
2500	Rubber and plastic products	n/a	4	4
4500	Construction	n/a	11	11
5500	Hotels & restaurants	n/a	?	?
9000	Sewage and refuse disposal	n/a	?	230

n/a = not available

SIC Codes

The UK Standard Industrial Classification of Economic Activities (UK SIC(92)) is used to classify business establishments and other statistical units by the type of economic activities they are engaged in.
(Source - National Statistics)

3.2 Agriculture and forestry

3.2.1 Agriculture inputs

The agricultural sector deals almost exclusively with the growing of biomass, be it plant or livestock, and it dominates both the nitrogen cycle within the UK and the total input of nitrogen into the economy. Agriculture is the biggest user of nitrogen and due to inherently poor conversion rates between nitrogen supply and nitrogen assimilation, also the biggest producer of nitrogen-based pollutants.

As long ago as 1850 it was recognised that, in order to meet the food requirements of a growing population, plants nutrients in addition to those provided by the existing farming systems would be required. Nitrogen was recognised as the key element in achieving greater yield and productivity so additional supplies of nitrogen were required. Initially, different types of manures were used, especially guano. However, it was soon recognised that this source was limited so attention turned to industrial synthesis of nitrogen fertilizer. Since 1913, nitrogen fertilizer has been produced from ammonia using the Haber-Bosch process and it is this input which dominates agriculture in the UK. In 1998, the Fertilizer Manufacturers Association (FMA) estimated that UK fertilizer consumption was 1.375 million tonnes nitrogen, of which approximately 550,000 tonnes was imported.

Nitrogen inputs to agriculture fall into two categories (Table 2): those which are readily quantifiable and those which have to be estimated. The quantities and use of nitrogen fertilizer, seed and sewage sludges are the subject of annual reporting and are fairly reliable. However, the quantities of animal manures, arable and vegetable residues, together with wet and dry deposition, are not. Natural nitrogen fixation in the soil adds further uncertainty.

Manures, which for the purposes of this report include slurries, are the by-product of livestock production and contain large and valuable amounts of nitrogen. Manures have been used since the beginning of agriculture as a source of plant nutrients. However, the management of manures has always been haphazard. While they are recognised as containing valuable plant nutrients, their method and timing of application has not always made optimal use of these nutrients. In the past, manures have been applied to agricultural land during winter and wet periods, resulting in nitrogen being lost to the atmosphere and to rivers via leaching, without being used by a growing crop. However, recent designation of nitrate vulnerable zones (NVZs) and better farming practices may have reduced losses of nitrogen from manures.

Table 2. Inputs to agriculture ('000 tonnes)

Product	Product quality	Nitrogen content
Nitrogen Fertilizer (2.1)		1,375.0
Animal Feedstock (2.2)	19,000	570.0
Seed (2.3)	883	17.7
Sewage Sludge (2.4)	504	25.2
Animal Manures (2.5)	140,000	725.0
Arable and Vegetable Residues (2.6)	10,029	62.8
Wet and Dry Deposition (2.7)		380.0
N_2 Fixation (2.8)		428.4
Total		**3,584.1**

The total amount of livestock manures which are returned to agricultural land every year has been estimated by a number of workers (Chambers et al., 2000; Frost & Stevens, 2000; EA SWMA 2000). Most involve estimation of livestock numbers multiplied by an output based on livestock type. The combined production of manure's and slurries, from both housed and outdoor livestock is estimated to contain 725,000 tonnes nitrogen per annum. Unfortunately, nitrogen is readily lost from manures as ammonia which NETCEN estimate to amount to 221,529 tonnes nitrogen.

Ammonia in the UK

The biggest contributors to the UK's ammonia emissions are cattle (44%), poultry (14%), pigs (9%) and nitrogen fertilizers (9%); with sheep and non-agricultural sources contributing the rest. Methods for reducing ammonia emissions from livestock include improved methods of manure management and the use of different types of fertilizer (Defra, 2002)

Arable and vegetable residues comprise a number of different materials but it is essentially the non-marketable part of any growing crop, be it straw from a cereal crop or stalk and leaves from Brussels sprouts, and can comprise between 20 - 80% of the total plant weight. At harvest, this portion is normally left in the field and ploughed in as part of the normal tillage operation. In the case of brassicas, the residue can contain up to 200 kg ha^{-1} nitrogen (Rahn, 1992).

Aerial deposition is a major input of nitrogen to the UK terrestrial environment. The main sources of nitrogen contained within the atmosphere are twofold: agricultural production and the combustion of fossil fuels. Agriculture emits two main types of gaseous nitrogen, ammonia and nitrous oxide, while the combustion of fossil fuels, mainly in power generation and road transport, emits nitrogen oxide and nitrogen dioxide. A large percentage of this nitrogen is returned to the terrestrial environment through wet and dry deposition, estimated at 380,000 tonnes (NEGTAP, 2001) per annum.

Natural biological fixation of N_2 by free living organisms and bacteria, and by nodulated plants, e.g. legumes, is another area of uncertainty. The Royal Society's estimates of annual N_2 fixation by varying plants ranges from 4 kg ha^{-1} for cereals up to 300 kg ha^{-1} for lucerne. Our UK total of 428,374 tonnes is arrived at by multiplying Defra's figures for agricultural land by the Royal Society estimates for fixation.

3.2.2 Output from agriculture

Table 3. Output of nitrogen from agriculture ('000 tonnes)

Product	Product quantity	Nitrogen content
Food & animal feedstuffs (3.1)	64,559	901.2
Timber (3.2)	7,587	30.4
Manures & slurries (3.3)	145,000	725
Straw & vegetable residues (3.4)	10,029	62.8
Nitrate (NO_3) leaching (3.5)		473
Ammonia (NH_3) (3.6)	279	229.8
Nitrous oxide (N_2O) (3.7)	99	63.1
Denitrification to N_2 (3.8)		~250.0
Total		**2,735.30**

Defra and the Forestry Commission, respectively, collect and publish returns on food and animal feedstuffs, and timber production. All other outputs from agriculture are estimates. An unusual result is that the biggest output in terms of volume is not food but manure, this is because meat production is very inefficient.

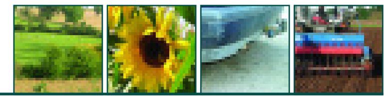
Table 3 shows that food and animal feedstuffs contain the largest proportion of the nitrogen contained in agricultural output. Table 4 shows this was calculated by multiplying total production volume (Defra) by an average nitrogen percentage (Food Standards Agency 2002).

Nitrogen recovery in agriculture

Plants recover, on average, 50% of the nitrogen applied as fertilizer; unfortunately, this means 50% is 'wasted'. Livestock production using a mix of grass and cereal based protein concentrates is even less efficient, with beef production recovering only 9% of nitrogen contained in feed.

Table 4. Breakdown of UK food & feedstuffs production ('000 tonnnes)

Product	Product quantity	% Nitrogen	Nitrogen content
Wheat	15,465	1.72	266.0
Barley	6,630	1.60	106.7
Oats	587	1.50	8.8
Mixed Corn	108	2.00	2.2
Peas for Harvesting	259	3.80	9.9
Field Beans	378	1.50	5.7
Potatoes	6,417	0.33	21.2
Sugar Beet	10,002	2.00	200.0
Oil Seed Rape	1,498	3.05	45.7
Linseed	140	1.50	2.1
Other Vegetables	2,852	0.62	17.7
Small Fruit	277	0.10	0.3
Mutton and Lamb	386	2.50	9.7
Beef and Veal	699	3.00	21.0
Pork	1,135	2.50	28.4
Poultry	1,532	2.75	46.0
Eggs	808	3.00	16.2
Milk	14,220	0.50	71.1
Butter	137	0.08	0.1
Cheese	366	3.00	11.0
Cream	267	0.50	1.3
Milk Powder	204	4.00	8.2
Condensed Milk	192	1.00	1.9
Total	**64,559**		**901.2**



The UK is one of the least afforested countries in Europe with woodland covering 2.8 million ha, that is 11.6% of the UK land area, compared to a European average of 46% (Forestry Commission, 2001). Timber production in 1998 amounted to 7.2 million cubic metres of underbark, which represented 15% of UK requirements, the balance being met from imports. Woodlands are not fertilised but receive their nitrogen input from atmospheric deposition which, assuming an average deposition rate of 33 kg ha^{-1}, amounts to 89,100 tonnes nitrogen (NEGTAP, 2001). Nitrogen removed in harvested timber is estimated at 30,400 tonnes per annum.

Nitrogen losses to the environment from agriculture come in many forms: nitrate leaching in soil water, gaseous nitrous oxide and ammonia from soil processes, nitrous oxide from the breakdown of fertilizer, volatilization of ammonia from slurries and manures, and nitrogen oxides from agricultural machinery. Leached nitrogen ends up in ground or surface water while gaseous losses will eventually return to land or sea via deposition.

Of major concern within agriculture is the emission of gaseous nitrogen, particularly ammonia and nitrous oxide, because they are the result of biological processes and difficult to control. Agriculture is the single biggest producer of ammonia in the UK, so recent work has concentrated on improved techniques and management of livestock housing to reduce emissions. Nitrous oxide emissions can be reduced by improved tillage of agricultural land. Whatever the source of gaseous nitrogen the majority is returned to agricultural land by either wet or dry deposition which unfortunately is uneven. Dry deposition of ammonia is especially variable since the rate of deposition depends on many factors including concentration, prevailing wind speed and direction, distance from source and the type of land cover. All agricultural land, semi-natural land and woodland have different ammonia compensation points and therefore different deposition rates (Sutton et al., 1998).

Nitrate leaching is also difficult to estimate although various estimates have been prepared. The Royal Society report 'The Nitrogen Cycle of the UK' (1983) suggested that one-third of all applied inorganic nitrogen fertilizer was lost as nitrate leaching from arable soils; using the figure of 1,375,000 tonnes nitrogen applied would mean 458,333 tonnes loss due to leaching. Silgram et al. (2001) made a comparison between the standard IPCC model for calculating national nitrate leaching, where leaching accounts for 30% loss of all applied nitrogen, and two other approaches: a modified IPCC and NEAP-N, a UK simulation model. Their simulations showed that leaching ranged between 39 and 88 kg N ha^{-1}, resulting in a total loss of between 455,064 and 1,026,810 tonnes nitrogen.

The most up to date estimate of UK-wide nitrate leaching has been provided by ADAS using the MAGPIE simulation model. They estimate that agricultural land leaches approximately 40 kg ha^{-1} nitrogen per annum and non-agricultural land 3 kg ha^{-1} which, using Defra figures for UK land holdings, suggests that total nitrate leaching amounts to 472,598 tonnes nitrogen (Lord & Anthony, 2000). An alternative approach by the same workers (Lord et al. 2002) estimates the nitrogen surplus, or the pollution potential, at 115 kg ha^{-1} or 1.34 million tonnes.

Intergovernmental Panel on Climate Change (IPCC)

Recognising the problem of potential global climate change, the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) established the Intergovernmental Panel on Climate Change (IPCC) in 1988. It is open to all members of the UN and WMO. The role of the IPCC is to assess on a comprehensive, objective, open and transparent basis the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation. The IPCC does not carry out research nor does it monitor climate related data or other relevant parameters. It bases its assessment mainly on peer reviewed and published scientific/technical literature.

Schematic mass balance

An alternative way of looking at sectorial mass balances is to quantify inputs and outputs and leave out the recycled portion. This gives an excellent overview but is short on detail. However, what it does when applied to agriculture is to highlight the large amount of nitrogen that is recycled within the system in livestock manures and slurries, crop residues, gaseous emissions and depositions, and livestock grazing and feedstocks.

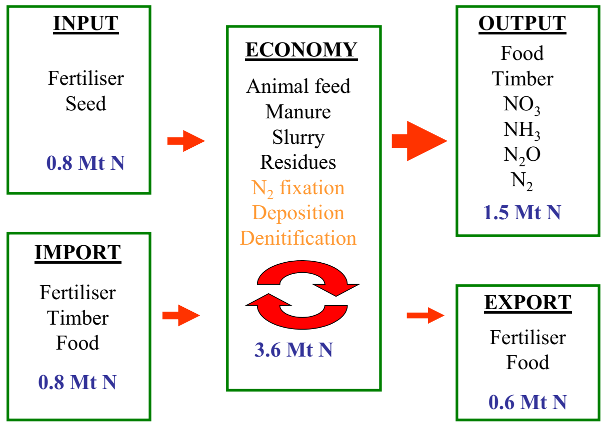


Figure 5. A mass balance for the agricultural industry

The total nitrogen which the UK discharges to its marine waters is made up of nitrate leaching from agricultural land, organic nitrogen contained within sewage effluent and limited amounts from industry. The Royal Society (1983) estimated the nitrogen content of sewage at 155,000 tonnes while the Select Committee on Environment, Transport and Regional Affairs suggest 178,850 tonnes. By combining these figures with those from the MAGPIE model, the amount of nitrogen entering the UK's river system should be between 627,000 and 652,000 tonnes. Alternatively, using the 'pollution potential' figure and adding the nitrogen contained in sewage would give a value of over 1,500,000 tonnes. It is likely that the true value lies somewhere in between. Using river flow and nitrate concentration data, Defra estimate that 420,000 tonnes nitrogen enters UK marine waters annually. The difference between Defra's estimation and the 'true' value represents an 'unknown' in the nitrogen balance. The 'missing' nitrogen may be denitrified to N_2 or N_2O in the terrestrial environment or stored as nitrate in ground and surface waters.

Information on the volume of livestock manures and slurries produced in the UK is available from a variety of sources. In England and Wales, the Environment Agency estimate almost 60 million tonnes of manures and slurries from housed livestock, while Chambers et al. (2000) puts this figure at 67 million tonnes, containing 340,000 tonnes nitrogen, with another 45 million tonnes of manures excreted by grazing animals. SEPA's 'Strategic Review of Organic Waste Spread on Land' gives a figure for Scotland of 25 million tonnes manure per annum. In Northern Ireland, a pro-rata estimate (Frost & Stevens, 2000) puts the quantity at around 15 million tonnes. We estimate total manure and slurry arisings for the UK are 145 million tonnes, containing 725,000 tonnes nitrogen.

Manures have different and opposing roles in agriculture since they can be both a resource and a waste. Nitrogen is a cost in agriculture systems, so in this respect, the nitrogen contained within manures is a valuable asset, however, applied in excess, manures can become a pollutant. Management of manures is a balancing act between good and bad and is increasingly important at both farm and national level. Manures need to be managed to maximise their nutrient content but also to minimise their adverse environmental impact; this is partly recognised in the rules and regulations relating to Nitrate Vulnerable Zones (NVZs) where the amount and timing of manure application is controlled.

3.2.3 Import and export

Efficient, cheap transport has enabled the import and export of low value bulk products such as nitrogen fertilizer and high value items such as fresh food. The gap between imports and exports is now 205,000 tonnes of nitrogen per annum.

Table 5. Major imports and exports of nitrogen ('000 tonnes)

Sector	Nitrogen import	Nitrogen export
Food and feedstuffs (5.1)	236.6	200.2
Timber (5.2)	47.6	7.1
Fertilizer (5.3)	545.8	418.4
Total	**830.0**	**625.7**

3.3 Fishing

The UK fisheries industry can be divided into two components: sea fisheries with landings of 614,000 tonnes fresh fish and aquaculture adding another 137,611 tonnes. Assuming that fish have a nitrogen content of 2.75% (McCance & Widdowson, 1992), this equates to 20,669 tonnes nitrogen. Fish taken by UK vessels, but landed outside the UK amounted to 371,000 tonnes (10,203 tonnes nitrogen).

One input into Scottish aquaculture which should be quantifiable is fish feed. However no data was found so, based on MacGarvin (2000), we calculated that 165,600 tonnes (12,420 tonnes nitrogen) was used in 1998. The same report also estimates that 6,900 tonnes nitrogen entered the Scottish marine environment as a result of wasted feed.

UK marine waters

Establishing project boundaries for either fish landings or the extent of pollution is an arbitrary exercise in open seas. Legislative boundaries, such as the 12 nautical mile (nm) territorial limit, and the Habitats Directive limit, applying to the UK continental shelf (UKCS) and super adjacent waters up to a limit of 200 nm, cannot be applied to the movements of either fish or pollutants. In terms of size, the area contained within the UK 12 and 200 nm limits is 65,517 square miles (169,688 km^2) and 279,598 square miles (724,155 km^2), respectively. In comparison, the land area of the UK is 94,216 square miles (244,019 km^2).

Table 6. Inputs to the marine environment ('000 tonnes)

Product	Product quantity	Nitrogen content
Land based & riverine (6.1)		420.0
Deposition (6.2)		153.0
Feedstuffs for aquaculture (6.3)	165,000	12.4
Total		**585.4**

Table 7. Outputs from the marine environment ('000 tonnes)

Product	Product quantity	Ntrogen content
Landed fish (7.1)	614	16.9
Aquaculture (7.2)	138	3.8
Denitrification to N_2 (7.3)		?
Total		**20.7**

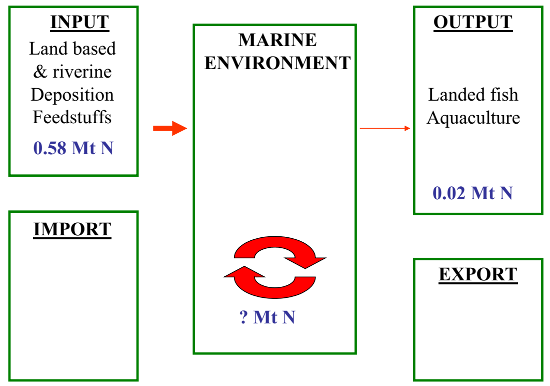
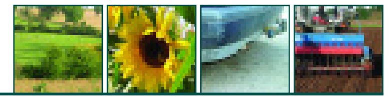


Figure 6. A mass balance for the marine environment industry

In section 3.2.2 it was stated that approximately 600,000 tonnes of nitrogen enters the UK river system, although not all of this enters the open sea. Nixon et al. (1996) suggested that between 30-65% of riverine nitrogen is retained or denitrified in estuarine environments and that all riverine nitrogen is either denitrified or buried in sediments before reaching open seas. He added that 'denitrification in shelf sediments exceeds the combined N input from land and atmosphere by a factor of 1.4-2.2'. Hydes et al. (1999) go further by suggesting 'that shelf seas like the North Sea may in fact be sinks for nitrogen in spite of the large terrestrial inputs to these areas' and 'may be significant net sinks for nitrogen in global budgets'. We estimate, using the data for nitrate leaching and waste waters that between 627,000 and 1,500,000 tonnes of nitrogen enters the UK river system. However, the amount actually reaching the marine environment remains un-resolved. Defra in their 'Digest of Environmental Statistics' estimate the nitrogen load to marine waters as 420,000 tonnes, which includes nitrogen from all sources, suggesting that up to 1,080,000 tonnes is denitrified on route to the sea. Denitrification, be it terrestrial, freshwater or marine remains an area of uncertainty, where more research and data are required.

Asman and Berkowicz (1994) estimated that atmospheric deposition of nitrogen from all sources to the North Sea was 340,000 tonnes and that the UK contributed between 40-50% of the total (136,000 - 170,000 tonnes nitrogen).



3.4 Mining and quarrying of energy producing materials

3.4.1 Oil

The UK is a major producer, user, importer and exporter of oil and associated products. The UK, primarily from the North Sea oil fields, has substantial reserves of crude oil (3000 million tonnes, of which 600 million tonnes are proven). The nitrogen content of crude oil is assumed to be 0.1% (personal comm., UKPIA) so based on the proven reserves, this contains 600,000 tonnes nitrogen. Expanding this calculation to take in possible and probable reserves suggests that UK oil fields may contain 3,000,000 tonnes nitrogen. The UK is a net exporter of oil and therefore of nitrogen.

In 1998, the UK consumed 84.5 million tonnes of oil based products. The main products were: petrol (26%), gas oil (27%), aviation fuel (11%), fuel oil (6%) and burning oil (4%); the remainder was split between other industrial uses (DTI, 2000)

3.4.2 Coal

The UK has proven reserves of coal of 1500 million tonnes, however estimating the amount of nitrogen is difficult since the nitrogen content varies between 0.4 and 2.2%, depending on its source. We assume 1.6% nitrogen based on 97% dry weight (personal comm., IEA Coal Research) giving 23,280,000 tonnes nitrogen. However, a note of caution here, given the large volumes involved, any variation in nitrogen content could result in major errors in the mass balance calculations. Despite these large reserves, the UK is a net importer of coal and therefore of nitrogen.

UK coal consumption in 1998 was 63.1 million tonnes, of which 48.5 million tonnes (77%) was combusted to generate electricity (DTI, 2000). The majority of the rest went to coke manufacture and domestic use. UK coal consumption is in decline for two main reasons, cheap imports and the switch to natural gas as a source in electricity generation.

3.4.3 Peat

UK consumption of peat was 3.26 million cubic metres, half of which was imported. We assume that peat has a density of four cubic metres per tonne resulting in 816,000 tonnes. We assume that peat contains 10% nitrogen.

Table 8. Inputs from mining ('000 tonnes)

Product	Product quantity	Nitrogen content
Peat (8.1)	816	10.0
Coal (8.2)	63,152	980.1
Crude oil (8.3)	84,510	84.5
Total	**148,478**	**1,074.6**

3.4.4 Combustion

The mining and subsequent combustion of fossil fuels is responsible for the largest output of reactive nitrogen after the combined agriculture and food industries. The input prior to combustion is quantifiable, being 1.07 million tonnes nitrogen split between coal and oil. However, calculating the output is more difficult. All these inputs, excluding peat and small quantities of oil, are combusted to provide heat and energy in power stations and transport; the other product of combustion is NO_x.

The formation, and accounting, of the nitrogen contained within NO_x is complicated because it is supplied from both the fuel and from the atmosphere. During combustion, nitrogen chemically bound within the fuel is released to form 'fuel NO_x' while nitrogen contained with the air is oxidized to form 'thermal NO_x'. The type of fuel, temperature of combustion, level of oxygen and duration of combustion all influence the ratio of thermal to fuel NO_x. The level of fuel NO_x in total NO_x varies between zero using natural gas as a fuel, up to 50% in the combustion of coals and oils with a higher nitrogen content, although it is typically in the range 15% to 35%.

Although not always true, we assume that all the chemically bound nitrogen in fuel is converted to NO_x during combustion.

Total emissions of NO_x can also be reduced by altering the temperature of combustion and the fuel to air ratio to ensure that the nitrogen released during combustion is reduced to N_2 rather than NO_x; alternatively, NO_x may be chemically reduced post combustion by catalytic converters.

The combustion of fossil fuels also releases minor amounts of N_2O. The National Expert Group on Transboundary Air Pollution (NEGTAP) value for NO_x emissions is 1.73 million tonnes (527,130 tonnes nitrogen).

Catalytic converters

Catalytic converters in road transport use platinum and rhodium to reduce nitrogen oxides, NO and NO_2, to N_2. Unfortunately, one of the by-products of the reduction process is nitrous oxide (N_2O), a powerful greenhouse gas. This normally occurs in the start-up phase or in cold weather running when the conversion of NO_x into nitrogen is incomplete. Levels of atmospheric N_2O have risen since the introduction of catalytic converters. (US EPA Inventory of US Greenhouse Gas Emissions and Sinks 1990-1996.)

The very large difference, of approximately half a million tonnes nitrogen, between the input and output is probably accounted for by denitrification to N_2 and N_2O in the combustion process. However, it is difficult to support this assumption since little or no data is available. In order to clarify this difference, more information on both the emission of nitrogen oxides and their denitrification to N_2 during combustion is required.

Table 9 Outputs from mining ('000 tonnes)

Product	Product quantity	Nitrogen content
NO_x (9.1)	1,735	528.0
N_2O (9.2)	25	15.6
Total	**1,760**	**543.6**

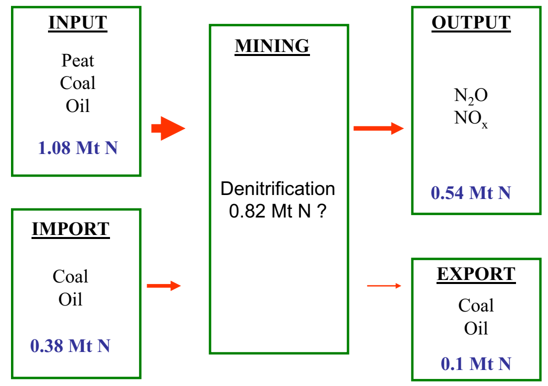
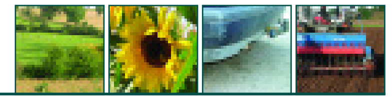


Figure 7. A mass balance for the mining sector

The UK imports coal but exports oil, however since coal has a higher nitrogen content, the UK is a net importer of 284,164 tonnes nitrogen per annum.

Table 10. Imports and exports of energy producing materials ('000 tonnes)

Product	Imported product	Imported nitrogen	Exported product	Exported nitrogen	Net gain nitrogen
Coal (10.1)	21,244	339.9	971	15.5	324.4
Oil (10.2)	39,447	39.5	79,651	79.7	-40.2
Total	**60,691**	**379.4**	**80,622**	**95.2**	**284.2**



3.5 Manufacture of food products, beverages and tobacco

3.5.1 Food

Food and drink processing is one of the largest industrial sectors in the UK comprising approximately 8,500 companies which means that accurate data can be difficult to obtain. We have used three methods to calculate food (and animal feedstock) volumes and have applied a nitrogen co-efficient to obtain total values for the nitrogen of: bulk agricultural output, product sales or by population diet. Multiplying bulk agricultural production statistics (Defra) by crop nitrogen percentages (Food Standards Agency 2002) results in 901,200 tonnes nitrogen per annum (Table 4). This includes nitrogen contained within cereals, which ends up as feed for livestock or industrial products, and also any loss during processing.

Table 11. Input of food and animal feedstuffs ('000 tonnes)

Product	Product quantity	Nitrogen content
UK production (11.1)	64,559	901.2
Imports into UK (11.2)	26,495	236.6
Total	**91,054**	**1,137.8**

Sales of food (PRODCOM) total 73.2 million tonnes (746,533 tonnes nitrogen) although a number of these datasets are incomplete or suppressed and therefore may not be representative. Defra figures show imports of food and feedstuffs totalling 26.5 million tonnes (236,571 tonnes nitrogen) while exports amount to 14.3 million tonnes (200,159 tonnes nitrogen). The UK is 68% self sufficient across all food groups and 82% self sufficient in indigenous foods (Defra). Starting with the value of 901,200 tonnes nitrogen contained within UK production of food and feedstuffs and by adding imports, and subtracting exports, animal feedstuffs and food waste, we estimate the nitrogen in UK consumed food amounts to 280,041 tonnes.

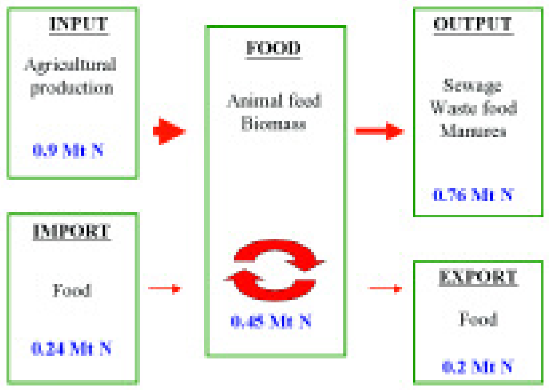


Figure 8. A mass balance for the food industry

This approach is supported by GANE, who estimate that the average person eating meat, fish and vegetables excretes about 10-15 grammes of nitrogen per day; 85% in urine and the rest in faeces. Assuming an average value of 12.5 grammes per person for the entire population of the UK this comes to a total of 250,000 tonnes per year although it could be 310,000 tonnes nitrogen or greater. This is well in excess of the daily requirement which the Food Standards Agency suggests is between 40 - 50 grams of protein a day which equates to between 6.4 and 8 grams of nitrogen.

Table 12. Output from food and feedstuffs ('000 tonnes)

Product	Product quantity	Nitrogen content
Exports from UK (12.1)	14,331	200.2
Sewage Sludge (12.2)	1,058	31.7
Sewage Discharge (12.3)		245.0
Agricultural Manures (12.4)	70,000	362.5
Food Industrial & Commercial Waste (12.5)	2,590	36.2
Food in Municipal Solid Waste (landfill) (12.6)	6,170	86.4
Total		**962.0**

The UK Food and Drink Processing Mass Balance

For more information and detail on food processing and waste refer to The UK Food and Drink Processing Mass Balance. C-Tech Innovation Ltd 2004

3.5.2 Waste food

Up to nine million tonnes of food are discarded as waste per annum. Municipal solid waste contains between 10 and 21% food (3.98 and 8.36 million tonnes, respectively), most of which goes to landfill. The commercial and industrial sectors in England and Wales add another 2.59 million tonnes (Environment Agency, 2000, SWMA), although only 629,000 tonnes goes to landfill, the rest goes to some form of recycling: 175,000 tonnes is spread to land, 1,597,000 tonnes is re-used or recycled and 164,000 tonnes goes to other sources. Insufficient information is available for Scotland and Northern Ireland to allow calculation of food waste volumes.

It is not necessary to landfill any food since alternative routes for disposal already exist, notably re-use as livestock feed (after suitable processing) and composting. Improved and source separated collection at kerbside would allow these alternative routes to be better used.

3.5.3 Sewage and waste water

The average healthy human adult does not accumulate nitrogen in their body, so the nitrogen consumed in food must be accounted for in excreta. So excluding the nitrogen that accumulates in growing children and that in food waste, all the nitrogen contained in food should reappear in sewage.

Food in the National Health Service (NHS)

'Material Health' a mass balance of the NHS in England and Wales reports that NHS consumed 53,256 tonnes of food and that on average 10% was wasted

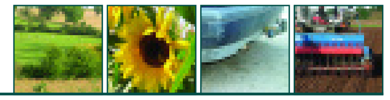
Sewage can be divided into two categories: dried sewage sludge (or biosolids) and waste water. Defra estimate the weight of dried sewage sludge at 1.06 million tonnes per annum. The nitrogen content of sludge is variable being between 0.2 & 6.9 % (MAFF, Bulletin 210) and 0.2 & 3.3% (Defra, RB209), we assume a value of 3% giving 31,700 tonnes nitrogen.

Nitrogen in waste water comes in three main forms: organic, nitrate and ammonia. The nitrogen content of discharge water from sewage treatment works is regulated under the The Urban Waste Water Treatment (England and Wales) Regulations 1994; similar legislation exists for Scotland and Northern Ireland, see section 5.2.1. This states that for urban populations between 10,000 and 100,000 the nitrogen limit is 15 mg l^{-1} and for populations exceeding 100,000 it is 10 mg l^{-1}.

Ammonia

Average concentrations of ammoniacal nitrogen (NH_3 and NH_4) in UK rivers vary between 0.05 mg l^{-1} in parts of Wales to 0.67 mg l^{-1} in the North West with an average value of 0.20 mg l^{-1}. In 1998, 11,420 tonnes of ammonia was discharged by sewage treatment works in England and Wales. Even at very low concentrations, 0.25 mg l^{-1}, ammonia is toxic to fish.

The amounts of nitrogen in waste water are difficult to calculate since the volumes of water are vast and the nitrogen content varies depending on its source. The Environment Agency estimates the quantity of waste water collected in the UK is approximately 3.65 x 10^{12} litres per year. At an average N content of 35 mg l^{-1} this amounts to 127,750 tonnes nitrogen. However, this may not include direct discharges to the sea.



The second report from the Select Committee on Environment, Transport and Regional Affairs estimates waste water at 5.11 x 10^{12} litres per annum giving 178,850 tonnes nitrogen. A third source, The Royal Society's 1983 report on the nitrogen cycle in the UK estimated 155,000 tonnes of nitrogen were discharged to inland waters while another 90,000 tonnes were discharged to the sea. Adding together the nitrogen contained in sewage sludge and waste water gives a total sewage content of between 159,450 and 276,500 tonnes nitrogen.

Biosolids

Biosolids are processed sludges from sewage treatment. Methods of disposal in 1998 included application to farmland (48%), landfill (11%), incineration (17%), dumping at sea (14%) and other (10%); however, the practice of sea disposal was banned at the end of 1998. This and the increasing cost of landfill have resulted in greater interest in using biosolids in agriculture. In 1998, approximately 504,000 tonnes of biosolids were applied to agricultural land. This amount is expected to increase. Guidelines for applying biosolids to agriculture land are contained in The Safe Sludge Matrix.

An alternative approach is to multiply the nitrogen content of the average daily human excreta, which GANE suggested was in the range 10 to 15 g, by the UK population of 57 million giving a total nitrogen output in the range 208,050 to 312,075 tonnes. The results from both approaches are in general agreement with section 3.5.1, where consumed food was estimated to contain 280,412 tonnes nitrogen.

3.5.4 Agricultural manures

The total production of agricultural manures contains 725,000 tonnes nitrogen. It is assumed that only half originates in cereal based feedstuffs and is therefore included in this section. The other half is assumed to originate from grass.

The GROWS project

The Green Recycling of Organic Wastes from Supermarkets project estimate that waste food from UK supermarkets amounts to 375,000 tonnes per annum, containing between 3750 and 6000 tonnes nitrogen. The project collects and composts waste fruit and vegetables from Waitrose and Sainsburys.

Dumping the Diaper

A report from Sustainable Wales estimates that the UK spends £40 million per annum collecting and disposing of 800,000 tonnes of used nappies. Our assumption that a used diaper contains between 0.5 and 1% nitrogen, means that up to 8000 tonnes of nitrogen enters landfill in this way.

3.5.5 Beverages

The majority of fruit juices, carbonated drinks, beers and wines contain only trace amounts of nitrogen and are not considered further.

3.5.6 Tobacco

In 1998, the UK imported 239,756 tonnes of raw tobacco and exported 16,326 tonnes of finished product. We assume raw tobacco contains 4.5% nitrogen, suggesting approximately 10,000 tonnes nitrogen was retained within the UK. However, the UK is an exporter of manufactured tobacco products so the true value is probably under half of this. The waste from tobacco manufacturing produces tobacco slurries, paper, wood, plastics, packaging materials and nicotine ($C_{10}H_{14}N_2$). Combustion of tobacco releases various nitrogen oxides.

3.6 Manufacture of textiles and textile products

Textiles can be divided into two categories, natural and man-made. Natural types include wool, silk, cotton, linen, hemp, ramie and jute; wool and silk are animal based and have a nitrogen content between 2.25 and 5%, while cotton, linen, hemp, ramie and jute are plant based with a nitrogen content around 0.25%. Man-made textiles which contain nitrogen include acetate, acrylic, latex, nylon, polyester, rayon and spandex.

The UK's turnover from textiles and clothing amounted to £17.7 billion (Textile & Clothing Strategy Group). Unfortunately, trade statistics on volume sales are difficult to come by since most sales are reported as number of items sold rather than by weight. However, BTTG's Textile Mass Balance (1999) reports that fibre generated in the UK amounted to 680,000 tonnes and that a further 1.1 million tones was imported. There is no breakdown by type, so we assume an overall nitrogen content of 1% (17,800 tonnes nitrogen).

Data from some individual sectors is available. In 1998, the UK used 52,974 tonnes clean wool which, with a 5% nitrogen content amounts to 2,649 tonnes nitrogen. This wool, both domestic and imported, went mainly into carpet manufacture and apparel yarn spinning with lesser amounts being used in upholstery, hand knitting yarns and bedding (personal comm., British Wool). The Silk Association of Great Britain's figures for 1999 suggest that the UK imported 8112 tonnes of silk and exported 1130 tonnes, leaving a balance of 6982 tonnes. Assuming a nitrogen content of 2.25%, this is 157 tonnes nitrogen.

Waste textiles are another area of uncertainly. Waste Strategy 2000, section 7.145, suggests that between 400,000 and 700,000 tonnes of waste textiles are landfilled every year. Waste Watch put the figure at about 650,000 tonnes. The Environment Agency SWMA reports put industrial waste textile production at 544,000 tonnes and wearing apparel at 208,000 tonnes, giving a total of 752,000 tonnes, of which approximately 25% is recovered. The textile mass balance suggests 1 million tonnes. However, given the relatively low nitrogen content of textiles, approximately 1%, this means a maximum of 10,000 tonnes nitrogen is involved.

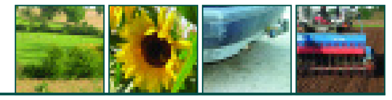
3.7 Manufacture of leather and leather products

The leather industry comprises the tanning and dressing of leather, and the manufacture of leather products. In 1998 there were 1,200 enterprises with a turnover of £2 billion. Leather, or rather the raw hides, is a by-product of meat production. An indication of the volume involved can be obtained from the number of livestock slaughtered annually in England and Wales; 1.3 million cattle, 15.8 million sheep and 12.7 million pigs. The production of leather in 1998 amounted to 11 million m^2. In that same period the UK sheepskin industry used 276,000 skins suggesting that large quantities of hides are being exported.

The nitrogen content of leather is assumed to be 6% (MAFF Bulletin 210 - Organic Manures). The SWMA reports for England and Wales produced by the Environment Agency estimate that the SIC industry sector produced 237,000 tonnes waste in 1998. However, that is all waste, not just leather. Using a lower estimate of 4% for the nitrogen content of this waste, to take into account non-leather component, nitrogen is estimated to be 9,480 tonnes. Production of finished goods is very difficult to quantify. The PRODCOM reports relating to this sector contain too many incomplete data sets for an accurate assessment to be made.

Rendering industry

Rendering is the processing of non-food animal waste. We estimate that the UK industry produces 1.4 million tonnes of waste meat, 200,000 tonnes of tallow and 400,000 tonnes of meat and bone meal. The nitrogen content is approximately 54,000 tonnes.



3.8 Manufacture of wood and wood products

The timber and wood industries encompass a wide range of sectors and products from the production of raw timber, which belongs in SIC 01 Agriculture, through the manufacture of timber products (this SIC sector) to the processing of pulp into paper (SIC 2000). The nitrogen content of wood varies depending on species and age however we assume an overall content of 0.1%.

The UK is a large consumer of wood and wood products, nearly 48 million tonnes in 1998. Since woodland covers only 11.6% of the UK land area, 84% of our requirement is imported mainly from the EU and Scandinavia. The Forestry Commission estimated that UK production of timber in 1998 amounted to 7.57 million tonnes (7,586 tonnes nitrogen). The same report also estimated that the UK imported 47.64 million tonnes and exported 7.13 million tonnes. Apparent consumption in 1998 was therefore 47.88 million tonnes.

Table 13. Inputs from timber industry ('000 tonnes)

Product	Product quantity	Nitrogen content
Wood-Softwood (13.1)	14,323	14.3
Wood-Hardwood (13.2)	1,731	1.7
Wood Based Panels (13.3)	6,426	6.4
Paper and Paperboard (13.4)	25,396	25.4
Total	**47,876**	**47.8**

Outputs from the timber, wood and joinery industries are many and varied. These range from forest products through construction to home based items. The volumes of these items and the waste generated during the production process are not well documented. Waste, or residue, is produced at all stages in wood processing, from log to finished product. Many of these stages, e.g. timber merchants, furniture makers, joinery and construction, do not quantify their volumes of waste and much of it is burnt or sent to landfill (Magin, 2001). This makes the task of quantifying the amount of waste produced difficult. We assume that accumulated product and waste account for the majority of the difference between the input and output figures.

Table 14. Outputs from timber industry ('000 tonnes)

Product	Product quantity	Nitrogen content
Paper (14.1)	12,500	12.5
Panel prodution in Great Britain(14.2)	7,126	7.1
Used in construction industry(12.3)	9,241	9.2
Miscellaneous british wood (14.4)	692	0.7
Horticultural mulch (14.5)	1,000	1.0
Waste in MSW (14.6)	420	0.4
Waste (Commercial) (14.7)	1,367	1.4
Waste (Industrial) (14.8)	1,297	1.3
Waste (construction & demolition) (14.9)	1,658	1.7
Total	**35,301**	**35.3**

More information is available regarding post-processing waste. Waste Watch estimates that municipal solid waste contains approximately 420,000 tonnes waste timber and that commercial, industrial, and construction and demolition wastes contain 5%, 2.5% and 2%, respectively. This suggests that total waste wood amounts to 4.7 million tonnes per annum (4,742 tonnes nitrogen). However, how much of this is disposed of as waste and how much is recycled is unknown.

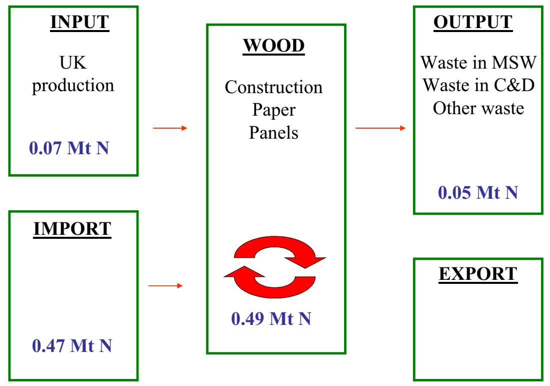


Figure 9. A mass balance for the timber industry industry

Forests and woodlands
The UK is one of the least afforested countries in Europe with only 11.6% of the land area being wooded. The European average is 46%

It is not surprising, given the diversity of wood products and their uses, that there exists a large number of sometimes conflicting estimates on wood waste: Wasteguide suggests 1.5 million tonnes of wood goes to landfill and that a similar amount is used in packaging. VIRDIS's construction industry mass balance suggests 236,700 tonnes of waste wood are produced per annum while 1.5 million tonnes is generated by demolition work (Smith et al., 2002). Friends of the Earth in 'Out of the Woods' estimate that 500,000 tonnes of wood are disposed of from the furniture industry and that post consumer waste amounts to between 3 and 5 million tonnes per annum. WRAP propose that total arisings of wood waste are 8-10 million tonnes. In Scotland, the Scottish Waste Statistics for 1997 and 1998 states that wood packaging waste was 206,397 tonnes and for the UK as a whole 2.37 million tonnes. The significance of this contradictory information will only become relevant by improved record keeping for both wood products and waste.

3.9 Manufacture of pulp, paper and paper products

The UK paper and board industry comprises nearly 3000 companies with a turnover of approximately £13 billion. In 1998, UK consumption was 12.5 million tonnes, comprising UK production of 6.5 million tonnes, imports of 7.4 million tonnes and exports of 1.4 million tonnes (The Paper Federation of Great Britain). These figures agree with the Waste Strategy 2000 and Paper Industry Mass Balance which suggests that 6.5 million tonnes of varying grades were manufactured in the UK. The nitrogen content of paper and board is assumed to be 0.1%.

Table 15. UK production of paper and board ('000 tonnes)

Product	Product quantity	Nitrogen content
Newsprint (15.1)	1,030	1.0
Printings & writings (15.2)	1,779	1.8
Corrugated case materials (15.3)	1,755	1.8
Packaging papers (15.4)	155	0.2
Packaging boards (15.5)	706	0.7
Household & sanitary (15.6)	635	0.6
Other (15.7)	415	0.4
Total	**6,476**	**6.5**

Table 16. Inputs of paper and pulp ('000 tonnes)

Product	Product quantity	Nitrogen content
UK production (16.1)	6,500	6.5
Imports (16.2)	7,400	7.4
Exports (16.3)	1,400	1.4
UK consumption	**12,500**	**12.5**

Recycling and reuse of paper and card is well established in the UK with approximately 38% being reused in some form (Waste Watch). The Paper Industry Mass Balance indicates that 2.24 million tonnes of wood pulp and 2.64 million tonnes of paper and paperboard were mechanically or chemically recovered. A small amount is spread to agricultural land which The Foundation for Water Research estimates at 440,000 tonnes; the Paper Federation of Great Britain produce a Code of Practice for Landspreading Paper Mill Sludge. ENDS (2002, No 327) suggested that almost one million tonnes of waste paper are exported each year.

Despite a good recycling rate, the amount of paper and card going to landfill is still large. Burton and Watson-Craik (1996) estimated that 33% of municipal solid waste is paper and card. The UK generated 26.8 million tonnes municipal solid waste in 1998 meaning that 8.8 million tonnes of paper and card went to landfill. This figure is in agreement with the value obtained by deducting the recycled total from the UK consumption figure.

There is a difference of 1.36 million tonnes between the input and output figures. There are three possible explanations for this: the percentage paper content of municipal solid waste has a significant effect i.e. a 5-6% variation would account for this difference; industrial and commercial wastes contain 274,000 tonnes of paper and card which may or may not be included in municipal solid waste (EA-SWMA); and not all municipal solid waste goes to landfill, a certain amount is incinerated.

Paper and card recycling has the highest consumer uptake amongst waste materials. However, 7.5 million tonnes still goes to landfill. Recovering or recycling this would reduce the need for virgin pulp, extend the life of existing landfill sites and go some way towards meeting the requirements of the Landfill Directive.

The Woodlands Trust

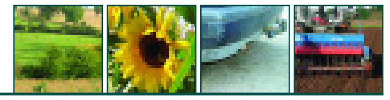
In 2002, The Woodland Trust, in partnership with Tesco, collected 34 million used Christmas cards for recycling. That's 671 tonnes of card that didn't go to landfill.

3.10 Manufacture of chemicals, chemical products and man-made fibres

The chemicals sector comprises about 2,400 manufacturers, with annual sales of approximately £35 billion, and is one of the UK's largest exporters. The range of products is large and diverse, and includes plastics, fertilizers, agricultural and industrial chemicals, industrial gases, soaps, detergents and nylon. The manufacture of nitrogen fertilizers makes this sector the biggest producer of new nitrogen. For reasons of commercial confidentiality the chemicals industry is notoriously secretive so the majority of the information contained here is extracted from the chemical industry mass balance. Unfortunately, we have insufficient data to draw up a mass balance for this sector.

Table 17. Output of paper and pulp ('000 tonnes)

Product	Product quantity	Nitrogen content
Recycled & recovered (17.1)	4,880	4.9
Landfill (17.2)	7,524	7.5
Landspread (17.3)	440	0.4
Exported (17.4)	1,000	1.0
UK consumption	**13,844**	**13.8**



Among the processes identified in the chemical industry mass balance we consider the following either use or extract significant quantities of nitrogen: air separation and extraction, production of ammonia, manufacture of nitric acid and production of fertilizer. The basis for the majority of nitrogen use in the chemical industry is the production of ammonia using the Haber-Bosch process. Unfortunately production volumes are unavailable. Specific items identified in the report include ammonia (20,047 tonnes), nitric acid (269,165 tonnes) and nitrogen (454,567 tonnes).

Little information is available in the public domain, so even estimates of UK production are difficult to make. As far as fertilizer is concerned, Terra Nitrogen manufactures approximately 750,000 tonnes of anhydrous ammonia and 1 million tonnes of nitric acid in the UK per annum. Kemira manufacture approximately 900,000 tonnes of fertilizer for the UK, however this includes both straight nitrogen and compound fertilizers; we assume that between 200,000 and 250,000 tonnes of this is nitrogen. Analysis of PRODCOM reports, again hindered by the suppression of some data, suggests that sales in SIC 2414 (other organic chemicals) contain 43,000 tonnes nitrogen and SIC 2415 (fertilizers and nitrogen compounds), 1.25 million tonnes nitrogen.

SIC 2415 relates to sales of agricultural fertilizers containing nitrogen. This sector is reported on annually in 'The British Survey of Fertilizer Practice' (1998) which estimated that applied fertilizer contained 1.375 million tonnes nitrogen.

The British Survey of Fertilizer Practice funded jointly by the Department for Environment, Food and Rural Affairs, the Scottish Executive Environment and Rural Affairs Department and FMA, is an independent annual report of fertilizer application rates providing data for farmers, environmentalists, regulators and the industry. It also provides information on lime use and organic manure application. The Survey shows fertilizer practice in Britain is generally good with mineral fertilizers being used closely in line with accepted recommendations.

3.11 Manufacture of rubber and plastic products

The plastics sector in the UK has a turnover of around £19 billion, employing over 150,000 people. Unfortunately, like the chemicals sector, collection of data for this sector was difficult. The only area for which information is readily available is the manufacture, subsequent reuse and disposal of tyres.

Table 18. Waste tyre disposals ('000 tonnes)

Product	Product quantity	Nitrogen content
Exported (18.1)	48	0.48
Reused/recycled (18.2)	270	2.70
Landfill (18.3)	100	1.00
Stockpiled/illegal dump (18.4)	17	0.17
Total	**435**	**4.35**

VIRIDIS (Hird et al., 2002) suggest that 88,000 tonnes of natural rubber were used in the UK for tyre manufacture. Natural rubber contains between 3 and 5% nitrogen, depending on tree variety and location, so taking an average of 4% we calculate that 3,520 tonnes of nitrogen are contained within UK manufactured tyres. However, tyres contain both natural and synthetic rubber, as well as steel, so the overall nitrogen content is generally lower; we assume tyres contain 1% nitrogen. Estimates for the amount of waste tyres produced per annum range between 435,000 tonnes (Viridis) and 467,650 tonnes (Waste Watch), so the amount of nitrogen is in the range 4350 to 4677 tonnes. Although the majority of waste tyres go through a secondary process, be it reuse, retreading or energy recovery, 100,000 tonnes still goes to landfill. This practice is due to cease by 2006. However, as tyres contain such small quantities of nitrogen; this will make little difference to the amount of nitrogen going to landfill. It is probable in the future the majority of these tyres will be combusted in cement kilns.

In plastics and polymer manufacturing, nitrogen is contained within both feedstocks and finished products. Familiar products include ABS, alkyds, melamine, nitriles, nylon, polyimides, polyurethanes and urea-formaldehydes. Production of nylon is estimated to account for over 50% of the UK's nitrous oxide emissions, amounting to 59,818 tonnes nitrogen.

The Environment Agency estimates that plastics make up 11% of municipal solid waste. In 1998, municipal solid waste amounted to 26.83 million tonnes giving 2.95 million tonnes of mixed plastics. Unfortunately, not all plastics contain nitrogen, and those that do vary in their content, so the total amount of nitrogen contained within waste plastics is unknown.

3.12 Construction

In terms of volume, the construction industry is the biggest industrial sector in the UK. Sector turnover is approximately £70 billion annually, amounting to 5% of Gross Domestic Product (GDP). It is the biggest user of resources and the biggest producer of waste in the UK.

The majority of materials used in construction contain very little or no nitrogen although certain materials are of interest. In 1998, 10.62 million tonnes of timber and wood products were used in construction which, assuming a nitrogen content of 0.1%, equates to 10,621 tonnes nitrogen, while the amount of wood products classified as waste was put at 236,760 tonnes (Smith et al., 2002). A limited amount of wood products are recycled each year. However, the authors are unable to quantify this.

The construction industry mass balance suggests that 29 million tonnes of soil arise as part of the construction process. Assuming nitrogen content of 0.5%, this would represent 145,040 tonnes nitrogen. However, since this soil undergoes no elemental change, and is reused at or near its original location, we will not consider it further.

The Construction Industry Mass Balance

For more information on the construction industry in general, and areas relating to organic products and wastes, refer to The Construction Industry Mass Balance: resource use, wastes and emissions. Smith et al., (2002)

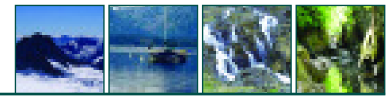
3.13 Hotels and restaurants

The hotel, restaurant and catering sector is very diverse, consisting of over 100,000 separate businesses, mainly quite small. This makes detailed analysis difficult, so we have adopted a broad overview approach. We assume the main flow of nitrogen through this sector is contained within food which the SWMA reports suggest amounted to 380,000 tonnes for the commercial sector in England and Wales. Estimates for Scotland and Northern Ireland probably bring the figure close to 500,000 tonnes (7,500 tonnes nitrogen)

Waste food

In the past, approximately 90,000 tonnes of waste food has been recycled into swill, mainly for feeding to pigs, although in the wake of the 2001 food and mouth crisis, this has been banned for any waste food containing meat. In-vessel composting followed by application to land may offer a viable alternative method of disposal in the future.

4 Nitrogen in the environment



4.1 Water

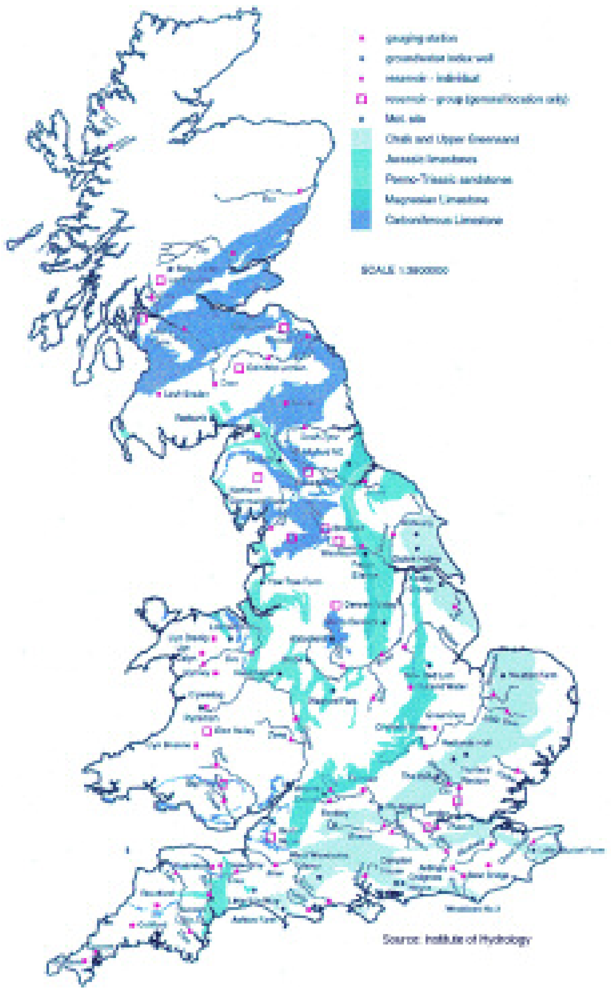
The water industry supplies around 1.8 x 10^{10} litres of water per year to the population of the UK (Water UK, Environment Agency, Scottish Water). It also collects and disposes of over 4 x 10^{12} litres of waste and run-off water every year. To achieve this, the industry has over 700,000 km of mains and sewers, 2,500 water treatment works and 9,000 sewage treatment works. As a result of this infrastructure and volume, the water industry, together with agriculture, has the greatest potential of all industries to impact the environment. The water industry is managed differently in the home countries: In England and Wales water services are supplied by the private sector comprising 10 water and sewerage companies and the 15 water supply companies, in Scotland and Northern Ireland the water service remains in the public sector, being the responsibility of Scottish Water and The Water Service, respectively.

In many respects, water is a little like the air that surrounds us; we know it's there, but generally pay it little attention. We know that our atmosphere contains large amounts of nitrogen, and so does our water. The concentration in water is never very high but the volume involved is immense. Water, in all its various locations and guises is the final depository and storage medium for the vast amounts of the nitrogen that have entered the environment over the last hundred years. Unfortunately, the difficulty of accurately measuring the huge amounts of water that circulates within our environment makes quantifying the nitrogen load very difficult.

We consider water in four categories: overall water supply, ground, surface and marine water. Nitrogen in water comes in two main forms, dissolved organic nitrogen and nitrate.

4.1.1 Water supply

The UK has a temperate, maritime climate, with rainfall ranging from 550 mm in eastern England to 3200 mm in the Scottish highlands. The annual volume of rainfall is estimated at 7.7 x 10^{13} litres which contains approximately 200,000 tonnes of nitrogen as a result of dissolved nitrogen oxides and ammonia.



4.1.2 Groundwater

England, because of its favourable geology, has large reservoirs of groundwater. The Environment Agency estimated that 2.43 x 10^{12} litres were abstracted from groundwater in 1998. Assuming a value of 30 mg l^{-1}, there are 16,000 tonnes of nitrogen in abstracted groundwater. Nitrate is the main source of nitrogen in water. Concentrations before the industrial revolution are estimated to have been in the range 4 to 8 mg l^{-1} but since commercial nitrogen fertilizer became available 100 years ago, large quantities of nitrate have leached into groundwater. Nitrate concentrations are now in the range 10 to 80 mg l^{-1}. Wales and Scotland, due to less favourable geology, and to a lesser extent pollution, rely less on groundwater; only 3% of Scotland's water supply comes from groundwater as compared to 35% for England and Wales. The extent of all UK groundwater is unknown but even assuming a low estimate of ten times the annual abstractable value, UK groundwaters may contain between 5,000 and 44,000 tonnes nitrogen.

> **Nitrate Vulnerable Zones (NVZs)**
>
> In 1991, Europe adopted the Nitrates Directive (91/676/EC). This is an environmental measure designed to reduce water pollution by nitrate from agricultural sources and to prevent such pollution occurring in the future. The Nitrates Directive requires all known areas of land draining into nitrate polluted waters to be identified for designation as NVZs. Farmers within an NVZ are required to limit the amount of nitrogen applied to crops to that which will satisfy the crops' requirements, and should only apply fertilizers and manures at certain times of the year

The EU limit for nitrate in drinking water is 50 mg l^{-1}, a level exceeded in some UK waters. Prior to being supplied as drinking water, water high in nitrate has to be either blended with water low in nitrate, treated to lower the nitrate content or the source has to be abandoned. High nitrate can cause inland and, especially, marine eutrophication. In 2002, the number of Nitrate Vulnerable Zones (NVZs) were extended to cover 55% of England, 3% of Wales and 14.3% of Scotland in an attempt to limit excessive nitrogen losses from agricultural land.

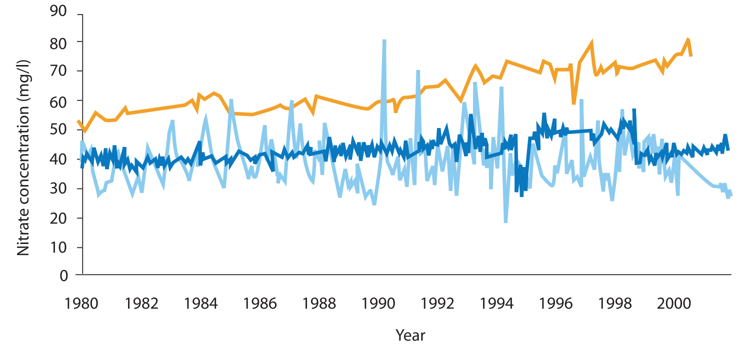
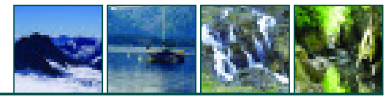


Figure 10. Nitrate concentrations in three different types of aquifer

4.1.3 Surface water

Non-tidal surface waters in the UK comprise rivers and reservoirs with estimated abstractions from these sources in 1998 amounting to 1.28 x 10^{13} litres. In 2000, 32% of rivers surveyed had nitrate concentrations greater than 30 mg l^{-1}. Despite this, we assume that surface water abstractions contained 30 mg l^{-1} nitrate and so contain approximately 87,000 tonnes nitrogen. However, abstracted water is only a small part of the total surface water supply.



4.1.4 Marine

The UK has extensive coastal waters which we define as those waters over the continental shelf surrounding the UK, extending to 449,000 sq km. In comparison to inland waters the nitrogen (dissolved ammonia and nitrate) content of marine waters is generally very low, under 2 mg l^{-1}, so we assume that UK seas contain approximately 4 million tonnes nitrogen.

Nitrogen enters the coastal waters from three sources: river discharge, waste water discharge (sewage) and atmospheric deposition. Defra estimate that the UK discharges 420,000 tonnes nitrogen into the surrounding seas through the river system. Aerial nitrogen deposition to the whole of the North Sea is estimated at 340,000 tonnes per annum, split between 140,000 tonnes ammonia and 200,000 tonnes nitrogen oxides. The UK contributes between 40 and 50% of this total giving 136,000 to 170,000 tonnes. Combining both riverine and aerial sources gives a total load from the UK to the marine environment of around 570,000 tonnes nitrogen. However, given the complex pathways that exist for nitrogen losses which include agricultural leaching and run-off, the waste water system and various types of gaseous emissions, it is possible that this estimate is well short of the actual value.

An alternative approach was taken in recent modelling work by Heath et al. (2002) suggesting that the total nitrogen load to the seas surrounding the UK from urban waste water, industrial and terrestrial sources, from England, Scotland and Wales amounts to 648,400 tonnes nitrogen. Although they do not consider Northern Ireland separately, they suggest that Ireland contributes another 270,800 tonnes nitrogen. Using pro-rata land areas we calculate that Northern Ireland contributes 45,305 tonnes, so the total figure for the UK is 693,705 tonnes nitrogen. In the near future, the Urban Wastewater Directive may require waste water discharged to estuaries by UK water companies to be treated to reduce nitrogen content.

4.1.5 Water Use

Water use is dominated by the power production sector, accounting for 55% of the total with the public water supply using 27%. Fish farming and other industrial uses account for the majority of the remaining 18%.

Water in the chemical and foundry industries

The chemical industry estimated their sector consumption of water at 1.71×10^{11} litres; mainly one-off use for cooling. The foundry sector estimated 1.9×10^9 litres, again mainly for cooling.

4.2 Gaseous emissions

Gaseous emissions of nitrogen comprise three main compounds: nitrous oxide (N_2O) and ammonia (NH_3), mainly from agriculture, and other nitrogen oxides (grouped together as NO_x) from the combustion of fossil fuels. DEFRA estimates that road transport and power generation account for 45% and 23% of all NO_x emissions, respectively.

Table 19. Gaseous emissions ('000 tonnes)

Product	Product quantity	Nitrogen content
NO_x (19.1)	1,735	528
N_2O (19.2)	188	119.6
NH_3 (19.3)	349	287.4
Total	**2,272**	**935.0**

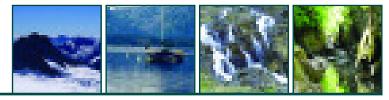
A large proportion of the nitrogen emitted as gaseous products is returned to the terrestrial environment through wet and dry deposition. Estimates for total deposition fluctuate widely. A 1994 study by The British Ecological Society suggested a total deposition of 454,000 tonnes which includes 231,000 tonnes as NH_3.

A common approach for estimating nitrogen deposition is the use of a single coefficient multiplied by the total agricultural area. In 1998, DEFRA estimated total agricultural land at 17.4 million ha. However, estimating a coefficient is far more difficult since deposition varies with land topography and surface vegetation. Wet deposition has been estimated at between 10 and 30 kg ha^{-1} in the 1994 study by The British Ecological Society, between 7 and 20 kg ha^{-1} over selected UK sites by Webb et al. (2000), while Goulding et al. (1998) estimated total deposition between 28 and 46 kg ha^{-1}. NEGTAP's 2001 report 'Transboundary Air Pollution' estimates total deposition at 17 kg ha^{-1} N giving UK total deposition at 380,000 tonnes nitrogen.

Irrespective of the amount returned to the UK landmass, the balance is assumed to be deposited in the North and Baltic Seas, mainland Europe and Scandinavia. As stated in section 4.1.4., Asman and Berkowicz (1994) estimated that atmospheric deposition of nitrogen to the North Sea, from all sources, was 340,000 tonnes, and that the UK contributed between 40-50% of the total. NEGTAP suggest that 90,000 tonnes nitrogen were imported into the UK and that 510,000 tonnes was exported.

Table 20. Deposition from gaseous emissions

Product	Nitrogen content ('000 tonnes)
UK landmass deposition (20.1)	380.0
Exported (20.2)	555.1
Total	**935.1**



4.3 The cost of nitrogen

There are various costs associated with nitrogen: production, initial purchase, the environmental cost of using it and the human cost of not using it. In this section, we will try and expand on the monetary and economic costs of production, purchase and use.

Of the sectors and products considered in this report, there is only one where nitrogen is an economic input and that is fertilizer into agriculture; in all other sectors, nitrogen input is just a byproduct.

The economics of nitrogen fertilizer production are unusual since the main component, nitrogen, is free as it is extracted from the atmosphere. The major cost in fertilizer production is natural gas, both as a source of hydrogen and energy. So the price of fertilizer is governed by the price of natural gas. In 1998, UK agriculture used fertilizer containing 1.38 million tonnes nitrogen which at 2004 prices of £450 per tonne of fertilizer nitrogen is £619 million.

Two factors need to be considered when estimating the cost of environment pollution. The first is the direct cost involved in ensuring that a product meets a statutory limit. There is only one limit of this type involving nitrogen and that is that drinking water may not contain more than 50 mg l^{-1} nitrate. The cost of ensuring that this limit is met, £16-20 million per annum, is paid for by the water companies. There are no limits on the concentration of nitrogen pollutants in our atmosphere. The second factor is the indirect cost that can be attributed to national wellbeing. Under this category should be considered clean rivers and unpolluted air. These are more difficult to estimate since there is no financial market for clean air or water, or maintaining national wellbeing.

A recent study has has calculated monetary values for common pollutants in agriculture (Atkinson et al., 2004). They assigned the following costs to common nitrogen pollutants:

NO_x - £541 per tonne
N_2O - £5588 per tonne
NH_3 - £178 per tonne
Water - £5560 per km of river.

Using these unit values and the pollution data from this report, nitrogen pollution from all sources can be valued at £2051 million. Although environmental accounting is still a relatively new concept and estimating the monetary value of environmental impacts is open to interpretation this is still a very large amount of money. However, perhaps we should consider the cost of not creating the nitrogen pollutants in the first place. Food production would be halved, no coal could be burnt and nobody would be allowed to drive a car. It is probable that these conditions would be unacceptable to the majority of people, so perhaps that is the true cost of nitrogen.

Nitrogen pollutants are an unwelcome but necessary part of a modern economy, however, there are various economic levers which can be used to reduce emissions. There are three areas to which regulation can be applied: NO_x emissions from industry, NO_x emissions from road transport and diffuse pollution from agriculture.

In the UK, a successful emissions trading scheme has been in operation since 2002 and an EU wide scheme will come into effect in 2005. These schemes operate by issuing a permit to pollute to industry and then creating a market for the permits. Industry that takes the opportunity to reduce emissions can then trade, or bank for future use, their permits. Over time, the quantity of pollutants attached to the permits is reduced, thereby reducing overall pollution. Although the UK scheme has only been operating for two years it is generally considered a success (Radov and Klevnäs, 2004).

NO_x emissions from road transport have decreased with the introduction of more efficient engines and greater levels of fuel duty. In the agricultural sector, Defra is still consulting over the best approach to limit diffuse pollution but will probably use a combination of regulation, voluntary action and an economic instrument to achieve their aims.

5 Law and legislation

The statutory differences between England, Wales, Scotland, and Northern Ireland can make the legislative position confusing. Whilst the driving force behind most regulations are European Directives, the legislation and enforcement is different across the UK. In England and Wales, Defra and The Environment Agency are responsible for implementing and enforcing regulations. However, in Scotland, the Scottish Executive and The Scottish Environment Protection Agency (SEPA) are the regulating bodies while in Northern Ireland it is The Department of the Environment and The Environment and Heritage Service. The devolved parliament in Scotland, the assembly in Wales and executive in Northern Ireland prepare their own strategies for waste.

UK legislation is underpinned by the Environmental Protection Act (1990) which has a wide ranging remit.

5.1 Air

5.1.1 The Air Quality (England) Regulations 2000

This regulation came into force on 6th April 2000 and supersedes the 1997 regulations of the same name; this applies to England only. This regulation requires that by the end of December 2005 levels of nitrogen dioxide should not exceed 200 µg m^{-3} on an hourly basis or 40 µg m^{-3} on an annual basis. Similar regulations cover the other three home countries:

- The Air Quality (Scotland) Regulations 2000
- The Air Quality (Wales) Regulations 2000
- The Air Quality (Northern Ireland) Regulations 2003

5.1.2 Air Quality Limit Values (England) Regulations 2001

This legislation will incorporate the EC Air Quality Framework Directive and 1st Daughter Directive. These two directives define policy framework and limits for specific pollutants, including nitrogen dioxide and oxides of nitrogen. The limits are similar to those already in place, so should involve no extra arrangements. Similar regulations cover the other three home countries:

- The Air Quality Limit Values (Scotland) Regulations 2003
- The Air Quality Limit Values (Wales) Regulations 2002
- The Air Quality Limit Values Regulations (Northern Ireland) 2002

5.2 Water

5.2.1 The Urban Waste Water Treatment (England and Wales) Regulations 1994

These regulations came into force on 30th November 1994 and relate to the collection, treatment and discharge of urban waste water, and the treatment and discharge of waste water from certain industrial sectors. The effects of the regulation are:

- to limit the nitrogen content of discharged water from water treatment plants to under 15 mg l^{-1},
- to phase out the dumping of sewage sludge to surface waters by the end of 1998,
- to control the discharge of biodegradable industrial waste water which does not enter urban waste water treatment plants; most of these biodegradable wastes are related to the food and feedstocks processing industries.
- to require sewage sludge is re-used where possible and that its disposal does not form a risk to the environment. The use of sludge is regulated under the Sludge (use in Agriculture) Regulations 1989. Practical application is covered by 'The Safe Sludge Matrix'.

Mirror legislation exists for the other home countries:

- The Urban Waste Water Treatment (Scotland) Regulations 1994
- The Urban Waste Water Treatment Regulations (Northern Ireland) 1995

5.2.2 The Nitrates Directive (91/676/EC)

The 1991 Nitrates Directive sets out to establish nitrate vulnerable zones (NVZs). These are areas where there is a risk that the nitrate content of the surface freshwaters and groundwaters may exceed 50 mg l^{-1}. Within NVZs, farmers are required to adopt management practices to reduce nitrate leaching including reduction of inputs of inorganic fertilizers and limiting both amount and timing of organic manure applications. In 1996, NVZ status was applied to 8% of the arable land in England and extended to cover 55% in 2002.

The Nitrates Directive is implemented through the following legislation:
* The Protection of Water Against Agricultural Nitrate Pollution (England and Wales) Regulations 1996
* The Action Programme for Nitrate Vulnerable Zones (England and Wales) Regulations 1998
* The Protection of Water Against Agricultural Nitrate Pollution (Scotland) Regulations 1996
* The Protection of Water Against Agricultural Nitrate Pollution (Northern Ireland) Regulations 1996

MAFF, and subsequently Defra, have spent large sums of money on research into reducing nitrate loss from agriculture. Some European countries have gone further and now limit the overall application of inorganic nitrogen to crops e.g. Germany and the Netherlands.

5.2.3 The Water Framework Directive (2000/60/EC)

The Water Framework Directive (WFD) requires all inland and coastal waters to reach "good status" by 2015. It will do this by establishing a river basin district structure within which demanding environmental objectives will be set, including ecological targets for surface waters. This directive is intended to provide an integrated approach to all areas of water management and to provide a link between surface and groundwater, and water quantity. The UK transposed this directive into law by the following legislation:

* The Water Environment (Water Framework Directive) (England and Wales) Regulations 2003
* The Water Environment (Water Framework Directive) (Northumbria River Basin District) Regulations 2003
* The Water Environment (Water Framework Directive) (Solway Tweed River Basin District) Regulations 2004
* Water Environment and Water Services (Scotland) Act 2003
* The Water Environment (Water Framework Directive) (Northern Ireland) Regulations 2003

A key objective of this Directive is to protect, enhance and prevent further deterioration of aquatic ecosystems and associated wetlands. One of the main targets of this legislation will be to reduce substances which contribute to eutrophication (in particular, nitrates and phosphates). Further information can be obtained from the Defra website and 'Directing the flow: Priorities for future water policy' (Defra, 2002).

5.2.4 The Bathing Water Quality Directive (76/160/EEC)

The objective of the 1976 bathing water directive was to protect public health and the environment from faecal pollution of bathing waters. Revision of this directive to tighten the quality parameters has been suggested. One of the areas which would be focused on is faecal contamination from agricultural sources. Possible outcomes could include preventing animal access to watercourses, improvements to farm drainage systems, changes to manure spreading and grazing practices, and reducing livestock numbers. Any revisions will be incorporated into the Water Directive.

5.2.5 The Groundwater Directive (80/68/EEC)

The objective of the 1979 directive was to provide enhanced protection of groundwater against pollution caused by certain dangerous substances. This directive was implemented in England, Wales and Scotland by the Groundwater Regulations in 1998. However, many of the objectives have been superseded by the Water Framework Directive.

5.3 Land

5.3.1 The Landfill Directive (1999/31/EC)

The objective of this directive is to reduce methane production by limiting the amount of biodegradable waste going to landfill. In the UK, biodegradable waste going to landfill must be reduced to 75% of the amount produced in 1995 by 2010, to 50% of the 1995 figure by 2013, and to 35% of the 1995 figure by 2020. Limiting Landfill, a 1999 DETR consultation paper put forward various methods by which this could be achieved. The Landfill Directive was transposed into law by the following regulations:

* The Landfill (England and Wales) Regulations 2002
* The Landfill (England and Wales) (Amendment) Regulations 2004
* The Waste and Emissions Trading Act 2003
* The Landfill (Scotland) Regulations 2003
* The Landfill (Scotland) Amendment Regulations 2003
* The Landfill (Northern Ireland) Regulations 2003
* The Landfill (Amendment) Regulations (Northern Ireland) 2004

Waste not, Want not (2002)

A review by the Strategy Unit with the following objectives:
* to analyse the scale of the waste problem, its causes and barriers to progress
* to identify the most cost-effective and environmentally sustainable options for dealing with the growing volume of municipal waste in England
* to make recommendations on how the EU Landfill Directive targets could be delivered
* to set out a vision of the waste management system to 2020 that will allow the nation to prosper whilst protecting human health and reducing harm to the environment

5.3.2 The Waste Framework Directive (75/442/EEC)

The Waste Framework Directive (WFD) and its subsequent daughter directives have spawned various waste regulations in the UK, one of which is The Waste Management Licensing Regulations 1994. This regulates the protection of groundwater against pollution by certain substances including ammonia, nitrate and nitrite. This legislation is likely to be amended in the near future in areas dealing with land treatment, composting and sewage sludge. This is in response to a perceived problem of what it is that constitutes waste disposal compared to waste recovery for these materials, so the amendment will set out what constitutes agricultural benefit or ecological improvement.

6 Nitrogen and waste management

6.1 Landfill

Landfill is currently the easiest and cheapest method of waste disposal in the UK (£14 tonne^{-1} for general waste in 2003). In 1998, 69.9 million tonnes of waste went to landfill including 26.8 million tonnes municipal solid waste (The Environment Agency's SWMA's, ERM's Scottish Waste Statistics and EHS's Waste Arisings Survey for Northern Ireland).

The nitrogen content of landfilled material varies with the time of year, location and type of material. The National Household Waste Project (DoE, 1994) found the nitrogen content of fresh waste, with a 28 to 41% moisture content, was between 0.4 and 1.2% while Burton and Watson-Craik's 1996 report 'Nitrogen balances in landfills' gives an average nitrogen concentration of between 0.5 and 0.8% suggesting that between 76,500 and 136,000 tonnes nitrogen went to landfill. We assume that municipal solid waste, industrial waste and commercial waste contain 5%, 1% and 1% nitrogen, respectively.

Table 21. Waste going to landfill in the UK, 1998 ('000 tonnes)

Product	Product quantity	Nitrogen content
Municipal solid waste (MSW) (21.1)	26,832	129.6
Industrial (21.2)	27,647	27.4
Commercial (21.3)	15,399	15.4
Total	**69,878**	**172.4**

Table 22. Type and nitrogen content of waste going to landfill ('000 tonnes)

Region (22.1)	MSW	Nitrogen in MSW	Industrial & commercial	Nitrogen in industrial & commercial	Total nitrogen
East of England	2,385	11.9	3,240	3.2	15.2
East Midlands	1,758	8.8	3,787	3.8	12.6
London	3,069	15.4	3,547	3.5	18.9
North East	1,126	5.6	2,169	2.2	7.8
North West	3,464	17.3	4,107	4.1	21.4
South East	3,402	17.0	4,559	4.6	21.6
South West	2,107	10.5	2,387	2.4	12.9
West Midlands	1,642	8.2	3,204	3.2	11.4
Yorkshire & the Humber	2,412	12.1	4,606	4.6	16.7
Northern Ireland	917	4.6	217	0.2	4.8
Scotland	3,082	15.4	8,792	8.8	24.2
Wales	1,468	7.3	2,431	2.4	9.8
Total	**26,832**	**134.2**	**43,046**	**43**	**177.2**

Landfill sites are not static as the wastes they contain undergo the processes of aerobic decomposition and anaerobic digestion during the lifetime of the site. Both of these processes are microbial and require a source of nitrogen. Unfortunately, the nitrogenous compound found in the greatest amount in landfill sites is ammonia dissolved in leachate, which most microbial processes cannot utilise. However, dissolved ammonia can be converted aerobically into nitrate which can then be recirculated back through the landfill and be used by microbial processes. The exact amount and form of nitrogen required to maintain the microbial population over the lifetime of a landfill site, maybe up to one hundred years, is unknown. Currently, nitrogen surplus to the requirements of the microbial population is being deposited in landfill although at this point in time we do not know by how much. Landfills are managed to be nitrogen neutral which results in approximately 177,000 tonnes of nitrogen, dissolved in leachate, per annum being removed from landfill each year. Landfill leachate contains high, sometimes very high, (>4000 mg l^{-1}) levels of dissolved nitrogen which requires treatment prior to disposal. The leachate can be diluted or chemically altered until it can meet the requirements of the discharge permit, normally under 15 mg l^{-1}, and is then removed via the existing waste water system.

However, all this will change with the introduction of the Landfill Directive which seeks to reduce the amount of biodegradable material being sent to landfill. In a series of steps between now and 2020, the amount of biodegradable waste going to landfill must be reduced to 35% of the 1995 figure. Removal of biodegradable material will halve the amount of waste going to landfill, and result in sites becoming biologically less active. By 2020, approximately 15 million tonnes per annum of biodegradable waste, containing 75,000 tonnes nitrogen, will be diverted away from landfill. This waste contains valuable plant nutrients which could be returned to arable land.

The way forward?

If the UK is going to meet EU targets, a radical review is required of the processes of regulation, collection, composting and distribution of biodegradable material. The volumes to be diverted away from landfill, if managed effectively, are small in comparison to volumes of the agricultural sector which already deals with 100 million tonnes plus of agricultural waste per annum, and apply in excess of 2 million tonnes nitrogen in mineral fertilizers and animal manures.

In 1998, 115,000 tonnes of sewage sludge went to landfill which represents 5,750 tonnes nitrogen. This quantity is likely to increase dramatically since dumping at sea has now been banned and spreading to land is coming under increasing environmental pressure. However, sewage sludge going to landfill is not making best use of its valuable plant nutrients.

6.2 Land recovery

Land recovery or the spreading of waste to agricultural land covers a wide range of materials and practices. At its most basic level are livestock manures and crop residues, either generated in-situ or collected from livestock housing and subsequently spread to land for agricultural benefit. This form of land recovery is not currently covered by any regulations, except in locations where Nitrate Vulnerable Zone (NVZs) are applicable. However, the Government intends to extend waste management controls, included within the EU Waste Framework Directive, to include waste from the agriculture sector. The proposed position is that if the manures and slurries are exploited for their beneficial nutrients, and are not applied in excess of the requirements of the land, e.g. they are an agricultural benefit, then they are not regarded as waste. However, if they are applied in excess of the requirements of the land, i.e. purely as a means of disposal, then they can be regarded as waste and will be subject to the permit requirements of Article 9 of the Waste Framework Directive.

Table 23. Organic material applied to land ('000 tonnes)

Product	Product quantity	Nitrogen content
Food processing waste (23.1)	175	17.5
Paper (23.2)	440	1.1
Sewage sludge (23.3)	504	25.2
Other general and biodegradable (23.4)	355	0.9
Total	**1,474**	**44.7**

The Environment Agency estimates that 1.47 million tonnes of other waste are spread to land including milk, food, paper and sewage sludge. Due to concerns regarding the pathogen content of sewage sludge and composted food, and the heavy metal and chemical content of waste papers, the amount of this material going to land disposal represents only a fraction of that available. Since land disposal represents one of the most logical and cost effective disposal options available at the moment, far greater use should be made of it. Technologies, such as in-vessel composting, which allow the 'cleaning' of waste materials prior to land disposal could be at the forefront of the fight to reduce or halt the disposal of biodegradable materials to landfill.

Even the most rudimentary calculations suggest that municipal solid waste contains over 14 million tonnes biodegradable waste, estimated to contain 270,000 tonnes nitrogen. Landfilling such a valuable resource, when alternatives already exist to make better use of it, illustrates how far the UK has to go in achieving true resource sustainability.

Land spreading of waste

The EC report 'Survey of Wastes Spread on Land' (2000) provides more information on the quantity and disposal routes for a wide variety of wastes. Surfers against Sewage have published their own consultation and strategy report 'A Green Blue-Print for Sewage Sludge Disposal' (2004)

6.3 Composting

Composting is the process of decomposing organic material under fully or partly controlled conditions in order to reduce the bulk of the starting material and to produce a stabilised end product. Biodegradable materials, such as organic agricultural wastes, local authority green wastes, domestic garden and kitchen wastes, paper and cardboard can be broken down by micro-organisms to form a stable and useful end product. During the composting process, the temperature of the compost can reach 45 - 70 °C, sufficient to kill the majority of pathogens. Composting is an aerobic process, the anaerobic equivalent is digestion.

The amount of biodegradable material being commercially composted in the UK is small. In 1998, the Composting Association estimated that 910,821 tonnes were composted with open-air turned-windrow systems being the most common composting method. However, as noted in section 6.1, this sector is likely to undergo massive expansion in the next few years to take account of the large amount of organic material which will be diverted away from landfill.

Composting is the ideal method of dealing with large amounts of biodegradable material, in that the end product can be returned to agricultural land. The benefits of applying compost to land are well known, increased organic matter and plant nutrients, but, in a wider view, it completes a full circle. Food came from the land, depleting it of its organic matter and nutrients, so it is seems only reasonable, that where ever possible, these resources should be returned to the land.

The Composting Association

The Composting Association publish an annual review 'The State of Composting'. This covers all aspects of composting in the UK, including policy and legislation, operators, types of composting, the end products and the market.

We estimate that in order to meet the requirements of the Landfill Directive, up to one-third of biodegradable municipal waste (BMW) will need to be diverted away from landfill (Waste Strategy 2000, Defra 2002 Spending Review, and the Strategy Unit report 'Waste Not, Want Not'). Although this diversion will be gradual, as facilities become available, by 2010 the UK may need to compost or find alternative methods of disposal for between 4.9 and 7.7 million tonnes (Mt) of BMW per annum, increasing to between 10.6 and 15.5 Mt by 2020.

Green wastes

Waste Strategy 2000 suggests that vegetation and plant matter from household gardens, local authority parks and gardens and commercial landscaped gardens, amounts to 5 million tonnes per annum (12,500 tonnes nitrogen). Most of this was sent to landfill with only 460,000 tonnes being composted.

Composts vary greatly in composition depending on their original feedstock and proposed use. The best, being well sorted, containing no contaminants and consistent in quality can be sold as peat substitutes for growing media. Further down the quality scale come mulches, soil improvers and landfill cover that have little or no retail value and are used on the same site as they are produced. Compost quality is determined by the feedstock material e.g. grass cuttings and food waste make wet composts with high nitrogen contents while wood and paper make dry composts with low nitrogen contents. Composts can be used as fertilizers depending on the nitrogen content and the carbon to nitrogen ratio. The higher the nitrogen content then the greater the potential as a fertilizer, however, if the ratio is too high, the nitrogen will less available as a plant nutrient, too low and the nitrogen will readily leach out of the compost.

6.4 Output from agriculture

The non-food output from agriculture falls into two main categories, inorganic and organic. Inorganic wastes are those arising mainly from packaging and plastic wrapping, and were the subject of 'Towards sustainable agricultural waste management' (Marcus Hodges, 2001). These wastes contain little or no nitrogen and will not be considered further.

Table 24. Solid and liquid outputs from agriculture

Product	Product quantity ('000 tonnes)	Nitrogen content ('000 tonnes)
Manures and slurries (24.1)	145,000	725.0
Plant residues (24.2)	10,029	62.8
Total	**155,029**	**787.8**

Table 25. Diffuse pollution from agriculture ('000 tonnes)

Product	Product quantity ('000 tonnes)	Nitrogen content ('000 tonnes)
Nitrate (25.1)	2,095	473.0
Ammonia (25.2)	279	229.8
Nitrous oxide (25.3)	99	63.0
Total	**2,473**	**765.8**

Diffuse water pollution

Diffuse water pollution from agriculture was the subject of a 2002 Defra report which suggested that up to 70% of nitrate entering English waters was estimated to come from agricultural land. The bill for removing nitrate from UK drinking waters is estimated at £16 million. (Defra. 2002. Agriculture and Water: A Diffuse Pollution Review.)

Ammonia in agriculture

Agriculture, particularly livestock, is the largest producer of ammonia in the UK. Ammonia emissions in 2000 were estimated in the range 270,000 to 370,000 tonnes. (Defra. 2002. Ammonia in the UK). Deposition of nitrogen, principally ammonia, to semi-natural habitats is altering the mix of plant species present and is acidifying soils.

The organic residues created from agriculture are rich in nitrogen and vast in quantity. The amount of manures, slurries, straw and vegetable residues produced annually are approaching 170 million tonnes. Traditionally, these have been handled in-situ, e.g. incorporated into agricultural land although increasing concerns over nitrogen as a diffuse environmental pollutant have brought this subject back into the public domain. This organic material is sometimes referred to as 'waste' rather than appreciated for its nutrient value although it is still subject to NVZ regulations and the codes of good agricultural practice. However this may change in the future with the introduction of the Waste Directive (section 5.3.2.).

Agriculture also produces gaseous nitrogen compounds such as ammonia from livestock rearing and nitrous oxide from arable tillage. Agriculture is responsible for 80% of all ammonia and 53% of all nitrous oxide emissions within the UK. These products contribute to atmospheric and soil acidification and to global warming. Nitrates accumulate in groundwater as a result of mineralization in the soil, applied nitrogen fertilizer, aerial deposition and from animal manures.

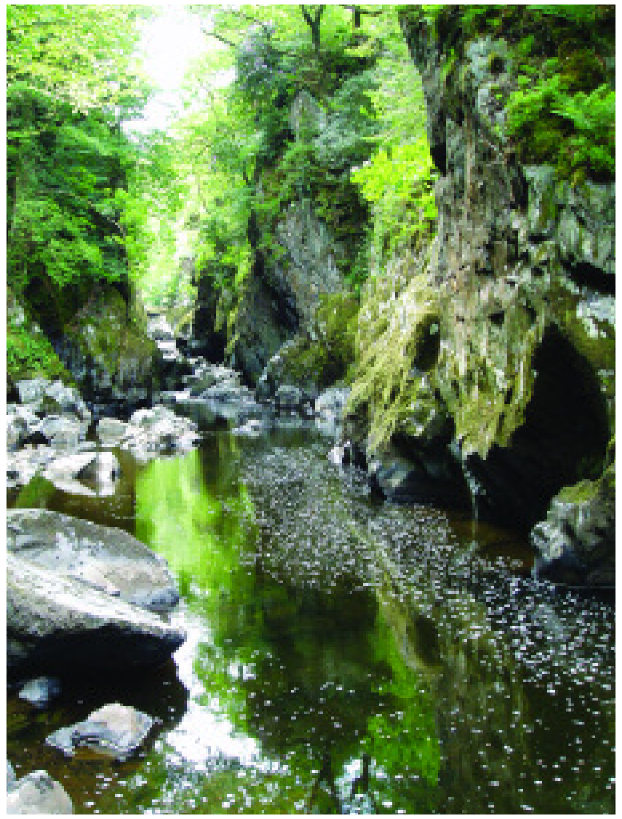
6.5 Construction and demolition waste

In terms of sheer volume, the construction and demolition industries produce the largest amounts of waste in the UK. As the wastes are basically inert, with only soil having any nitrogen content, the amounts of nitrogen involved are small. Soil arisings due to construction amount to approximately 24 million tonnes, which contains around 24,000 tonnes nitrogen. Treatment of soils includes reuse in restoration or engineering and disposal to landfill.

Table 26. Production of construction and demolition waste ('000 tonnes)

Product	Production
England & Wales (26.1)	72,500
Scotland (26.2)	5,400
Northern Ireland (26.3)	5,000
Total	**82,900**

7 Nitrogen wastage



Many researchers and environmentalists consider that the release and accumulation of reactive nitrogen to our environment is the next 'big' environmental problem. At all levels, local, national and global, mankind has been converting inert atmospheric nitrogen into reactive forms for a hundred years and releasing it into the environment. The consequences of this slow build up of nitrogen are now being recognised; excessive nitrates in water have caused eutrophication, and nitrous oxide contributes to global warming. Up to now, the global environment has been able to absorb and denitrify large amounts of reactive nitrogen. However, we must now heed the warning signs and take action to prevent problems in the future.

Agriculture is responsible for the greatest 'leakage' of nitrogen to the environment. Therefore it is the agricultural sector where efforts to reduce nitrogen use have to date been focused and where we must continue to act. In the same way that global warming has raised awareness of increasing levels of carbon dioxide, eutrophication could be used to highlight the problems nitrogen can cause because excessive nitrogen is potentially more damaging on a global scale than carbon dioxide.

7.1 History

Nitrogen, the element, was discovered in the late 18th century and its role as a plant nutrient in the mid 19th century. By 1900, it was recognised that nitrogen was the major limiting nutrient in food production. It is possible that the Haber-Bosch process for manufacturing ammonia, first introduced in 1913, was the most important invention of the 20th century in that the fertilizer produced from it allowed mass food production at a relatively cheap cost. Human activities have roughly doubled the amount of reactive nitrogen entering the element's biospheric cycle (Smil, 1999). Alternatively, nitrogen fertilizer may be considered the lynch-pin for the uncontrolled expansion of the human population; in 1900 the world population was 1.6 billion rising to 6.1 billion at the beginning of the 21st century.

The increasing demand for food has seen the world consumption of nitrogen fertilizer rise from 1.3 million tonnes in 1930/1 to 82.3 million tonnes in 1998/9. This large amount of fertilizer, combined with a crop assimilation rate of 50% means the amount of reactive nitrogen being released into our biosphere has resulted in the natural nitrogen cycle being overloaded.

7.2 Current situation

In the UK, we 'waste' over one million tonnes of reactive nitrogen a year (Table 27). Although the term 'waste' is misleading since only nitrogen contained within inert products going to landfill is waste. A better explanation is to say that of the 3.4 Mt reactive nitrogen that we either create or produce per annum, over 1 Mt is returned to the environment without any benefit being realised from it. This loss is not, of course, deliberate but as a result of unavoidable inefficiencies in agriculture, electricity production and road transport. However, whether or not this nitrogen is wasted, the energy and other resources required to manufacture and transport the products could be saved by improving the efficiency of its use and could reduce some of the environmental problems caused by the release of reactive nitrogen.

Table 27. Production of environmental pollutants ('000 tonnes nitrogen)

Product	1990	1998
Nitrogen oxides (NO_x) (27.1)	840.3	528.0
Nitrous oxide (N_2O) (27.2)	139.3	118.9
Ammonia (NH_3) (27.3)	300.6	287.4
Riverine nitrogen (27.4)	315.0	420.0
Total	**1,595.2**	**1,354.3**

The amount of gaseous nitrogen pollutants released into the UK environment between 1990 and 1998 has fallen: nitrogen oxides (NO_x) by 37%, nitrous oxides (N_2O) by 15% and ammonia (NH_3) by 4%. However, in the same period the input of nitrate to UK coastal waters increased by 33%. In absolute terms, during the period 1990-2000, the UK reduced output of nitrogen into the environment by approximately 15% although it should be remembered that the error involved in estimating the riverine nitrogen load is subject to many assumptions and that the true figure may be quite different. According to NEGTAP 2001, emissions of NO_x, N_2O and NH_3 will continue to fall in line with UK commitments to international protocols.

The majority of nitrate reaching the oceans via the river system is denitrified in estuarine and coastal waters. What is unclear is whether there has been a large increase in denitrifying organisms in response to the increased nitrate load, and what effect this has had on the local, national and international environment (Galloway, 1996; Nixon, 1996; Ogilvie, 1997).

This nitrogen enrichment has lead to accumulation on a global scale which encompasses both the oceans and atmosphere. Excessive nitrates in our oceans have led to algal blooms in areas such as the North Sea and Gulf of Mexico, and a build up of greenhouse gases such as nitrous oxide and nitrogen oxides. Although any long term damage to our environment is as yet unproven, it would be prudent to control our nitrogen inputs until further research has been undertaken.

7.3 The future

7.3.1 Nitrogen fertilizer

In the UK, the use of nitrogen fertilizer has decreased from 1.5 million tonnes in 1990 to 1.3 million tonnes in 1999. This trend is common across the developed world although use is still increasing in the developing world. Global consumption was up 7% between 1990 and 1999 to 82.8 million tonnes. Currently, half of global food needs are grown using nitrogen fertilizer and this proportion will increase with increasing population.

Since the use of nitrogen fertilizer is driven by the demand for food, especially meat, and given that United Nations estimate that global population will increase from six billion now to nine billion by 2050, then it is obvious that the use of nitrogen fertilizer is set to increase dramatically. If environmental pollution on a global scale is to be avoided, then improvements in the efficiency of nitrogen use are urgently required.

The holy grail of plant breeding since the 1950's has been to incorporate nitrogen fixing bacteria into the world's main cereal crops. However despite many years of research and many millions of pounds, that goal is no closer.

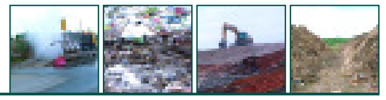
7.3.2 Landfill nitrogen

Nitrogen contained within landfill comes in two forms, organic nitrogen contained within biomass such as food and garden wastes, and ammonium resulting from the breakdown and decomposition of these biomasses. Maintaining a fairly constant level of nitrogen within a landfill is necessary as some nitrogen is required for bacterial decomposition while excess is toxic.

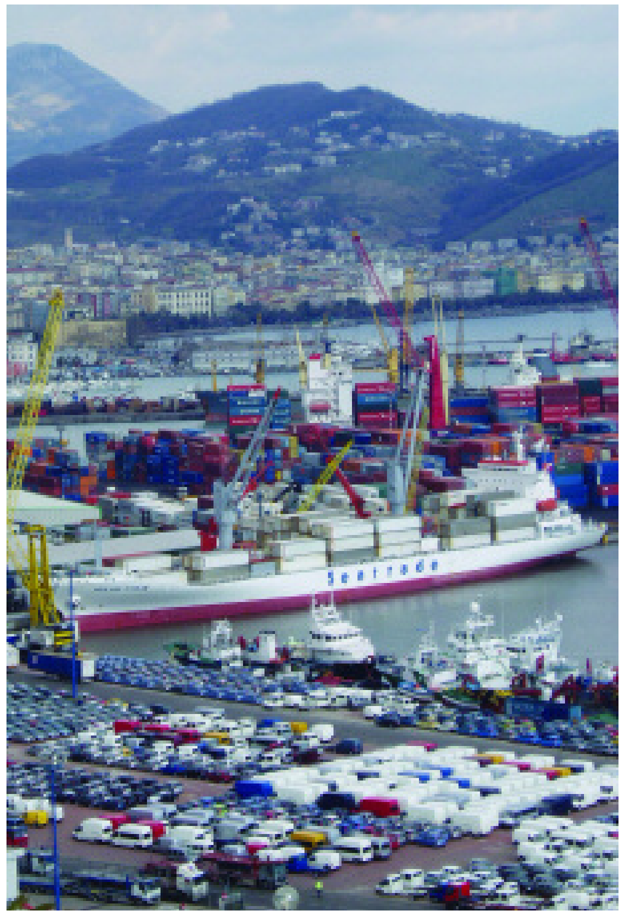
The introduction of the Landfill Directive, although designed to reduce methane levels by restricting biodegradable material, will also reduce the amount of nitrogen going to landfill. The Landfill Directive sets the following targets:

- By 2010, to reduce biodegradable municipal waste being landfilled to 75% of that produced in 1995
- By 2013, to reduce biodegradable municipal waste being landfilled to 50% of that produced in 1995
- By 2020, to reduce biodegradable municipal waste being landfilled to 35% of that produced in 1995

The UK produced 29 million tonnes municipal solid waste in 1995 with 60% assumed to be biodegradable. In order to comply with the directive, assuming that waste arisings are growing at 3% per annum, by 2020 the UK needs to be diverting 10 million tonnes of biodegradable municipal solid waste, containing 50,000 tonnes nitrogen, away from landfill every year. One potential disposal route for this biodegradable municipal solid waste would be composting, followed by land disposal. However, before this can happen the composting capability of the UK will have to be expanded to cope. In 1998, only 900,000 tonnes waste was composted, and this was primarily municipal green waste. Government policy and public education will be required to divert biodegradable from landfill to other disposal routes, with composting probably being the favoured option. Other options include incineration with or without energy recovery.



7.4 Conclusions



On a global basis, the enormous increase in human population, and associated insatiable demand for nitrogen fertilizer and food, has swamped the natural nitrogen cycle. World-wide, many scientists and environmentalists now consider that we have moved into a new era of global nitrogen over-use that will result in serious environmental problems in the years ahead.

In the UK, and Europe as a whole, nitrogen fertilizer use appears to have reduced or at least stabilised. However, this is not because we have recognised, and taken responsibility for our use of nitrogen fertilizer, it is because we have moved the problem elsewhere. We now import far more of our food than we did in the past. Nitrogen is as much a global problem, as a regional one.

The agriculture industry has a large responsibility for nitrogen in the UK since years of use has built up a reservoir in soil and water, however, agriculture is not the only source of reactive nitrogen. The combustion of fossil fuels for power generation and in vehicles also releases large amounts of reactive nitrogen to the environment.

There are no easy ways to reduce our reliance on, and output of, reactive nitrogen. Research and development, and improved management practices in agriculture will help reduce the overall amounts of nitrogen being used to grow our food, while improvements in combustion technology will continue to reduce outputs of NO_x.

However, in some areas the damage may already have been done. The greater amounts of nitrogen present in water has changed the biodiversity of rivers, estuaries and seas and the organisms that inhabit them. The increased nitrogen content in water is likely to be one of the biggest areas of concern in the foreseeable future.

Nitrous oxide is a greenhouse gas with a greater destructive ability than CO_2. Whilst outputs are small in comparison, the potential damage should not be underestimated.

In a modern and growing economy we cannot live without reactive nitrogen, so before we poison the environment, we must learn to manage it better. Legislation can be used to establish the rules, however, the first step in solving any problem is to recognise and understand what the problem is.

8 Data sources for tables

Table 1 .... page 11
Standard Industrial Classification codes & nitrogen content

Table 2 .... page12
2.1 - The Fertilizer Manufactures Association (personal communication).
2.2 - Market & Business Development, UK Animal Feeds Report.
2.3 - Defra. Agriculture in the UK 1998.
2.4 - Defra Digest of Environment Statistics.
2.5 - Environment Agency Strategic Waste Management Assessment 2000.
2.6 - Environment Agency Strategic Waste Management Assessment 2000.
2.7 - National Expert Group on Transboundary Air Pollution (NEGTAP).
2.8 - The Royal Society. The Nitrogen Cycle of the United Kingdom 1983 & Defra. Agriculture in the UK 1998.

Table 3 .... page 13
3.1 - Defra Agriculture in the UK 1999
3.2 - Forestry Commission, Forestry statistics 2001
3.3 - Environment Agency & The Scottish Environment Protection Agency
3.4 - Environment Agency Strategic Waste Management Assessment 2000
3.5 - ADAS Wolverhampton (personal communication)
3.6 - NETCEN / Defra
3.7 - NETCEN / Defra
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BTTG. British Textile Technology Group. www.bttg.co.uk

COTANCE. Confederation of National Associations of Tanners and Dressers of the European Community. www.euroleather.com

CEH. The Centre for Ecology and Hydrology is the UK body for research, survey, and monitoring in terrestrial and freshwater environments. www.ceh.ac.uk/

Chemical Industries Association. www.cia.org.uk/

CIRIA. A UK-based research association concerned with improving the performance of all involved in construction and the environment. www.ciria.org.uk/

Composting Association, The. www.compost.org.uk/

EHS. Department for the Environment in Northern Ireland. http://www.ehsni.gov.uk/

Elm Farm Research Centre. www.efrc.co.uk/

ENDS Report, The. www.endsreport.com/

English Nature. Champions the conservation of wildlife, geology and wild places in England. A Government agency set up by the Environment Protection Act 1990 and funded by the Defra. www.english-nature.org.uk/

Environment Agency. www.environment-agency.gov.uk/

Defra. Department for Food & Rural Affairs. www.defra.gov.uk/

DTI. Department of Trade & Industry. www.dti.gov.uk/

European Environment Agency. www.eea.eu.int/

EUROSTAT. The Statistical Office of the European Community. epp.eurostat.cec.eu.int

Fertilizer Manufacturers Association. To represent the views and interests of the fertilizer industry to governments and to appropriate organisations and bodies, and to promote the proper and responsible use of fertilizers. www.fma.org.uk/

Forestry Commission of Great Britain. www.forestry.gov.uk/

Foundation for Water Research. http://www.fwr.org/

Friends of the Earth. www.foe.co.uk/

GANE is a £7.1 million Thematic Programme funded by NERC (£6 million), with substantial additional contributions from Defra and the Scottish Executive. It is investigating the problems posed by the massive additions we are making to the UK and global nitrogen cycle. gane.ceh.ac.uk/

HM Customs and Excise. www.hmce.gov.uk/

IEA Coal Research. A provider of information on efficient coal supply and use. www.iea-coal.org.uk/

IPCC. Intergovernmental Panel on Climate Change. www.ipcc.ch/

Recycling and waste management www.letsrecycle.com.

Marcus Hodges Environment Ltd. www.mhe.co.uk/

National Statistics. The home of UK's official statistics. www.nationalstatistics.org.uk/

NEGTAP. National Expert Group on Transboundary Air Pollution. www.nbu.ac.uk/negtap/

NERC. The National Environment Research Council. www.nerc.ac.uk/

NETCEN. www.netcen.co.uk/

OSPAR. The Convention for the Protection of the Marine Environment of the North-East Atlantic. www.ospar.org/

Paper Federation of Great Britain, The. The trade association for the paper industry representing large and small paper manufacturing companies in the UK. www.paper.org.uk/

Scottish Executive. www.scotland.gov.uk/

SEPA. Scottish Environment Protection Agency. www.sepa.org.uk/

Terra Nitrogen (UK) Ltd. www.terranitrogen.co.uk/

TRADA. The Timber Research and Development Association services the timber and woodworking industries and their suppliers and customers. www.trada.co.uk/

UK National Air Quality Information Archive, The. www.airquality.co.uk/archive/index.php

UKPIA. UK Petroleum Industry Association. www.ukpia.com

Wasteguide. www.wasteguide.org.uk

Waste Watch. A national organisation promoting and encouraging action on the 3Rs - waste reduction, reuse and recycling. www.wastewatch.org.uk/

Water UK. www.water.org.uk/

Woodland Trust, The. http://www.woodland-trust.org.uk/

WRAP. The Waste and Resources Action Programme. www.wrap.org.uk/

11 Appendix
Mass Balance Projects

Biffaward Programme on Sustainable Resource Use

This report forms part of the Biffaward Programme on Sustainable Resource Use. The aim of this programme is to provide accessible, well researched information about the flows of different resources through the UK economy, based either singly, or on a combination of regions, material streams or industry sectors.

Information about material resource flows through the UK economy is of fundamental importance to the cost-effective management of resource flows, especially at the stage when the resources become 'waste'.

In order to maximise the Programme's full potential, data will be generated and classified in ways that are both consistent with each other, and with the methodologies of the other generators of resource flow/waste management data. In addition to the projects having their own means of dissemination to their own constituencies, their data and information will be gathered together in a common format to facilitate policy making at corporate, regional and national levels.

Further information on the Programme is available at www.biffaward.org/studies.

Geographical	Sector	Material
Completed		
Isle of Wight *www.bestfootforward.com/reports.html*	Agricultural Report (Marcus Hodges)	Carbon UK Report www.eci.ox.ac.uk/lowercf/carbonuk.html
City Limits Report (London) *www.citylimitslondon.com*	Agricultural Waste Report (C-Tech) *www.ctechinnovation.com/publications.htm*	UK Tyres Report (Viridis) *www.trl.co.uk/viridis/1024/mainpage.asp?page=71*
Mass Balance UK book	Construction Report (Viridis) *www.trl.co.uk/viridis/1024/mainpage.asp?page=71*	European Tyres Report (Viridis) *www.trl.co.uk/viridis/1024/mainpage.asp?page=111*
Mass Balance UK book 2 *www.forumforthefuture.org.uk/publications/Massbalance_page1478.aspx*	BedZed Construction Report pt1 *http://www.bioregional.com/retail/customer/product.php?productid=13&cat=&page=&PHPSESSID=2e3b7e79e38727051427ca0968eadd01*	Chemical Report
Mass Balance UK book 2 *www.forumforthefuture.org.uk/publications/Massbalance_page1478.aspx*	BedZed Construction Report pt1 *http://www.bioregional.com/retail/customer/product.php?productid=13&cat=&page=&PHPSESSID=2e3b7e79e38727051427ca0968eadd01*	
South East Report *www.takingstock.org*	4sight – Rocks to Rubble – eco-region *www.4sight.org.uk/*	Thermal Methods Report *www.ctechinnovation.com/publications.htm*
Northern Ireland Report *www.northern-limits.com/*	Public Sector Report (Waste Watch *www.wastewatch.org.uk/research/view_research.aspx?id=3*	PIRA Packaging Report *www.pirapaper.com/pack/pdfs/massflow.pdf*
Scotland Report *www.scotlands-footprint.com/*	Solvent Waste in UK Furniture Manufacturing Industry *www.bfmenvironment.co.uk*	Benchmarking Wood Combustion

Wales Report *www.walesfootprint.org/policy/index.htm*	Exhibition Industry *www.envirobiz.co.uk/projects.html#sexi*	Large Scale Glass Manufacture *www.britglass.co.uk/Files/UKGlassManufactureAMassBalance.pdf*
	Greening Britain's Schools *www.environmentcentre.com/siena.html#Projects*	Sustainable Timber Waste
	Publishing *www.pirapaper.com/pack/pdfs/UK_Publishing_Mass_Balance.pdf*	Furniture Packaging Optimisation *www.fira.co.uk/scripts/runisa_107k.dll?fira:membershome*
	Electricity Report *www.ctechinnovation.com/publications.htm*	Plastic Report *www.plasticsintheuk.org.uk/*
	Foundry Report	Sustainable Markets for Waste Glass from Fluorescent Tubes and Lamps
	UK Status Report on Waste from Electrical & Electronic Equipment (ICER)	Paper
	Mass Balance Study into Waste Arisings from the Food & Drink Processing Industries *www.ctechinnovation.com/foodprocessing.pdf*	Material Flows of Iron, Steel and Aluminium *www.psi.org.uk/research/project.asp?project_id=92*
	National Health Service *www.materialhealth.com/*	Civil Engineering Application of Tyres (Viridis) *www.trl.co.uk/viridis/1024/mainpage.asp?page=113*
	Financial Sector *www.wastewatch.org.uk/research/downloads/RethinkingWasteManagementToReapRewards1.pdf*	Packaging Report *http://www.piranet.com/*
	Newspaper Report *www.newspaper.paisley.ac.uk/chemistry/home/environmental/projects/newspaper/nieti_massbalance.htm*	Glass *www.britglass.co.uk/localauthorities/environment.html*
	UK Paper & Board Industry	Transport Options for Waste in Scotland *www.trl.co.uk/viridis/static/projects/WasteStreams/VR7.pdf*
	Ceramics Industry	
	Magazines Sector	
	Automotive *www.trl.co.uk/viridis/1024/mainpage.asp*	
South West		
		Methane
To be completed		
	Pigs	Mass Balance & Scenario Analysis for UK Clothing & Textiles
Ecological Budget UK (WWF), regional series	Poultry	Embodied Wood: The UK Mass Balance and Efficiency of Use