Soil Nutrient Balances
Draft Report

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UK Agriculture Nutrient Balances methodology review.

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## 1 Acknowledgements

Funding of this work through FERA is gratefully acknowledged. We have made extensive use of previous work by many others, particularly within Defra and ADAS. During the project, we were fortunate to receive constant encouragement and assistance from FERA and Defra staff. Last but by no means least, thanks are due to a number of others, in particular Bob Foy of the Agri-Food & Biosciences Institute, Belfast, for detailed and always helpful comments on the relationship between our calculations and those carried out within Northern Ireland; Gary Owens of ADAS; Alan Hopkins of GES Consulting and Gillian Goodlass of ADAS.
2 Executive Summary

This project was commissioned by Defra to continue the work developing the nutrient balances. It was funded under the Defra Strategic Evidence Fund which is specifically aimed at identifying high priority work in cross-cutting areas. The project is based on the overall approach and methodology developed and published by OECD and subsequently adopted by Eurostat as one of its agri-environment indicators. It builds on an earlier project (Fernall & Murray, 2009) funded under the EU TAPAS funding stream which reviewed the robustness of the overall approach and methodology and identified a number of areas where further development was needed to improve the estimates.

Defra is obliged to provide estimates of soil nutrient balances to Eurostat. There is also growing interest within Defra and its network in the nutrient balances as a strategic indicator of farming's environmental impacts. The overall aim of this project is to assist Defra in its commitment to be able to produce reliable estimates of soil surface nutrient balances at a UK and country level. The goal for Defra is to be able to produce annual estimates to provide a coherent time series to monitor change over time. These estimates will be published on the Defra website as Official Statistics providing the definitive estimates for the UK.

Nutrient balances are used as indicators of risk of environmental pollution, and the UK seeks to provide N and P balance data to international bodies including the OECD and EUROSTAT. The UK has thus both an international obligation to provide N and P balance data, and an interest in developing a robust method for use as an indicator for policy support.

The objectives of this project were to update and review the UK methodology for N balance calculation, complete the development of an analogous P balance, extend the method to calculate balances at national as well as UK scale, and develop a method to regionalise the balance further, as requested by EUROSTAT. The method was to be as robust and accurate as possible, while satisfying the requirements of the OECD nutrient balance proforma. A review of how nutrient balances relate to other policy indicators was also required.

During the project, the Steering Group agreed that the methodology should be changed from the Soil Surface balance approach, as specified by OECD, to the Farm Gate approach, because the input data for the latter are more accurately knowable, and more responsive to changing practices. The relationship between these two balances therefore had to be defined, and a method created for conversion from one to the other.

The calculation approach was designed to be as transparent and updateable as possible. It consists of Excel spreadsheets for collation of input data; an ACCESS database to provide the required results and tabulations; a second ACCESS database to process the spatial distribution of the results among regions; and a linked GIS system to display the regionalised data.

Outputs

The project has provided to FERA and Defra, for the example year 2004, with the following outputs:

- A calculation method based on the Farm Gate balance, for both N and P
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- A method for conversion of Farm Gate to Soil Surface balance
- Calculation at national level (as well as UK totals)
- Regionalisation and mapping of the balance within countries
- Data entry, calculation and GIS systems, with documentation, created to facilitate future updating
- Assessment of uncertainty and bias
- Assessment of priorities for improvement
- Review of policy uses of the balance, and its relationship to other environmental indicators

We hope and intend that this provides a sound foundation for future improvements to the balance calculations.
3 Policy context for nutrient balance indicators

3.1 Policy uses of nutrient balances
This project was commissioned by Defra to continue the work developing the nutrient balances. It was funded under the Defra Strategic Evidence Fund which is specifically aimed at identifying high priority work in cross-cutting areas. The project is based on the overall approach and methodology developed and published by OECD and subsequently adopted by Eurostat as one of its agri-environment indicators. It builds on an earlier project (Fernall & Murray, 2009) funded under the EU TAPAS funding stream which reviewed the robustness of the overall approach and methodology and identified a number of areas where further development was needed to improve the estimates.

Defra is obliged to provide estimates of soil nutrient balances to Eurostat. There is also growing interest within Defra and its network in the nutrient balances as a strategic indicator of farming's environmental impacts. The overall aim of this project is to assist Defra in its commitment to be able to produce reliable estimates of soil surface nutrient balances at a UK and country level. The goal for Defra is to be able to produce annual estimates to provide a coherent time series to monitor change over time. These estimates will be published on the Defra website as Official Statistics providing the definitive estimates for the UK.

Nutrient balances are used as indicators of the risk of pollution. A balance measures the difference between nitrogen (or phosphorus) inputs and outputs to agricultural land or systems, and may be used as an indicator of potential losses to the environment including water.

The OECD (Organisation for Economic Co-operation and Development) publishes national agricultural soil surface balances for nitrogen and phosphorus, presented according to a standard calculation methodology (OECD, 2007a,b). Methods of developing national balances, and assessments of their usefulness as predictors of water quality, were developed within the OSPAR framework (concerning marine pollution from countries bordering the North Sea). More recently EUROSTAT (the EC statistical organisation) has begun collating nutrient balances from EC member states, and requesting the balances at finer spatial resolution than UK or national. The European Environment Agency has also proposed a nutrient balance indicator for agricultural land as a core indicator of environmental health, alongside indicators such as fertiliser consumption.

Provision of these balances in a coherent and consistent way for international policy fora is an important goal. A change in methodology (e.g. presenting results per ha of managed versus total agricultural land) can affect the balance, and a nation’s ranking within the group, and could lead to inappropriate conclusions on progress towards pollution reduction.

Although the UK does not use a balance as a headline indicator internally, the balance is often used as a component in assessing progress towards environmental goals. Thus the UK in reporting progress with implementation of the Nitrates Directive, cited the fact that the OECD nitrogen balance from agriculture in the UK between 1985 and 2002 (the latest year with a calculated balance) had declined substantially (Noel et al., 2009). Nutrient balances are also increasingly used at farm scale in the UK, to encourage and facilitate nutrient planning (e.g. Goodlass et al., 2003; Halberg et al., 2005). The Defra-funded farm fertiliser software PLANET (PLANET 2006) now embodies a farm gate nutrient balance,
with benchmarks to enable farmers to compare their performance with typical values for similar systems (Anon, 2007a).

Northern Ireland has adopted high level targets for N and P balances to assess the impact of environmental measures aimed at reducing eutrophication. The current targets for 2011 are 135 kg N/ha and 10 kg P/ha. Eutrophication is an important environmental issue in Northern Ireland and agriculture is the largest single source of nutrients in freshwaters (Smith et al., 2005). Control of eutrophication was the primary justification for designating the whole territory as a sensitive area under the Nitrates Directive (ND), the introduction of an Action Programme (AP) under the ND and a new Phosphorus Regulation. The AP sets upper stocking limits on farms, closed periods for the application of manure and fertilisers which are designed to lower risk of loss from land to water and to increase the efficiency with which nutrients are used by crops. This in turn should lower the demand for chemical fertilisers. For P, the dominant driver for eutrophication, a Phosphorus Regulation was introduced which links the use of chemical fertilisers containing P to a defined agronomic need for nutrients as defined by a current soil P test, crop P demand as defined by RB209 (MAFF 2000, Defra 2010) and the availability of P from manure. These measures would be expected to affect the national balance. The DARD nutrient balance was developed in Agri-Food and BioSciences Institute in Belfast (AFBI) and is a regional input less output balance – sometimes referred to as a regional farm gate balance (Foy et al. 2002). It uses agricultural statistics that DARD produce on an annual basis and are published on its website. Inputs are the nutrients in imported chemical fertilisers and imported animal feeds. The outputs are the nutrients that are exported (i.e. sold) in meat, milk, eggs and arable products. It thus resembles closely the approach adopted in the current work.

3.2 Types of nutrient balance

The main types of nutrient balance are Farm Gate, in which the inputs and removals are calculated for the agricultural system; and Soil Surface, in which the balance is based on applications and removals from the soil. The Farm Gate balance assesses inputs including fertiliser and feed, and outputs as product or other removals from the farm. Internal transfers such as grass intake or excretal deposition are ignored. The Soil Surface balance assesses inputs including fertiliser and manures; and outputs as crop offtake including grass and fodder consumption. The pros and cons of these approaches are discussed below.

Nutrient Balance methodologies also vary in relation to the scale of calculation (field, farm, regional, national) and the extent to which gaseous inputs and losses are accounted for.

3.3 Desirable characteristics of nutrient balance

If the balance is to function as a useful indicator, it must change year on year in a way which reflects the evolving risk of pollution, and should be interpretable in relation to other indicators of pollution. It should therefore be calculated as far as possible from regularly updated data, which reflect changing inputs and outputs. The balance should also be transparent, and easy to compare with equivalent data from other times or places. It may be helpful to design the balance so that it can be split into contributing sectors, and also regionalised.

The agricultural nutrient balance should be as far as possible - evidence based
3.4 Relationship to other environmental indicators

The nutrient balance cannot be an accurate predictor of nutrient loss to the environment, because so many other factors determine that loss. Its main advantage is that its calculation can be standardised. An additional argument is that if there is a surplus, it is likely to end up in increased emissions to the environment at some point, even if we cannot quantify where or when. In contrast, modelled predictions of nutrient emissions, while potentially and by intent more accurate as indicators of the pollution of interest, can be difficult to use either for comparison between nations, or for assessment of progress, because methodologies are not standardised.

Many of the inputs to the nutrient balance are also drivers for nutrient emissions models, notably fertiliser inputs, and offtake in crops. As regards the Farm Gate balance, not all models would use measured feed inputs or quantity of livestock production to calculate losses at grazing, partly because such data are available only at national or at best regional scale. It is in principle possible to tune the model such that the livestock system has the same pro rata inputs, outputs and nutrient balance as the national livestock system, and this approach is being developed under a number of recent and ongoing projects (e.g. Defra project WQ0106). As regards the Soil Surface balance, two of the largest components (manure/excretal returns and grass consumption) would normally be calculated within a model, rather than being taken as input data. They are not measured routinely in any comprehensive way, although national coefficients for excretal and manure outputs are regularly updated for policy purposes (Cottrill & Smith, 2010; Defra, 2008 a,b)

The balance cannot specify the fate of the surplus – this is the role of models (see review of models from “Setting the priorities for future work on nutrient decision support systems - IF0111”). The relationship between surplus and any one fate (such as nitrate loss to water) will differ between systems. Thus, grassland systems may have a greater N surplus than arable systems, but usually result in smaller losses to water – much of the N loss being in gaseous form.

Balances are consistently greater in livestock than arable systems. For this reason a balance in itself may not be a good guide to progress in mitigation – more information may be gained by studying trends; and by notionally splitting the balance into sectors.

A nutrient balance can be relatively easily calculated at farm scale using the ‘Farm Gate’ approach. This approach can allow comparison between farms or against benchmarks – provided each system (e.g. dairy, cereals etc) is treated separately (e.g. Goodlass et al., 2006; Anon 2007a ). Thus, at farm scale the balance can be used as one tool for promoting mitigation actions. However, there are many improvements in management practice which could reduce emissions without any effect on the balance statistics. Examples include timing of fertiliser and manure applications to minimise runoff risk; use of cover crops to minimise erosion and nitrate leaching (Lord et al., 2002).
3.5 **Strengths and weaknesses of nutrient balances as environmental indicators**

In summary therefore, the nutrient balance is a simple headline indicator of the risk of nutrient transfer to the environment, and as such has value for tracking progress year on year. However its use in isolation for comparing different systems can be misleading, and also risks focussing attention on nutrient inputs only, at the expense of other methods of minimising pollution. To be truly informative, the contributing sector balances should be considered separately. The balance can be a powerful tool for assessing trends over time, and potentially for identifying areas of greatest risk of emissions to air and water. However its use for comparison between different climates or systems requires care, since these factors will confound the relationship between balance and pollution.

Within any one system and location, there is a positive correlation between nutrient balance and nutrient loss to the environment (whether water or, in the case of nitrogen compounds, also air). It is this relationship that justifies the use of the balance as indicator.

However, this relationship is non-linear, differs between systems and is affected by climate (Lord *et al.*, 2002). Arable systems tend to have greater nutrient losses to water at a given balance, and yet tend to have smaller balances than areas dominated by livestock systems. It is therefore possible for agricultural land use to change in such a way that the balance is decreased while the nutrient loss is increased.

Nutrient loss to water is positively correlated with rainfall quantity, while concentrations are negatively correlated with rainfall quantity. In the UK, wetter areas tend to be dominated by livestock grazing systems rather than arable. The net result is that the areas of greatest nutrient concentrations in waters are in the drier parts of the country, dominated by arable farming. The areas of greatest nutrient balance are in the west, due to the greater concentration of livestock. Total losses to water do not show a strong east-west trend. Water quality targets are most commonly set in terms of concentration.

Another aspect which can confound interpretation of the balance, particularly relevant in the UK, is its sensitivity to the definition of agricultural land. The UK contains large areas of ‘rough grazing’ which support low intensity grazing, especially of sheep. These areas receive no fertiliser or manure, and are not cultivated, but they do receive atmospheric deposition and therefore contribute to production. Inclusion of these areas therefore increases the total balance, but decreases the balance per ha of land. The OECD definition of agricultural land would appear to exclude rough grazing. However this can lead to apparently very large balances in some upland areas, where stock which actually roam the rough grazing are all attributed to the small area of ‘managed’ land.

Responses to changes in nutrient balance, within a given system, may not be immediately detected in changes in the environment, especially water quality. In the case of N a major cause is the delay caused by transit through groundwaters, which may be decades or more. In the case of P, a major cause of delay is that P loss in sediment is a function of P concentration in the soil, and achieving measurable change in soil P concentration requires many years of negative (or positive) P balance. More immediate changes can be achieved by measures which may not affect the balance (e.g. reduction of surface runoff; avoidance of manure applications during high-risk periods; use of cover crops). Thus the balance is only one of a suite of indicators of environmental status, which should be considered together.
4 Outline approach

4.1 Scope and objectives of work
The objectives of this study were to

- develop a robust, relatively simple methodology for calculation of the N and P balance of agriculture in the UK and the Devolved Administrations;
- base the balance as far as possible on the same input data as used for other indicators or models of nutrient pollution
- base the balance as far as possible on regularly updated standard statistics such that it could respond to changes in agricultural inputs and outputs
- develop a method for converting between the calculated balance and other forms of balance as required for example by the EU (EUROSTAT), OECD or other organisations
- develop a method for apportioning the balance, by agricultural activity/sector, and by region
- map the resulting balance and selected source data;
- document the methodology with particular emphasis on the source of coefficients not provided by annual statistics.
- Identify the major uncertainties in the balance, and the scope for improvement.

4.2 Approach
The balance is calculated using a farm gate approach (i.e. inputs and outputs to the system, rather than the land itself) because this enables response to changes in livestock feeding for which statistics are collected annually, and reduces uncertainty in the main components.

The arable (cropped) area is treated as one “farm”, and the grassland sector with its grazing livestock and green fodder crops (including maize) as another “farm”. Pigs and poultry are also best treated as separate “farms”. By this approach, all harvested crops which are typically sold off-farm (cereals, combinable legumes, OSR etc) are treated as exports from the national arable farm. Some of these are then re-imported to the national livestock farm, as feed. This separation makes the arable sector calculation almost identical for farm gate or soil surface balance, and simplifies the remaining work.

Choice of method
The OECD has traditionally required presentation of the soil surface balance (OECD & EUROSTAT, 2007a,b). However direct estimation of the components of this balance in grassland systems is prone to major – indeed dominating – uncertainties as can be seen by following the historical variations in the estimates. The steering group for this project therefore concluded that the calculation method should be via a Farm Gate balance, and the Soil Surface balance should be derived from this.

At national or regional level these balances should be quantitatively identical for P, while for N they will differ slightly due to the inclusion within the SS balance of (non-agricultural) gaseous deposition. This component is relatively small and has been calculated on a mapped national basis by the Centre for Ecology and Hydrology, Edinburgh (CEH 2010).

Scale
Core calculation is at national (devolved administration) scale. Most data are available at this scale, although there is some requirement for interpolation from the UK or Great Britain
level due to minor inconsistencies in definition or production of some statistical series between Administrations. This interpolation can be made on the basis of agricultural census data (crop areas or livestock numbers) using a similar approach as for regionalisation of the balances.

In order to map the balance, sector balances are calculated, and then split into sub-sector balances in proportion to the nutrient excretion of the various stock within that sector and nation. Thus, the grazing system balance per head of sheep and lambs is smaller than that per head of dairy breeding herd. These coefficients are then used with the small area statistics to create a regional balance. The same approach could be used with spatially interpolated data (e.g. to 1 km or 10km pixels), thereby allowing the balance to be derived for any desired area e.g. river basin or major catchment.

We consider, at present, that the national balance is a coarse-scale, overview index, which should not be applied to small areas (e.g. less than 100 km²) because the statistical data on which it is based are not robust at fine scale. Even if we can be fairly confident of small area statistics for livestock and crops, we do not have access to comprehensive detailed farm-specific data on inputs and production. Farm-gate balance calculation tools are already available for use by individual farms, if the necessary data are available to the land manager.

**Usability of product**

The balance calculation should be updated annually using standard statistical outputs to minimise effort. Clear documentation on data sources and frequency of update is therefore required. The calculation must also be flexible to accommodate changes in availability of input data, and the consequent need to derive information in different ways. Some coefficients change over time. To accommodate this, annual sets of coefficients are required even though many of the values will be the same year on year. Where new data are brought in to the calculation, their provenance and use should be documented in an agreed metadata format.

## 5 Structure of nutrient balances

There was consensus among scientists at the first Steering Group Meeting for this project, that the Farm Gate balance has some important advantages over the soil surface balance for policy use. It remains helpful to provide the Soil Surface balance since e.g. OECD and EUROSTAT request this form. In general, the Soil Surface Balance can be more relevant to environmental impacts whereas the Farm Gate balance is more relevant to efficient use of N and P as a resource. At national level, the two approaches should be quantitatively identical for P, while for N they will differ slightly due to the exclusion of gaseous emissions from excreta during storage from the Soil Surface balance.

### 5.1 Farm Gate Balance

The farm gate balance is made up of inputs to the national ‘farm’ (fertiliser, livestock feeds imported, non-agricultural wastes eg sewage sludge) and outputs (crop and animal products and waste removed from the system).
Table 1. Main components of Farm Gate balance

<table>
<thead>
<tr>
<th>INPUTS</th>
<th>OUTPUTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertiliser</td>
<td>Crop products removed</td>
</tr>
<tr>
<td>N fixed by legumes</td>
<td>Livestock products removed</td>
</tr>
<tr>
<td>Livestock Feed</td>
<td></td>
</tr>
<tr>
<td>Other Land Inputs eg sewage sludge, industrial wastes</td>
<td>Manures exported</td>
</tr>
<tr>
<td><strong>Atmospheric deposition</strong></td>
<td>(usually omitted at farm scale)</td>
</tr>
</tbody>
</table>

In principle, animals imported and exported should also be counted. Statistics exist to allow this calculation, but the numbers are small for the UK as a whole and have not been accounted for in the present work.

### 5.2 Soil Surface Balance

The soil surface balance in principle consists of inputs to the soil surface and removal from it. Crop residues immediately returned to land are normally most simply dealt with by ignoring them, and setting the uptake to refer to only the harvested portion of the crop. Grass and fodder eaten by livestock is however explicitly calculated as an offtake.

Table 2. Main components of Soil Surface balance

<table>
<thead>
<tr>
<th>INPUTS</th>
<th>OUTPUTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertiliser</td>
<td>Crop uptake</td>
</tr>
<tr>
<td>N fixed by legumes</td>
<td>Grass eaten by livestock</td>
</tr>
<tr>
<td>Excreta returned at grazing</td>
<td></td>
</tr>
<tr>
<td>Manure applied</td>
<td></td>
</tr>
<tr>
<td>Crop products returned to land</td>
<td></td>
</tr>
<tr>
<td>Other Land Inputs eg sewage sludge, industrial wastes</td>
<td></td>
</tr>
<tr>
<td><strong>Atmospheric deposition</strong></td>
<td>(usually omitted at farm scale)</td>
</tr>
</tbody>
</table>

#### The OECD soil surface balance

The OECD N and P balances, the main official continuing series of nutrient balances for the UK, are based on a soil surface approach. The UK data input for this model was updated by ADAS (officially) in 1999 (Report on data sources and calculations available in Defra contract report Goodlass & Lord, 2001) and again (without published report) in 2003/4. The current OECD web site contains data for 2004. See [www.oecd.org](http://www.oecd.org) for up to date balances and explanatory documents.

The OECD balance for the UK was recently provisionally extended to cover P, but there are still problems to iron out, i.e. the UK P balance data on the OECD web site at the time of writing are not reliable.

One of the difficulties in comparisons between years was that as better information became available in later years, or calculation methods were revised there were often...
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‘step’ changes in the balance. The reasons for these changes have not always been documented, but clearly it would be helpful to do so in future.

The EUROSTAT nutrient balance

A regional version of the OECD Soil Surface database was created by Defra on behalf of Eurostat (Fernall & Murray 2009). One of the tasks of this project is to build on and improve the approach to regionalisation.

5.3 Relationship between Farm Gate and Soil Surface balances

Theoretical considerations show that the Farm Gate and Soil Surface balance must be identical for P (assuming atmospheric deposition is included in both). For N, on the same assumption, they will differ by the quantity of N volatilised from livestock excreta prior to their application to land. The details of these relationships are discussed below.

Figure 1. Relationship between components of farm gate and soil surface balance

Thus
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FG balance – SS balance
= Livestock Feed - Manure spread - Excreta at grazing
– Products + Grass and fodder eaten

(In this formulation, fodder eaten on farm such as maize and turnips is included within the livestock system, and is not counted within arable crop production).

The sum of (manure spread – excreta at grazing) is equal to total nutrient excretion by livestock, minus losses before spreading. Total nutrient excretion by stock, the proportion excreted within housed systems and subsequently spread as manure, and the associated volatilisation losses of N prior to spreading, may be calculated using coefficients prepared for policy purposes (Cottrill and Smith, 2010) and should be regularly updated (i.e. perhaps every 5 years or so, or more frequently if major changes have occurred for example due to legislation or the price of feeds).

If we look at the system from the point of view of the livestock, then inputs must equal outputs. Thus:

Livestock feed + Grass and fodder eaten = Products + Excretion.

Therefore:

Soil Surface Balance = Farm Gate Balance – Losses from excreta prior to spreading as manure.

(This equation assumes other inputs (e.g. atmospheric deposition) are included equally within both balance calculations, otherwise further adjustments will obviously be required.)

The difference between Soil Surface and Farm Gate balance is negligible for P. For N, it is equal to the loss from excreta prior to spreading as manure. Standard coefficients exist for its estimation (Cottrill and Smith, 2010).

The method for the national OECD Soil Surface balance requires estimates of nutrients applied to land as manure and removed as grass by grazing livestock. Since

Excretion – Grass plus fodder eaten = Feed – Product,

we can constrain the estimate of grass eaten to its correct relationship with the estimate of excretal N and P. It does not matter greatly if these two values are imperfectly known, so long as their relationship is correct.

Gaseous emissions: The Soil Surface balance commonly includes gaseous deposition to land, and excludes gaseous losses from manure prior to spreading. It is sometimes suggested that this calculation could be simplified by not deducting the ‘in-house’ gaseous lossess form excreta applied to land, and not counting the part of gaseous deposition which originated from agriculture. An approximation to non-deposition of non-agricultural origin would be the oxidised N deposition – most ammonium (reduced N) originates from agriculture. The problem with this calculation however is that a great deal of N loss to air
occurs after application of manures to land. Furthermore not all volatilised N is re-deposited within the UK. There is no a priori reason why the two values should be equal.

5.4 Advantages and disadvantages of the two approaches for policy indicators

Availability of data
Clearly the balance should be built on the best available data. Some components are well quantified and regularly updated, and others have to be estimated using parameters that are only periodically reviewed and may be rather uncertain.

Updating in response to changing statistics
A prime purpose of the balance indicator is to show changing trends. Therefore the major items should as far as possible be based on data which are regularly updated standard official statistical sources or outputs.

Arable crops:
Soil Surface and Farm Gate balance are in principle the same, both use fertiliser inputs, yields, and crop composition data.

Pigs and Poultry:
Soil Surface balance is sensitive mainly to changes in stock numbers, and responses to farm management practices are dependent on the periodic updating of the manure coefficients in the light of new experimental/observational data or expert opinion. Farm Gate balance is sensitive to stock numbers, changes in feed quantity and composition and changes in production. Feed nutrient inputs are targeted by many mitigation measures. Feed composition data are currently not publicly available, and figures used here are based on current advisory experience, but these values are changing due to both economic and policy drivers.

Grassland systems
The Farm Gate balance is most responsive to fertiliser nutrients, feed quantity and product quantity, all of which are reported in annual statistics. Feed and product composition are largely based on standard coefficients, though some major components (N content of wheat, barley, and milk) are updated annually.

The main data items determining the evolution of the Soil Surface balance over time are grassland area (offtake has been usually calculated per ha of grass); numbers of stock (excreta/manure are calculated per head of livestock) and fertiliser inputs. The coefficients required are excreted nutrient per head of stock, losses prior to spreading of manure, and grass/fodder nutrient removal by stock, per ha. The grassland consumption is particularly uncertain, with different editions of the balance using widely different values per ha and including different grassland areas (e.g. rough grazing). Clearly application of the default yield appropriate to managed grass, to the much larger area including rough grazing, causes a major and inappropriate reduction in the balance.

Removal of nutrient in grass and input of nutrient as manure from grazing stock are not coupled in most versions of the Soil Surface balance. The quantity of manure generated is normally calculated as a function of stock numbers (which is reasonable) but the quantity of grass eaten is calculated as a standard value per ha. In times of falling stock density, the quantity of manure produced will decrease, but there is usually no calculation mechanism to reflect this change in a reduction in the estimate of grass consumed. The uncoupling of grass offtake and manure application has therefore sometimes produced inconsistent results.
As part of the Defra WQ0106 project on Catchment Sensitive Farming (Anon 2007a&b) the different approaches were compared. A farm gate balance was extended to a national level and compared with the Soil Surface balance, and with an approach based on coefficients calculated for different crops and livestock types (Shepherd & Goodlass, 2006). Reasonably similar results were obtained by the 3 methods for N (range 2% of mean) but discrepancies were greater for P (range 28% of mean), which reflects the fact that less work has been done on P surplus calculation.

6 Calculation method: UK

The calculation process and associated data requirements are summarised below, in outline (ie omitting conversion values and other details). Values in bold are derived from annually updated statistics.

**Inputs:**

Fertiliser: \[ \text{Crop area} \times \text{fertiliser applied, kg/ha N or P} \]

N fixation: \[ \text{Crop area} \times \text{typical N fixation kg/ha N} \]

Livestock feed: \[ \text{Tonnage} \times \text{N and P contents} \]

Sewage etc: \[ \text{Tonnage} \times \text{N and P contents} \]

Atmospheric deposition: \[ \text{N: Area} \times \text{deposition per ha} \]
\[ \text{P: Area} \times \text{annual rainfall} \times \text{concentration in rain} \]

**Offtakes**

Crops: wheat, barley \[ \text{Tonnage} \times \text{N,P per tonne} \]

Crops: other major \[ \text{Tonnage} \times \text{N,P per tonne} \]

Crops minor: \[ \text{Area} \times \text{yield per ha} \times \text{N,P per tonne} \]

Milk \[ \text{Volume} \times \text{N, P per litre} \]

Meat \[ \text{Tonnage} \times \text{Liveweight adjustment} \times \text{N,P per tonne} \]

Eggs \[ \text{Number} \times \text{weight each} \times \text{N,P per tonne} \]

Manure destroyed \[ \text{Tonnage} \times \text{N,(P) per tonne lost} \]

The above list indicates the main data requirements. It will be seen that, although not strictly an input, crop areas are required for estimation of N fixation by legumes, and also for estimation of production of minor crops. Furthermore, both crop areas and livestock numbers are required for subdividing the balance by sector, and by region (see below).

Coefficients are required to convert quantities of material to quantities of N or P. Most of these are fixed, with periodical review, but cereal and milk N content are reported annually.

Other minor inputs including biosolids, other wastes, and atmospheric deposition are taken from a variety of sources, most updated only periodically.
6.1 Data: Annually updated agricultural statistics

6.1.1 Crop Areas
Crop areas are not a direct component of the balance. However they are required in practice in order to estimate yields and other data for minor crops. They are also used to assign atmospheric deposition, and the application of sewage sludge and other wastes for which detailed mapping of input is not available.

Land use areas are obtained from the national June Survey datasets. Where areas were not reported, they have in most cases been set to zero in the knowledge that they are certainly small (e.g. linseed in Wales). Where a number of minor crops have been grouped (eg horticultural land in Wales) the constituent areas have been notionally partitioned between vegetables, fruit etc using the proportions as recorded for England.

A subset of the data are also reported as ‘small area statistics’ (SAS). These have been used as the basis for regionalisation of the balance. These statistics are slightly less detailed than the full survey, partly to avoid disclosive information. The data for Wales and Northern Ireland give less detail on arable crops than those for England and Scotland.

6.1.2 Livestock numbers
As is the case for crop areas, livestock numbers are not a direct component of the balance. However they are used for interpolation of missing data and partitioning of the balance spatially and between sectors, as described below. The data were obtained from national agricultural census data. For regionalisation, the values were taken from the national Small Area Statistics.

The national livestock numbers were used to calculate total nutrient excretion, as an index for subdividing sector balances; for calculation of manure (after adjustment for volatilisation losses in store) as required by the Soil Surface balance; for estimation of products not reported (e.g. clipped wool); and for apportionment of feed between countries within Great Britain.

Livestock numbers were also used at regional level as indices for regionalisation of the balance.

6.1.3 Fertiliser Inputs
Fertiliser use is reported by crop in the British Survey of Fertiliser Practice (Defra & SEERAD, 2005, 2009). Detailed values are given for Scotland, and for England and Wales combined, while values for all tillage and all grass are given for Wales. For Northern Ireland, N and P fertiliser use are given at national level only. Values used here are taken from the Northern Ireland Statistical Review. The area of arable crops is small, and for these the Great Britain mean input to arable land has been used, with the remaining fertiliser assumed to be applied to managed grassland.

Fertiliser inputs to individual crops are not required for the national balance, except to separate fodder crops (fed on-farm, e.g. maize, turnips and kale) from crops harvested for sale. However, the individual inputs are also used to generate individual crop N balances, for regionalisation of the balance (see below).
The factor for conversion of P₂O₅ (the commonly used form for reporting of P fertiliser) to P is division by 2.291 (Defra 2010).

6.1.4 Crop Production
Crop production is reported annually by government for major crops, including cereals, oilseed rape, potatoes and sugar beet. In some cases data are not reported for all countries, and were apportioned from UK totals on the basis of crop areas.

Note that in the case of fodder crops and grass the exact yield is not critical as the yield is simply transferred from the arable to the grazing systems balance. It need not be calculated at all for the Farm Gate balance, but is a component of the OECD Soil Surface balance proforma.

Any crop residues returned to the land, whether directly or via use as animal bedding, are ignored by both the Farm Gate balance and the OECD Soil Surface balance proforma. Crop residues returned after processing are separately accounted for, usually as livestock feed components.

6.1.5 Livestock Feed Inputs
Non-forage feeds fed on farms are usually in the form of ‘straights’ (single feed materials, e.g. cereal by-products, sugar beet pulp), or compound feeds (mixtures of straights, usually with supplementary minerals and vitamins added) manufactured by one of the national or regional feed compounders. In addition, integrated producers and some farmers produce their own feed mixes. The feed categories used in this project were selected because they reflect the categories used in the Defra statistics derived from industry data on the amounts of feed produced by feed compounders and integrated producers.

Data on compound feed production are reported regularly within the Feed Facts Quarterly, for Great Britain and Northern Ireland. For GB, these are based on the Defra monthly survey of feed compounders, and for NI on DARDNI Survey Returns. Feed data statistics for GB were apportioned between countries in proportion to the numbers of stock. For example dairy feed was divided according to relative numbers of dairy cows in each country.

Quantities of home-fed grain are from Defra/National Statistics report for 2002/2003 based on a survey of farmers. This survey, which has since been discontinued, gave no indication as to which livestock the grains were fed to, and therefore they have been allocated on the basis of best professional judgement. It should be possible to estimate the quantity involved from other statistics, including the quantity of feed-grade grain produced and imported/exported, and the quantities used by feed compounders. The HGCA have developed a model (http://www.hgca.com/publications/documents/markets/UK_SnD_1207.pdf) to predict grain fed to livestock, which in the absence of official statistics is probably the best informed estimate of use. This model predicted 1,531 kt wheat and 2,699 kt barley in 2004/05, compared to the quoted values or 1304 kT wheat and 1685 kT barley. The estimates for 2007/8 were 1,270 kt wheat and 2,259 kt barley.

In addition, other feed materials, predominantly co-products from the food, distilling and brewing industries are fed, and need to be accounted for. Reliable data on the total amounts of these feeds, and in particular the livestock to which they are fed, are not readily available. Industry sources (Mr Richard Wynn, Technical Sales Manager, KW Trident, 2010) suggest the following breakdown:
UK Agriculture Nutrient Balances methodology review.

- Moist feeds (e.g. brewers grains, pressed beet pulp, moist distillers grains etc) ~1.2m to 1.5m tonnes, all of which would be fed to ruminants.
- Liquids (e.g. molasses, molasses blends, distillery liquids etc) ~ 120 to 140k tonnes, most of which will be fed to ruminants.
- Dry concentrate feeds (e.g. soybean meal, rapeseed meal, dried distillers grains, sugar beet pulp) ~ 900kt to 1.5m tonnes.

Sugar beet pulp is both sold directly for use on farms, and used in the manufacture of compound feeds. The data in this report refer only to sugar beet pulp sold directly to and used on farms. The industry 'best estimate' provided by Mr Richard Wynn, Technical Sales Manager, KW Trident (one of the UK's main suppliers of feed materials) was 9 kT. However this is much less than the Defra Crops Branch estimate of 193 kT (A Howsam, pers. comm.), which has been adopted. In the Defra survey of feed compounders for 2004, 217.1 kt sugar beet pulp was used in the manufacture of compound feeds. Data provided by Trident Feeds – which manufacture almost all the dried pulp used on farms in the UK – for another project indicates total production of beet pulp in 2005/06 was in excess of 530 kt. Therefore this industry estimate is likely to be a gross underestimate.

These additional materials contributed a weight equivalent to around 20% of manufactured compound feeds in 2004.

Confectionery by-products were calculated by Defra Crops Branch to contribute a further 122 kT. Information from one of the major processors of confectionary by-products suggests that approximately 188,000 tonnes (120,000 t bread and 68,000 t biscuit meals) are processed and sold directly to farms. It is probable that more is sold to feed compounders, but this does not need to be included in this calculation as it is included under compounded feed. This latter, larger figure of 188 kT was used in the calculations.

6.1.6 Livestock production: milk, meat and eggs

Production of milk, eggs and meat are reported by all 4 countries of the UK.

Data on wholesale dairy cow milk deliveries are published quarterly by Defra. These do not include direct farm sales. AUK gives a figure of 13,930 million litres milk for human consumption, while DairyCo Datum (http://www.dairyco.org.uk/library/market-information/datum/monthly-milk-production.aspx ) report 13,708 million litres of wholesale milk delivered to dairies, and AUK quotes 14,217 as total production by the dairy herd. The last and largest figure has been used here, on the assumption that it excludes suckled milk. Total milk production should include the milk which is delivered to dairies, milk used on farm in the production of dairy products, milk consumed in farm households, milk fed to livestock and farm waste (but exclude suckled milk).

In addition, there are approximately 35,000 dairy goats in the UK. Most of these are kept in small herds for home milk production but the Dairy Hygiene Inspectorate records 130 registered goat milk producers in England and Wales with many smaller unregistered units producing milk for home consumption. These herds vary in size from 1 goat to 2500 goats, with an average herd size of 211. There are no 'official' data on the amount of goats milk produced in the UK. The figure quoted was given by Mr Tom Rabbetts, Technical and Policy Advisor, Royal Association of British Dairy Farmers, whose 'educated guess' was that production was 20 and 30 million litres in 2004 and 2008, respectively. The former was adjusted to 20.8 million litres to allow for milk used on farm, consumed in farm households etc. Divided by the number of breeding female goats (dairy) in the UK (35,354,
UK Agriculture Nutrient Balances methodology review.

In4_Livestock) this works out at 588 litres per animal. In contrast, a publication from Bangor University\(^1\) suggests that they have an annual lactation yield nearer 1,000 litres. There may be uncertainties regarding definition of breeding goat. If the Bangor estimate is correct, the value we have used may be an underestimate.

The reported yield of goat milk for England was used to estimate the yield for other countries, pro rata. Milk production from cows and goats may be underestimated due to private use and direct farm sales.

Meat production is usually expressed in terms of dressed carcass weight, which does not take account of offals and gut contents. Standard conversions have been applied based on data from ARC (1980) for cattle and sheep and Wiseman and Lewis (1998) for poultry. In the absence of any data for deer, composition values for cattle have been applied.

Eggs are generally but not always reported in million dozen. These have been converted to a weight of eggs, assuming a standard weight of 63 g/egg (the boundary between large and medium graded eggs), of which 11% is shell (Source: British Egg Information Service 2010).

6.1.7 Livestock production: wool

Data on wool production was reported by Scotland and Wales, but no data could be found for England and Northern Ireland in 2004 or 2008. The average wool yield for Scotland and Wales in 2004 was respectively 1.9 and 1.8 kg per adult sheep recorded by the census. The average for Northern Ireland in earlier years has been around 3.1 kg/adult sheep (Bob Foy, pers. comm..) These data relate reasonably well to data reported by Davies (2010) of about 2 kg per adult upland sheep at first shearing.

The table below gives weights for some 600 crossbred Welsh yearlings at first shearing (Owen Davies, pers. Comm.)

Table 3. Typical wool yields of Welsh sheep.

<table>
<thead>
<tr>
<th></th>
<th>Cheviot</th>
<th>Dorset</th>
<th>Lleyn</th>
<th>Texel</th>
<th>SED</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liveweight (kg)</td>
<td>39.3(^a)</td>
<td>43.8(^c)</td>
<td>38.0(^a)</td>
<td>41.7(^b)</td>
<td>0.80</td>
<td>***</td>
</tr>
<tr>
<td>Fleece weight (kg)</td>
<td>2.14(^a)</td>
<td>2.92(^c)</td>
<td>2.38(^b)</td>
<td>2.52(^b)</td>
<td>0.10</td>
<td>***</td>
</tr>
</tbody>
</table>

The typical fleece weight was estimated from this and advisory information to be 2 kg per adult sheep for upland breeds, and 3 kg for lowland breeds. The values used were therefore 3 kg/sheep for Northern Ireland and 2.5 for England.

6.2 Agricultural statistics not annually updated

6.2.1 Crop yields

Yields of crops for which production is not reported were taken as 'average' values reported by Nix (2005 and annually) as being the standard, regularly updated farm management guide. Default yield values are also provided for crops where yields are normally reported, but the true value is used where available.

\(^1\) [http://www.calu.bangor.ac.uk/Technical%20leaflets/040101CALUdairygoats.pdf](http://www.calu.bangor.ac.uk/Technical%20leaflets/040101CALUdairygoats.pdf)
In the case of vegetable and fruit crops, which occupy relatively small total areas, yields are reported. However, it was decided that the work of annual detailed calculation was probably excessive, relative to the enhanced precision obtained. The fine detail on crop areas and annual yields were used for 2004 to calculate area-weighted average yield and offtake data to populate the coefficient table. If updating these values annually is considered disproportionately onerous, they could be reviewed periodically – perhaps every 5 years.

For fodder crops, a typical crop was chosen and the appropriate yield and composition data for that crop were used. Fodder crops comprise a mixture of crops with varying dry matter content at harvest (e.g. roots versus grain crops) and fresh weight yields will vary widely as a result. Dry matter yields and offtakes will vary less. It is therefore important to match the composition to the crop type. Detailed data on fodder crops grown in the different countries are not available. As discussed above, the exact offtake is not important to the value of the balance, as it is treated as an internal transfer.

Appendix 1 gives the default yield values, and nutrient contents, used in the 2004 calculations.

6.2.2 Manure incineration
A substantial quantity of broiler litter is incinerated. This results in total loss of associated N. In England and Wales, the residue (assumed to contain all of the original P) is spread to land, while in Scotland it goes to land fill. The data are obtained from the power stations concerned, and are collated within the ALOWANCE system (Nicholson et al., 2008).

6.3 Composition coefficients: annually updated

6.3.1 Grain N content

The Home Grown Cereals Authority (HGCA) undertakes an annual Cereal Quality Survey, and publishes annual regional values for protein content of wheat, and N content of barley, on a dry matter basis. The cereal yields reported by Defra are fresh weight, typically at about 15% moisture content. The conversion factor from protein to N is division by 5.7 (MAFF 2010: RB209 7th edition, p 79). These data do not cover Northern Ireland, which is therefore assumed equivalent to Scotland. Wales is assumed equal to the England – quantities are small and generally not reported separately.

The 2008 data are given below by way of illustration.
6.3.2 Composition of Milk

The protein content of cows milk is reported annually by Defra. Historically, milk protein has been estimated by Kjeldahl determination. As milk contains relatively little non-protein nitrogen, the true protein content of milk is estimated by multiplying the N value by 6.38, being the average N content in milk protein (DePeters & Ferguson, 1992.). The overall composition of goats’ milk is similar to that of cows’ milk. (Source: http://www.calu.bangor.ac.uk/technical%20leaflets/040101CALUdairygoats.pdf)

6.4 Composition coefficients: not annually updated

For those items not reported by annual statistics, a variety of sources of data were used. Some of these are based on regular and reasonably thorough surveys, although not annually updated.

6.4.1 Nitrogen fixation

Nitrogen fixation per ha of leguminous crop was taken from the review in Cuttle et al. (2003) (See Appendix 1 Table 1). The data for arable legumes are relatively robust, being based on experimental work, although it is known that the value varies substantially between seasons and sites. For grassland, there are good data to show that N fixation by grass-clover leys is of the order of 150 kg/ha N per annum (Cuttle et al., 2003), but there is little information on the area of such leys. The total area of all temporary grassland is about 16% of all managed grassland, and only a small proportion of this is sown to clover-grass leys. Permanent grassland is unlikely to maintain a large productive clover presence. A value of 5 kgN/ha was assumed across all managed grassland, based on advisory estimates. It is possible that this value is increasing as N fertiliser inputs to grass
decline, since clover is more competitive in low-N environments. Substantial uncertainty remains in the national value.

6.4.2 Nutrient content of plant material
The nitrogen content of major crops was taken from MAFF (2000), and Defra (2010), also known as RB209, and Sylvester-Bradley (1993). The P content was taken from Defra (2010) as developed with the Potash Development Association (PO Box 697, York YO32 5WP) with additional data from internal ADAS documents. For minor crops for human consumption, including fruit and vegetables, data were taken from Food Standards Agency (2002). Data on other minor crops were taken from an internal ADAS document (Fancett, 1979). The data used are in Appendix 1 Table 1. Additional data are in Appendix 1 Table 2.

The source data on cereal P content were reviewed by Shepherd (1988). Grain P content of winter wheat, winter barley and spring barley from a range of experimental data were found to be similar. Long term experiments on the effects of building up soil P content showed an average of 0.33, 0.35, 0.36 and 0.37 % P in grain dry matter for annual applications of 0, 50, 100 and 150 kg/ha P₂O₅ respectively. The typical maintenance application would be 50 kg/ha P₂O₅ per annum. For straw the corresponding figures were 0.07, 0.08, 0.08 and 0.09 % P in dry matter—slightly greater than those from the other experiments reviewed. Straw content of P on other experiments (about 200 samples over many experiments) averaged 0.06% at 100% dry matter (range 0.02 to 0.18).

The cited references include values for fodder crops. Fodder crop offtake is not required for the Farm Gate balance, but is required for the Soil Surface balance. The values for maize silage were modified from previous data because the original values for N appeared unrealistic and had an improbably wide N:P ratio (Alan Hopkins pers. comm.).

6.4.3 Nutrient content of livestock feeds
For straight feeds, N and P contents are taken from standard reference books (e.g. Ewing, W.N. (2002). These are not always identical to the data for nutrient content of crops as currently harvested, but it is not clear to what extent the differences are due to selection of grain for different purposes. For compound feeds, composition values given are based on expert advisory knowledge of feeds produced (Bruce Cottrill) and are typically an average of a range of feeds produced within each category. Legislation requires feed manufacturers to declare the crude protein content of their products on the label, but to our knowledge there are no official or publically available data on the N contents of manufactured feeds. There is no requirement to declare P contents on the label, and since manufacturers may consider this information to be commercially sensitive there is no database on the P content of manufactured feeds.

For the P content of manufactured feeds, two values are given in the reference tables, depending on whether a phytase enzyme has been added\(^2\). Supplementation with phytase enzyme generally allows a reduction of approximately 0.1% P. Not all pig and poultry compounds are supplemented with phytase enzymes. Phytase enzymes are manufactured by a number of companies, and since the amount of enzymes sold would be deemed as sensitive commercial information no official data are available on the proportions that do include enzymes. Industry sources suggested a value of approximately 70% for 2004, but this is likely to rise as a result of increasing economic cost of

\(^2\) Synthetic phytase enzymes are added to compound feeds for pigs and poultry to improve the digestibility of dietary P. As a result, it is possible to reduce the amount of P added, and hence the total P content of the diet.
supplementary P, reducing costs of the enzymes, increased perception of the environmental costs of P and developments in feed science. Feed compositions are changing. In particular the P content is falling in many feeds, due to the rising economic cost of P, increased perception of the environmental costs of P, and developments in feed science. It would therefore be helpful if proper statistics could be collected from the feed companies in future.

Northern Ireland has made particular efforts to reduce P inputs. As a result it is possible that feed composition differs for NI, with a greater proportion of feeds phytase-supplemented (up to 100%, Bob Foy, pers. comm.).

6.4.4 Nutrient content of livestock products

The default composition and associated values used are tabulated in Appendix 1.

Meat

Production is generally reported as ‘Dressed Carcase Weight’ (DCW), although occasionally data are reported as live weight. The relationship between these, the composition of the discarded material – and its fate – are not accurately known and much of the source information is old. In order to estimate total N & P contents leaving the farm it is necessary to have either (a) weights and composition data of both whole carcasses and discarded material or (b) whole-body composition, with a coefficient for DCW/liveweight for each nutrient. We are not aware of any data on the composition of the dressed carcass, offal and gut contents to allow whole body contents to be calculated. Tables in McCance and Widdowson (Food Standards Agency 2002) show compositional data on certain cuts of meat, but not the whole carcass. Limited compositional data on whole carcasses for cattle and sheep (ARC 1980) and broilers (Wiseman and Lewis, 1998) have been published; while the latter are likely to be representative of current strains of poultry, those for ruminants probably do not reflect current breeds or production systems. The ARC data need to be augmented by allowance for gut fill. In addition, composition of the different components is likely to vary, and data on this aspect are very limited.

We have applied standard relationships between liveweight and dead weight (and associated nutrients) based on limited scientific data. The ratio is likely to vary with size of the animal as well as animal type. For example Fox et al., (1976) found that:

Empty body weight (kg) = 1.40 * dressed carcass weight + 40.2.

(To this value would need to be added gut contents, ca 20% of body weight.) Given the uncertainty relating to nutrient composition of all these components, we have elected to keep the conversion factor simple at this stage, and values are in the range 50-75%.

Milk

There are limited – and variable – data on the P content of milk (both dairy and goats). Standard values for these have been applied.

Eggs

The weight of an egg varies during the period of lay, and is also influenced by breed and diet. The average weight (63 g) was given by the The British Egg Information Service.
The eggshell constitutes 11% of this weight, and consists predominantly of calcium carbonate, with very little N (2.2 kg/t) and P (1.2 kg/t) (British Egg Information service 2010) although these values can vary depending on breed, diet etc.. The composition of the edible content of the egg was taken from Food Standards Agency (2002). These values are not updated regularly.

**Wool**

Nutrient contents of sheep’s wool are quoted by D’Arcy (1990) as 17% on a dry matter basis, with P not mentioned and by difference less than 1%. This N content is consistent with wool as being dominantly protein. Real wool as shorn will however contain many impurities as well as water. Therefore the value of 122 kg/tonne, quoted by FWAG, has been allowed to stand. The P content is certainly low, and no robust references to this were found. Lee et al. (1992) quote 0.12 g P per kg wool, which is slightly smaller than that used for the Northern Ireland balance 0.4 kg/tonne P.

**6.5 Other inputs to land: sewage and wastes**

A number of inorganic and organic materials are applied to agricultural land in line with the Sludge (Use) in Agriculture Regulations (1989) and under the Environmental Permitting (England and Wales) Regulations and Waste Management (Licensing) Regulations (Scotland and Northern Ireland).

A selection of these inorganic and organic materials, and sources of information on them, is presented in Table 4.

Table 4. Inorganic and organic products (excluding livestock manures) applied to land and sources of information on quantities applied and nutrient contents.

<table>
<thead>
<tr>
<th>Material applied to agricultural land</th>
<th>Sources of information (source used for 2008 national scale nutrient balance underlined)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sewage sludge</td>
<td>• Water UK biosolids update&lt;br&gt;• Environment Agency sewage sludge survey&lt;br&gt;• Water companies data&lt;br&gt;• Fertiliser Recommendations/Manual (RB209)</td>
</tr>
<tr>
<td>Composts</td>
<td>• Association for Organics Recycling (AfOR) ‘State of Composting’ Reports&lt;br&gt;• The Fertiliser Manual (RB209)&lt;br&gt;• Defra/WRc report UC7899</td>
</tr>
<tr>
<td>Paper crumble</td>
<td>• Gibbs et al. (2005)&lt;br&gt;• Gendebien et al. (2001)&lt;br&gt;• The Fertiliser Manual (RB209)&lt;br&gt;• Defra/WRc report UC7899 (2009)</td>
</tr>
<tr>
<td>Food industry ‘waste’</td>
<td>• Gendebien et al. (2001)&lt;br&gt;• The Fertiliser Manual (RB209)&lt;br&gt;• Defra/WRc report UC7899 (2009)</td>
</tr>
<tr>
<td>Abattoir waste</td>
<td>• UK Renderers Association&lt;br&gt;• Defra/WRc report UC7899 (2009)</td>
</tr>
<tr>
<td>Water treatment cake</td>
<td>• Water companies data&lt;br&gt;• Gendebien et al. (2001)&lt;br&gt;• The Fertiliser Manual (RB209)&lt;br&gt;• Defra/WRc report UC7899 (2009)</td>
</tr>
</tbody>
</table>
ADAS have developed a database called ALOWANCE (Nicholson et al., 2008) which estimates the capacity for agricultural soils to receive organic materials without exceeding Nitrate Vulnerable Zone nitrogen loading limits. Much of the data is the same as that used in the nutrient balances calculations. ALOWANCE uses some of the information sources listed in Table 4 to calculate N loading at a 100 km² resolution for England and Wales. The current database only has data for one year (2005/06), so it is not possible to use ALOWANCE to provide information for a series of annual nutrient balances at present. However, if funding were available, ALOWANCE could potentially be used to provide information on nutrient loadings at a 100 km² resolution for an annual time step and for the whole of the UK.

The following sections summarise the information available for each of these materials, in terms of the scale at which information is available and any information on the variance and uncertainty associated with nutrient content values (coefficients).

With the exception of sewage sludge, most data are not updated annually, and 2008 data are considerably more complete than 2004 data. The 2008 estimates were therefore used for both test years.

Given the low relative importance of these materials (in terms of nutrient loading), we would not recommend updating information on the quantity spread or the nutrient content more frequently than every other year.

### 6.5.1 Sewage sludge

The Environment Agency (EA) provides annual information on the amount and the mean average nutrient content of sewage sludge applied to land in England Wales. The same information should be obtainable from the Scottish Environment Protection Agency (SEPA) and the Northern Ireland Environment Agency, but in the present calculation values have been calculated pro rata on the basis of population.

**Sewage sludge - nutrient contents**

Sewage sludge nutrient contents are provided in Defra 2010 (RB209). The Environment Agency Sewage Sludge Survey as used within ALOWANCE (Hicholson et al., 2008) provides more up to date information, which includes a mean annual nutrient content of sewages sludge (on a dry solids basis, mean for 2001-2007). There is no information on variance within the EA dataset, but such information could potentially be sourced from individual water companies or the EA. These annual data are available only at the national scale. However, ALOWANCE uses water company data to produce N and P loadings at a 100 km² resolution for England and Wales. If funding were available, this could potentially be produced on an annual basis for the whole of the UK.

### 6.5.2 Composts

In ‘The State of Composting’ Reports, the Association for Organics Recycling (AfOR, 2008, 2003) provides information on the annual quantity of compost applied to agricultural land in
the UK. In recent years, this information has also been provided for England and the devolved administrations.

Defra/WRc report UC7899 ‘On the Environmental Impacts of the Activity of Spreading Wastes to Land’ (Peacock & Turrell 2009) also provides information on the quantity and nutrient content of ‘composts’ spread to land based on European Waste Catalogue (EWC) codes. The European Waste Catalogue 2002 (EWC) is a hierarchical list of waste types established by the European Commission (2000/532/EC), under which all wastes are classified. Under the Environment Protection Act (Duty of Care) Regulations 1990 (as amended) in England and Wales, all waste producers (including waste spread to land) must classify their waste using one of the six-digit codes set out in the EWC.

Unfortunately, the use of EWC codes results in the inclusion of a number of quite diverse materials within the same category, such that (for example) green composts, compost leachate and liquor from the aerobic treatment of solid wastes are all included under the same EWC code, 19 05 99. This reduces the degree of confidence in the nutrient content information and the ability to extract information for specific materials, such as green compost or digestate.

**Compost - nutrient contents**
The nutrient content of composts is provided in Defra (2010) (RB209). Peacock & Turrell (2009; Defra/WRc report UC7899) give nutrient information, including mean values, ranges and 90th and 95th percentile values. However, the usefulness of this information is compromised by the issues with EWC codes described in section 1.2 (above). Additional data which could be used to improve the estimate and calculate statistical variability reside within AfOR and ADAS.

As part of the ALOWANCE project, AfOR also provided information on the quantity of compost produced at each composting site that is destined for agricultural use. This allows N and P loadings to be calculated at the 100 km² resolution for 2005/06. The EA also have information on materials spread to land by EWC code, but it is not possible to derive a good estimate of the amount of green compost applied to agricultural land from this data due to the issues with EWC codes described above.

### 6.5.3 Paper crumble
Gendebien *et al.* (2001) and Gibbs *et al.* (2005) provide information on the amount and nutrient content of paper ‘waste’ applied to agricultural land. Data is available for a single year in both cases. Total nutrient quantities from paper crumble amount to c.1.5 t N and c.500 t P for England and Wales out of total loadings for organic wastes (other than livestock manures) of 50 kt N and 80 kt P, so the total contribution of paper waste to N and P balances is not significant. However, if annual information is required, data could be sourced from:

- the Environment Agencies (EA, SEPA and NIEA), covering information held about land spreading activities under the Environmental Permitting and Waste Management (Licensing) Regulations
- Paper mills in the UK, detailing the types and amounts of paper wastes produced

ALOWANCE uses paper mills summary data from Gibbs et al. (2005) to estimate loadings at a 100 km² resolution for England and Wales. If funding was available and it was thought worthwhile, these data could be updated on an annual basis.

ALOWANCE uses energy company summary data to estimate nutrient loadings at a 100 km² resolution for England and Wales. If funding was available and it was thought worthwhile, these data could be updated on an annual basis for the whole of the UK.
Paper crumble - nutrient contents
The nutrient content of paper crumble is provided in ‘The Fertiliser Manual’ (RB209), due for release in 2010, but the document does not provide variability data.

Gibbs et al. (2005) provide nutrient contents, including minimum, maximum and mean values for primary treated, secondary biologically treated and secondary chemically/physically treated paper ‘waste’.

Peacock & Turrell (2009) provide nutrient information, including mean values, ranges and 90th and 95th percentile values. However, the usefulness of this information is compromised by the issues with EWC codes described in section1.2 (above).

6.5.4 Digestate
Information on anaerobic digestate for the ALOWANCE dataset was derived directly from the major renewable energy companies operating the main digesters in England and Wales. Similar information could be obtained for the main digesters commissioned in Scotland and Northern Ireland, but this was not possible within the timescale of the present project.

Digestate - nutrient contents
The renewable energy companies have provided mean nutrient contents for the digestate produced from each digester. However, only one company provided data on the variation in nutrient content over four months. The range for total N was 7.9-8.8 kg total N/m³ and for total P₂O₅ the range was 0.8-1.1 kg/m³. A more comprehensive dataset could potentially be provided by the Environment Agencies in each country.

6.5.5 Water treatment cake – sources of information
Peacock & Turrell (2009) (Defra/WRc report UC7899) is probably the best source of information on the quantity and nutrient content of water treatment cakes and cakes spread to land. EWC code 19 09 02 includes sludge/filter cake from water clarification; and potable water residual silt. Gendebien et al. (2001) also provides a value for the amount of water treatment cake spread to land (c.13 kt p.a.). However, the data are now out-of-date and the category includes materials from sectors such as metal production, gas/electricity/ water utilities, transport, storage and communications.

At present it is only possible to estimate loadings at the national scale. However, the EA source data used by Peacock & Turrell (2009) is spatially referenced for England and Wales.

Water treatment cake - nutrient contents
The nutrient content of water treatment cake is provided in Defra’s ‘The Fertiliser Manual’ (RB209), due for release in 2010, but the document does not provide interquartile ranges.

Peacock & Turrell (2009) give nutrient information on water treatment cakes (EWC code 19 09 02), including mean values, ranges and 90th and 95th percentile values. However, the usefulness of this information is compromised by the issues with EWC codes described in section1.2 (above). For example, the range of dry matters is reported as 1-93% with a 90th percentile of 37% DM.
6.5.6 Food industry ‘waste’, abattoir waste and dredgings
Gendebien et al. (2001), Peacock & Turrell (2009) and the Environment Agency provide information on the quantity of food industry ‘waste’, abattoir waste and dredgings applied to agricultural land. In addition, the UK Renderers Association has data on the amount of category 2 and 3 animal by-products spread to agricultural land (15.8 kt in 2008 from rendering plants) and British Waterways have information on dredgings (quantities and analytical data).

Food industry ‘waste’ includes waste from fruit/vegetable/cereal processing; the baking and confectionery industry; the production of alcoholic and non-alcoholic beverages; the dairy industry; and materials unsuitable for consumption. Also included are animal by-products from the meat and fish processing industry.

Information for these materials is available at the national scale (England and Wales), although the EA does hold spatially referenced data for England and Wales.

Food industry ‘waste’, abattoir waste and dredgings - nutrient contents
The nutrient content of food industry ‘waste’ is provided in Defra (2010) (RB209), due for release in 2010, but the document does not indicate variability.

Peacock & Turrell (2009) give nutrient information on food industry ‘waste’, abattoir waste and dredgings, including mean values, ranges, and 90th and 95th percentile values. There are two EWC codes for fish and meat processing materials and nine codes for materials from food and beverage processing (excluding animal by-products). The data provides a rough estimate of mean nutrient contents. Values for food industry ‘waste’ are similar to Defra (2010) values, although mean values for brewing waste are markedly different between the two sources (e.g. 2.0 kg N/t FW in Defra (2010), as opposed to 0.4 kg N/t FW in Peacock & Turrell).

6.6 Other inputs to land: gaseous deposition
The Centre for Ecology and Hydrology (CEH) at Edinburgh generates annual estimates of N deposition to land (kg N per ha by species) at a 5 km resolution. These are currently available at the UK Pollutant Deposition portal: http://www.uk-pollutantdeposition.ceh.ac.uk/data. The data are based on deposition measurements, and are annually updated for policy use. Hence, they were selected as the most appropriate source of information for the N balance calculation. Data were used to derive deposition per ha of land within each region, and a national total. The speciation into oxidised and reduced deposition allows an approximate assignment of source, if required, since the majority of reduced N is derived from agriculture while the majority of oxidised N is derived from other sources. The 2004 data were available for this report. The 2008 data were due to be released but were not available in time for this report.

The data are reported on 5km cells. The area of managed agricultural land within each cell was calculated and used to estimate the total deposition to agricultural land. The average of the deposition rates for all cells within a region was used to calculate the regional annual deposition rate. For the purpose of regionalisation, each cell was attributed to one of the regions chosen for reporting (see below), and the average deposition rate for each region could then be calculated.

For P, the evidence is less robust. A value of 0.045 mg/l P in rainfall was estimated based on the mean soluble P at Environmental Change Network sites (0.022 mg l⁻¹ P) divided by
the average ratio of soluble to total P reported by Neal et al. (2004). Mean rainfall was estimated for all agricultural land within each country, and within each region, based on the 5km UKCIPS data for 1961-1990. These rainfall values were used with the mean concentration to generate regional and national values for P deposition. This value is very uncertain, but constitutes only a small percentage of the balance, and like the N deposition, is not directly susceptible to manipulation by farmers.

Both N and P deposition are calculated at 5 km level and summed to national level, because of the great spatial variability in rainfall and, for N, in pollutant source.

6.7 **Soil Surface balance calculations**

The Soil Surface balance may be calculated from the Farm Gate balance by the addition of atmospheric deposition (if not already included) and the subtraction of N volatilisation from manures prior to spreading.

The internationally standardised OECD spreadsheet for calculation of the Soil Surface balance requires, in addition to items present in the Farm Gate balance, estimates of grass and fodder eaten by stock, and manure and excreta returned to land. These are both very large values and neither is measured annually. However they can be estimated in an internally consistent way.

Excreta are estimated from livestock numbers, as reported annually, using standard coefficients. Volatilisation losses from manure excreted in-house before spreading to land can be estimated from the proportion of excreta handled as manure, adjusted for in-house losses of N by volatilisation, for both of which standard coefficients are available (Cottrill & Smith, 2010). These are updated fairly regularly because of their importance in implementation of the Nitrates Directive Action Programme, and other environmental initiatives.

There is no explicit method for estimating grass and fodder nutrient intake by stock. The average yield per ha of grass is particularly difficult to estimate as most UK grassland is stocked at levels well below grass growth potential, and intake will therefore depend more on stock numbers than area. However, within the animal there is an indisputable relationship between intake and output of nutrients, such that it is possible to constrain the difference between total feed intake and total excretal output of nutrients to be equal to nutrients in the product.

**Calculation: Volatilisation losses from manures prior to spreading**

The quantity of excretion by stock is calculated from stock numbers and the coefficients provided by Cottrill & Smith (2010). These data also indicate the proportion of excreta voided in-house, and therefore handled as manure; the proportion of this that is managed as solid manure (FYM) or slurry; and the proportion of nitrogen in each manure type that is lost prior to spreading. Using these coefficients, the total quantity of nutrients applied to land as excreta at grazing plus handled manure is calculated as about 10% smaller than total N excretion. Losses of ammonia after spreading are not estimated, and therefore contribute to the total balance. Losses of P prior to spreading are assumed to be negligible.

**Calculation: grass and fodder consumed**

Grass and fodder intake is equal to production plus excretion minus other feeds consumed. The largest components in this equation by far are grass consumed and nutrient excreted. By constraining their difference to be consistent with more accurately known data (feed provided and livestock outputs) and with biological reality (food eaten minus excreta = product), the total balance is preserved. Feed input and production are calculated as part
of the farm gate balance. Excretal output is calculated as described in the section above. By difference, grass and fodder intake by stock can be estimated. The fodder uptake can be calculated from standard data on typical yields and composition, from which the grass uptake can be calculated by difference. The N and P offtake per ha of grass can then be derived, and using typical nutrient contents of grass, the yield per ha can be estimated. All of these values can then be inserted in the OECD Soil Surface Balance spreadsheets, to produce the nutrient offtake figure.

Final Calculation: Soil Surface Balance
As discussed earlier, the Soil Surface balance for livestock is in principle equal to the farm gate balance minus any losses of manure nutrient in the interval between excretion and spreading as manure. These losses are calculated as explained earlier in this section, from total excretion and the proportion lost during housing and storage, using the coefficients of Cottrill & Smith (2010).

The components of the arable Soil Surface balance are, in practice, the same as those of the Farm Gate balance.

Atmospheric deposition is generally included in the Soil Surface balance. It is often omitted in the Farm Gate balance when calculated at farm level, but can be included when calculated at national level.

7 Results: Farm Gate Balance: UK

7.1 N Balance
The UK national nitrogen balance in 2004 was 1110 kT N (excluding atmospheric inputs) or 1288 kT N (including atmospheric inputs). This equates to 92 and 107 kg N per ha of managed agricultural land respectively. The balance per ha was greatest in Northern Ireland, due to the relatively intensive grassland livestock systems there.

Table 5. Farm Gate nitrogen balance for the UK, 2004 (kT N) for managed agricultural land (i.e. excluding rough grazing)

<table>
<thead>
<tr>
<th>Component</th>
<th>Sector</th>
<th>England</th>
<th>Wales</th>
<th>Scotland</th>
<th>N Ireland</th>
<th>UK</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INPUTS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fertiliser</td>
<td>Harvested</td>
<td>588.5</td>
<td>6.7</td>
<td>70.6</td>
<td>5.6</td>
<td>671.4</td>
</tr>
<tr>
<td>N Fixed</td>
<td>Harvested</td>
<td>68.1</td>
<td>0.0</td>
<td>1.6</td>
<td>0.0</td>
<td>69.7</td>
</tr>
<tr>
<td>Feed</td>
<td>Grassland</td>
<td>127.2</td>
<td>30.2</td>
<td>32.9</td>
<td>35.2</td>
<td>225.6</td>
</tr>
<tr>
<td>Feed</td>
<td>Pigs</td>
<td>71.9</td>
<td>0.5</td>
<td>8.0</td>
<td>7.0</td>
<td>87.5</td>
</tr>
<tr>
<td>Feed</td>
<td>Poultry</td>
<td>164.0</td>
<td>8.3</td>
<td>17.3</td>
<td>21.4</td>
<td>211.0</td>
</tr>
<tr>
<td>Fertiliser</td>
<td>Grassland</td>
<td>289.1</td>
<td>80.1</td>
<td>114.4</td>
<td>93.4</td>
<td>576.9</td>
</tr>
<tr>
<td>N fixed</td>
<td>Grassland</td>
<td>18.7</td>
<td>5.7</td>
<td>6.3</td>
<td>4.2</td>
<td>34.9</td>
</tr>
<tr>
<td>Other inputs</td>
<td>All</td>
<td>38.8</td>
<td>2.8</td>
<td>4.7</td>
<td>0.7</td>
<td>46.9</td>
</tr>
<tr>
<td><strong>Total inputs</strong></td>
<td></td>
<td>1366.3</td>
<td>134.3</td>
<td>255.7</td>
<td>167.6</td>
<td>1923.7</td>
</tr>
<tr>
<td><strong>OUTPUTS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crop</td>
<td>Harvested</td>
<td>493.8</td>
<td>5.6</td>
<td>56.6</td>
<td>4.5</td>
<td>560.5</td>
</tr>
<tr>
<td>Product</td>
<td>Grassland</td>
<td>81.7</td>
<td>17.9</td>
<td>20.0</td>
<td>19.0</td>
<td>138.7</td>
</tr>
<tr>
<td>Product</td>
<td>Pigs</td>
<td>17.3</td>
<td>0.0</td>
<td>2.1</td>
<td>2.4</td>
<td>21.8</td>
</tr>
<tr>
<td>Product</td>
<td>Poultry</td>
<td>57.7</td>
<td>2.9</td>
<td>6.0</td>
<td>7.4</td>
<td>73.9</td>
</tr>
<tr>
<td>Manure export</td>
<td>All</td>
<td>15.6</td>
<td>0.0</td>
<td>3.3</td>
<td>0.0</td>
<td>18.9</td>
</tr>
<tr>
<td><strong>Total outputs</strong></td>
<td></td>
<td>666.0</td>
<td>26.4</td>
<td>88.0</td>
<td>33.3</td>
<td>813.8</td>
</tr>
</tbody>
</table>
7.2 P Balance

The UK national P balance in 2004 was 123.8 kT P (excluding atmospheric inputs) or 128.8 kT P (including atmospheric inputs). This equates to 10.3 and 10.7 kg P per ha of managed agricultural land respectively. The balance per ha was greater in countries with a predominance of grassland rather than arable systems.

Table 6. Farm gate phosphorus balance for the UK, 2004 (kT N)

<table>
<thead>
<tr>
<th>Component</th>
<th>Sector</th>
<th>England</th>
<th>Wales</th>
<th>Scotland</th>
<th>N Ireland</th>
<th>UK</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INPUTS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fertiliser</td>
<td>Harvested</td>
<td>63.3</td>
<td>0.8</td>
<td>14.7</td>
<td>0.8</td>
<td>79.6</td>
</tr>
<tr>
<td>Feed</td>
<td>Grassland</td>
<td>23.7</td>
<td>5.7</td>
<td>6.2</td>
<td>6.6</td>
<td>42.2</td>
</tr>
<tr>
<td>Feed</td>
<td>Pigs</td>
<td>13.2</td>
<td>0.1</td>
<td>1.5</td>
<td>1.3</td>
<td>16.0</td>
</tr>
<tr>
<td>Feed</td>
<td>Poultry</td>
<td>31.9</td>
<td>1.6</td>
<td>3.3</td>
<td>4.2</td>
<td>41.0</td>
</tr>
<tr>
<td>Fertiliser</td>
<td>Grassland</td>
<td>27.5</td>
<td>7.4</td>
<td>15.2</td>
<td>7.9</td>
<td>58.1</td>
</tr>
<tr>
<td>Other inputs</td>
<td>All</td>
<td>25.0</td>
<td>1.6</td>
<td>2.7</td>
<td>0.1</td>
<td>29.4</td>
</tr>
<tr>
<td><strong>Total inputs</strong></td>
<td></td>
<td>184.6</td>
<td>17.2</td>
<td>43.6</td>
<td>21.0</td>
<td>266.4</td>
</tr>
<tr>
<td><strong>OUTPUTS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crop</td>
<td>Harvested</td>
<td>83.1</td>
<td>1.1</td>
<td>11.1</td>
<td>0.9</td>
<td>96.2</td>
</tr>
<tr>
<td>Product</td>
<td>Grassland</td>
<td>17.3</td>
<td>3.5</td>
<td>4.6</td>
<td>4.4</td>
<td>29.8</td>
</tr>
<tr>
<td>Product</td>
<td>Pigs</td>
<td>3.7</td>
<td>0.0</td>
<td>0.4</td>
<td>0.5</td>
<td>4.6</td>
</tr>
<tr>
<td>Product</td>
<td>Poultry</td>
<td>8.4</td>
<td>0.4</td>
<td>0.9</td>
<td>1.1</td>
<td>10.8</td>
</tr>
<tr>
<td>Manure export</td>
<td>All</td>
<td>0.0</td>
<td>0.0</td>
<td>1.2</td>
<td>0.0</td>
<td>1.2</td>
</tr>
<tr>
<td><strong>Total outputs</strong></td>
<td></td>
<td>112.4</td>
<td>5.0</td>
<td>18.3</td>
<td>6.9</td>
<td>142.6</td>
</tr>
<tr>
<td><strong>BALANCE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excl. atm. dep.</td>
<td></td>
<td>72.1</td>
<td>12.2</td>
<td>25.3</td>
<td>14.1</td>
<td>123.8</td>
</tr>
<tr>
<td>(kg/ha P)</td>
<td></td>
<td>8.9</td>
<td>10.3</td>
<td>13.6</td>
<td>15.8</td>
<td>10.3</td>
</tr>
<tr>
<td>Atmospheric deposition</td>
<td></td>
<td>2.9</td>
<td>0.7</td>
<td>0.9</td>
<td>0.4</td>
<td>5.0</td>
</tr>
<tr>
<td><strong>BALANCE</strong></td>
<td>Incl. atm. dep.</td>
<td>75.1</td>
<td>13.0</td>
<td>26.2</td>
<td>14.6</td>
<td>128.8</td>
</tr>
<tr>
<td>(kg/ha P)</td>
<td></td>
<td>9.3</td>
<td>10.9</td>
<td>14.1</td>
<td>16.3</td>
<td>10.7</td>
</tr>
</tbody>
</table>

8 Results: Soil Surface Balance: UK

The additional components required for calculation of the soil surface balance were nutrients in manure and grazing excreta applied to land and consumed in fodder and grass grazed.
Fodder offtake was calculated within the farm gate balance database. Grassland offtake was then calculated by difference. The main components are summarised below.

Table 7. Calculation of nutrient offtake in grass

<table>
<thead>
<tr>
<th>Component</th>
<th>(kT N)</th>
<th>(kT P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grassland Systems Non-grass Livestock Feed</td>
<td>225.6</td>
<td>42.2</td>
</tr>
<tr>
<td>Grassland Systems Livestock product</td>
<td>138.7</td>
<td>29.8</td>
</tr>
<tr>
<td>Grassland Systems Livestock excreta</td>
<td>926.2</td>
<td>146.0</td>
</tr>
<tr>
<td>Fodder nutrient offtake</td>
<td>25.6</td>
<td>4.8</td>
</tr>
<tr>
<td>By difference of inputs and outputs:</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Offtake in grass</strong></td>
<td><strong>813.7</strong></td>
<td><strong>128.8</strong></td>
</tr>
<tr>
<td>Area of managed grass: ‘000 ha</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Offtake in grass, kg/ha managed grass</strong></td>
<td><strong>118</strong></td>
<td><strong>18.8</strong></td>
</tr>
</tbody>
</table>

The value of N offtake in grass may be compared with estimates from the NCycle model (Scholefield et al., 1991). This model was developed from experimental measurements of N cycling within grass systems, and estimates annual N intake by grazing cattle (without additional feed) to be 100-210 kg/ha N with fertiliser input of 50 kg/ha N, and 125-215 kg/ha N with inputs of 80 kg/ha N as fertiliser, depending in the system and the soil type. These values are reduced by about 30% in pasture with poor drainage. Fertiliser inputs to grass in Great Britain averaged 77 and 55 kg/ha N in 2004 and 2008 respectively. Thus the expected intake of nutrients by stock would be of the order of 150-170 kg/ha, of which ca 110-130 kg/ha would be as grass since the contribution by other feeds is about 25% of the total intake. These results are therefore consistent with the range of likely N removal in grass based on scientific data.

The Soil Surface balance also requires estimates of excreta returned to land, as grazing returns plus manure. The manure quantity is equal to excreta in-house minus losses prior to spreading. These data were calculated from the standard excretal coefficients (Cotrill & Smith, 2010).

Table 8. Calculation of manure applied to land and grazing returns

<table>
<thead>
<tr>
<th>Component</th>
<th>(kT N)</th>
<th>(kT P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Livestock excreta:</td>
<td>1104</td>
<td>189</td>
</tr>
<tr>
<td>In-house losses of N</td>
<td>96</td>
<td>-</td>
</tr>
<tr>
<td>Livestock excreta returned to land (before manure export for incineration)</td>
<td>1008</td>
<td>189</td>
</tr>
</tbody>
</table>

The Soil Surface balance, and the headline components required to calculate the Soil Surface balance were then as in the table below:
Table 9. Main components of the UK Soil Surface balance

<table>
<thead>
<tr>
<th></th>
<th>UK</th>
<th>UK</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INPUTS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fertiliser</td>
<td>1248.3</td>
<td>137.7</td>
</tr>
<tr>
<td>N Fixed</td>
<td>104.6</td>
<td></td>
</tr>
<tr>
<td>Other inputs</td>
<td>46.9</td>
<td>29.4</td>
</tr>
<tr>
<td>*Manure and direct excretion</td>
<td>1008</td>
<td>189</td>
</tr>
<tr>
<td>Atm deposition</td>
<td>178.4</td>
<td>5.0</td>
</tr>
<tr>
<td><strong>Total inputs</strong></td>
<td>2586.6</td>
<td>361.3</td>
</tr>
<tr>
<td><strong>OUTPUTS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crops</td>
<td>560.5</td>
<td>96.2</td>
</tr>
<tr>
<td>Fodder</td>
<td>25.6</td>
<td>4.8</td>
</tr>
<tr>
<td>Grassland</td>
<td>813.7</td>
<td>128.8</td>
</tr>
<tr>
<td>Manure removed</td>
<td>18.9</td>
<td>1.2</td>
</tr>
<tr>
<td><strong>Total outputs</strong></td>
<td>1418.7</td>
<td>230.9</td>
</tr>
<tr>
<td>Soil Surface Balance</td>
<td>989.5</td>
<td>125.4</td>
</tr>
<tr>
<td>Excluding atmospheric deposition</td>
<td>1168.0</td>
<td>130.4</td>
</tr>
</tbody>
</table>

The calculated Soil Surface balance is very similar to the farm gate balance in the case of P, as would be expected. It is smaller in the case of N, and the bulk of the discrepancy is accounted for by the exclusion from the SS balance of N volatilised prior to spreading of manures collected-in house. The remaining small discrepancies are attributable to the fact that the calculated difference between feed input and product output by the pig and poultry sectors is not quite identical to the quantity of excretion as estimated from the standard coefficients and livestock numbers, although in principle the two are equivalent.

9 Appraisal of method

9.1 Expert panel appraisal

The results for 2004 were submitted to a panel of national experts, including Bob Foy (Northern Ireland); Owen Davies (Wales) and Alex Sinclair (Scotland). The Northern Ireland government (DARD) has adopted targets for N and P balances as high level PSA targets to assess the impact of measures aimed at reducing eutrophication and improving water quality. The current targets for 2011 are 135 kg N/ha and 10 kg P/ha. DARD therefore have an interest in the development of both nutrient balances and their use as policy tools for nutrient related pollution, and considerable experience in this area. The balances obtained within this project were very similar to those calculated recently for DARD.

Some specific points raised by the panel or encountered by ourselves during this work, which may repay further consideration, are discussed below.
9.2  Data issues

9.2.1  Survey and annually updated statistics

The majority of the annually updated statistics are sourced from governments, and a range of tabulated data are provided via the government websites. Statistical data (e.g., crop areas, yields) were often not available in a form conducive to this use, and many interpolations were required to generate data at national level. The underlying data for calculation of these statistics almost certainly exist, since most are derived from June agricultural surveys. The nutrient balance calculation process could be improved in both reliability and ease by organising the generation of such data from source.

9.2.2  Coefficients

Data on livestock feed composition are based on expert estimates. The actual N data are published at point of sale (as labelling on the compounded feeds), and details are certainly known within the industry. If these data could be obtained, they would enable a more sensitive response of the balance to changes in feed composition, which are currently changing markedly.

9.3  Sensitivity analysis and Uncertainty

For the balance to be an effective environmental indicator, it should be as accurate as possible, especially as regards those elements that reflect influential farming practices, and should be consistent in its assumptions with any other balances with which it is to be compared. This section reviews the factors determining accuracy, the impact of uncertainty in each on the results, the consequent impact on interpretation of the balance, and the potential for improvement.

The policy purposes of the balance have generally focussed on
- trend analysis from year to year
- comparisons between countries.

In the former case, the accuracy of those components that do not change and are not affected by farming is relatively unimportant; in the latter case it can make a substantial difference.

9.3.1  Approach to expression of uncertainty

Some of the data items used in the balance calculation are from standard, well-documented data sets with known uncertainty. Others are based on expert opinion and there may be no properly sampled database on which to base uncertainty assessments. However, the experts concerned in compilation of the balance do have some knowledge of the reliability of the data, and we have tried to capture this knowledge.

The overall impact of uncertainty is also affected by the magnitude of the component that is calculated from each data item. Thus, if an item is very uncertain, but this affects only a very small percentage of the calculated input, the benefit of improved precision will be small.
The inherent variability of the balance result year on year will affect its usefulness as an indicator of trends, and factors that affect this variability are also discussed.

Uncertainty relates to both accuracy and precision. We have considered whether it is likely that particular items are biased, and any such information is included in the comments.

9.3.2 Magnitude of components of the balance for the UK

The greatest components of nutrient input to the UK agricultural system are fertiliser, and livestock feed. The latter is particularly important (i.e. relatively large) for P. The greatest component of output is arable crop products, constituting two thirds of total N and P removal, with livestock products accounting for most of the remainder (Table 10). Within cropping, wheat accounts for 60% of N and P offtake, and cereals as a whole for 78%.

Table 10. Percentage of UK agricultural Farm Gate balance inputs and outputs that is accounted for by each of the main components

<table>
<thead>
<tr>
<th>Component</th>
<th>Input N</th>
<th>Output N</th>
<th>Input P</th>
<th>Output P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertiliser</td>
<td>65</td>
<td>52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N Fixation</td>
<td>5</td>
<td>37</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Livestock feeds</td>
<td>27</td>
<td>27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sewage / wastes</td>
<td>2</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arable crops</td>
<td></td>
<td>69</td>
<td>67</td>
<td></td>
</tr>
<tr>
<td>Livestock products</td>
<td></td>
<td>29</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>Manure incinerated</td>
<td></td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Atmospheric deposition is significant for N (ca 10% of inputs) but not P.

For reference, the same analysis is presented for the Soil Surface balance as prepared for the OECD. The greatest inputs to the soil surface are fertiliser and livestock excreta/manure; and the greatest outputs are grass/fodder consumed by livestock (ca 60% of offtake), and arable crop products. The two items that are different from those in the Farm Gate balance are excreta/manure inputs and grass/fodder consumption by stock, and both are major components.

Table 11. Percentage of UK agricultural Soil Surface balance inputs and outputs which is accounted for by each of the main components

<table>
<thead>
<tr>
<th>Component</th>
<th>Input N</th>
<th>Output N</th>
<th>Input P</th>
<th>Output P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertiliser</td>
<td>52</td>
<td>39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N Fixation</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manure minus incineration</td>
<td>42</td>
<td>53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sewage, wastes etc</td>
<td>2</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arable crops</td>
<td></td>
<td>40</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td>Grass and fodder eaten</td>
<td></td>
<td>59</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td>Manure exported</td>
<td></td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
Manure production may be estimated from livestock numbers, using coefficients that are periodically reviewed for policy purposes. The values are therefore annually responsive to changes in stock numbers, but response to changes in diet may not be expressed until some years later, depending on how promptly the excretion coefficients are updated to reflect the change. Grass and fodder consumption by stock accounts for about 60% of offtake, but is the most difficult major item to estimate in a consistent manner. No survey data are collected, and yields especially of grass vary widely depending on intensity of the production system as well as inherent site factors. In the past, grass yield has been estimated from grass area, but this method is unresponsive to spatial or temporal variation in stocking density, fertiliser input, climate or management, all of which may have substantial effects.

9.4 Review of main components of uncertainty in the Farm Gate balance

9.4.1 INPUTS

Fertiliser
Fertiliser inputs are taken from the British Survey of Fertiliser Practice (BSFP) (DEFRA & SEERAD 2005, 2009) for Great Britain, and DARD NI national statistics for Northern Ireland. There is no estimate of precision for the NI data, but the BSFP quotes detailed statistics.

The standard error on the estimate for GB in 2008 (DEFRA & SEERAD 2009) was 2.1 and 1.9 kg/ha for tillage and grass respectively, being 1.5% of the mean N fertiliser input for all tillage, and 3.5% of the mean for grass. The corresponding figures for P were 1.1 and 0.7 kg/ha P₂O₅, being 3.5 and 7% of the tillage and grass means. These standard errors correspond to 1.2% of the UK N input, and 2.6% of the UK P input. The standard errors were substantially greater for Scotland alone than for GB or for England and Wales combined, due to the smaller agricultural area and therefore sample size.

N Fixation
N fixation estimates for leguminous crops are based on experimental data over many years. As such, they are reasonably reliable, although the values are known to vary substantially from year to year, as a function both of growing conditions and the N supply from other sources. The UK values used here are significantly different to those assumed by other countries and by the current version of the OECD balance (95 kg/ha N for arable legumes), which further illustrates the uncertainty of the estimate, although the variation may partly reflect genuine differences due for example to length of growing season. Even greater uncertainty attaches to N fixation by clover within grassland systems, since the area of such grass-clover leys is uncertain, and the % coverage of clover within the sward and the quantity of N fixed are variable. The estimate for grassland was based on an assumption that about 10% of grass older than 5 years would contain some clover, and this would fix about 50 kg/ha N (total 5 kg N per ha permanent grass), while perhaps 15% of UK leys (grass < 5 years old) would contain clover fixing an average of 100 kg/ha N per annum (total 15 kg/ha N on grass < 5 years). (Alan Hopkins, pers. comm.). While there are few data to substantiate this value, the consensus was that the true value is likely to be within +/- 50% of that estimate. However it is possible that the contribution of clover to N supply in grassland systems is increasing as the N supply from fertiliser inputs diminishes, but we could find no data to substantiate this.

The OECD balance calculation also assumes 4 kg/ha N fixed by free living organisms, i.e. organisms not dependent on legumes. We have not used this figure in our calculations as we are not aware of any good data from the UK to quantify it. In any case, the value is not
under the farmer’s control and there appears to be no prospect of determining its value or its response to changing inputs and management.

Overall, we consider the estimate of N fixation to have a likely standard error of at least 20%. The estimate would be unbiased in terms of the data on which it is based, but the recent downward trend in fertiliser inputs may mean that it is now becoming an underestimate. N fixation by clover increases under conditions of low fertiliser N input, and clover plants become more competitive relative to grass.

Livestock feeds
The tonnages of compound feeds manufactured are reported by Defra based on industry survey. Not all compound feed manufacturers provide data to the survey. Since most of the large producers submit returns, the errors are likely to be relatively small, but could be improved if all manufacturers participated. Significant additional quantities of feed are not reported by these statistics. These include moist feeds, liquids and dried feeds, or ‘straights’, most of which are co-products from the food, alcohol and bioethanol industries. It is very difficult to get an accurate picture of the volume of non-compounded feeds fed on farm, particularly for dried ‘straights’ since sales of these products from shippers and food and drink producers can go down a number of routes before arriving on farm. Industry sources (Richard Wynn, KWTrident, pers. comm.) estimate the following:

- Moist feeds (brewers grains, pressed pulp, moist distillers etc) – ~1.2m to 1.5m (all of which would be fed to ruminants, but no breakdown available of how much is fed to different types)
- Liquids (molasses, molasses blends, distillery liquids etc) – ~ 120kt to 140kt (the majority of which will go to ruminants)
- Straights (soybean meal, rapeseed meal, dried distillers grains, sugar beet pulp etc) – ~ 900kt to 1.5m

Most of these feeds will be mixed with cereal grains on farm before being fed. Total quantities of home-fed grain are reported by Defra in 2004, but not subsequently. The breakdown by livestock classes to which they were fed was not reported. In the present report, the allocation has been based on expert knowledge of current feeding practice (for example, most of the wheat will be fed to monogastric animals such as pigs and poultry, while barley is predominantly and oats exclusively used for ruminants i.e. cattle and sheep, and horses) and the proportions of different livestock types. This partitioning estimate is clearly subject to error, but any errors will not affect the total national balance.

HGCA have produced an equation to predict the amount of home-grown cereals fed on farm, and this merits further investigation.

In Northern Ireland, data are available on feed purchases by farmers, which make some allowance for home fed grain, and this is the preferred data source used by the NI government (Bob Foy, Pers. Comm.) but as far as we are aware such data do not exist for GB farmers.

In addition, many livestock farmers, particularly in the ruminant sector, mix their own feeds from individual raw materials. There are no reliable data on the amount of feed produced in this way; the Agricultural Industries Confederation (AIC) estimated that in 2005 10% and 20% of concentrate feed fed to sheep and beef cattle, respectively, was home-mixed on farms. Although no data were provided for dairy cattle, the proportion is likely to be at least similar to that for beef cattle. Overall, statistics on total feed use for the pig and poultry sectors are relatively robust, and a tentative standard error of ~5% of tonnage is suggested. It is likely to be larger – 10-15% - for dairy and beef cattle, and sheep.
In our calculations we assumed that ‘imported’ feed consumed on farm generally consists of purchased compounds, cereals (wheat, barley etc.) and individual feed materials (e.g. sugar beet pulp, dried distillers grains, brewers’ grains, and generally referred to as ‘straight feedingstuffs’ or ‘straights’).

At the GB and NI whole-farm levels, the errors associated with on-farm use of feeds could potentially be reduced by using import statistics for all feed materials, and subtracting the quantities used in compound feed formulation. However, the data would not indicate livestock species to which the feeds were fed, nor allow allocation to the different Devolved Administrations.

Recently Defra have stopped collecting statistics on home-fed grain, and information from the HGCA suggests that even the 2004 statistics may be underestimates.

A potential new source of uncertainty is the fate of crop residues, especially in relation to the drive for bio fuels. Rapeseed meal was formerly almost entirely used for livestock feed, while recently it has been in demand for power stations to meet their Renewables Obligation (RO). It is not clear what alternative feeds might be used to replace such materials if their use as fuels increases.

Composition data, and the proportion of feed which is phytase enriched, are based on estimates from the enzyme manufacturers/suppliers. Most feed compounders formulate diets to standard levels of N and P, and therefore these have remained relatively constant over recent years. In response to pressures to reduce both the environmental impact of livestock and the cost of feeds, the N and P contents of feeds are likely to have reduced slightly in recent years, particularly in cattle and sheep diets. For the same reasons, the use of phytase enzymes in pig and poultry rations (to enable a reduction in P content while maintaining productivity) has increased in recent years, and this trend is likely to continue. Discussion between experts suggested a range of 20-30% may not be unrealistic, corresponding to a standard error of about 10% of the mean.

Feedingstuffs Regulations require that the crude protein content of manufactured compound is declared, and therefore the N content can be calculated. Therefore, the data to improve these estimates of N use exist, but are not collated or published. Current Regulations do not require P contents to be declared, but compound feed manufactures regularly monitor the P contents of their products for quality control and cost purposes, and so the information could be made available.

**Atmospheric deposition**
Atmospheric deposition of N is calculated from measured data, with spatial interpolation. The error of the estimate is not known. It is not locally under the farmer’s control nor responsive to his actions, so in terms of interpreting the balance as an indicator of progress, the main requirement is that the estimate should not fluctuate greatly from year to year. Efforts are underway to improve the estimates because of their great environmental importance.

**Sewage and other materials/ wastes applied to land**
The quantity of sewage applied to land, and its composition, are now relatively well documented and annually updated. A tentative error on this estimate of ca 5% is suggested. Within the current estimate, sewage sludge accounts for the great majority of both N (78%) and P (93%) applied in this category. For other materials, data on both quantities applied and composition are much less well understood, although this situation is improving. It is possible that the current estimate is too low, due to omission of sources which are not yet well documented. While this component of the balance is currently small,
the trend is towards maximising application to land of any materials with beneficial content such as nutrients.

**Omitted data**
The methodology presented here omits certain inputs for the sake of simplicity. Nutrients in irrigation water (e.g. to potatoes and vegetables) in drier parts of the country may add around 10 kg/ha of N, but only 2 kg/ha across the whole farm on a typical 5 year crop rotation. Drinking water consumed by dairy cows will typically import less than 1 kg/ha N averaged across the farmed area. (Anon, 2007a). Nutrient inputs from plant seeds are small and relatively unchanging at around 10 kT N for the UK. Cereals typically input 3 kg/ha of N and potatoes around 10 kg/ha of N in seed (OECD website, 2010). These data are documented on the OECD website, and in Goodlass & Lord (2001), and would be relatively simple to add.

As indicated, the statistics on feed inputs are imperfect and there are likely to be small omissions. Applications of other materials to land are also likely to be incompletely documented.

Imports of livestock to the farming system are small at UK level, and have not been included in the balance. Transport within the UK could affect regional balances, but the impact is thought to be minor.

**9.4.2 OUTPUTS**

**Crop yields**

**Annual yield estimates**
Yields for major arable crops are reported annually, based on survey data. Estimates of confidence intervals were given for England in Defra (2009). Since England is the largest producer of cereals by far, this error is probably appropriate for total UK cereal production estimates. The precision of the estimate of wheat area for England was given as 1.8%, corresponding to a standard error of 0.9% of the mean. The confidence interval for production for England was given as 2.4%, corresponding to a standard error of the total of 1.2%. Corresponding figures for other crops tended to increase slightly as the area of crop decreased. The standard errors on the production estimates were 2.1% for barley, and 2.0% for oilseed rape. Wheat accounts for ca 55% of total UK nutrient offtake in harvested crops (excluding fodder and grass), and barley and oilseed rape account for a further 30%. Crops where yield is not reported constitute less than 2% of the total production. Thus, the estimated standard error of the mean on crop production for major crops is of the order of 1-2%. Assuming no bias in the data, the error on the total production is likely to be less than 1%.

**Year to year variability in yield**
The policy purpose of the balance is as an indicator of environmental risk. As such, it is intended to reflect progress in practice towards minimising risk. Year to year variation in weather and other factors determining outputs is largely beyond the farmer’s control, and is to a large extent unknowable at the time that decisions on inputs have to be made, so that adaptation is also difficult. In this sense, the year-to-year variability in yield constitutes a factor limiting the precision of the balance as indicator in any one year. Increased precision beyond this ‘noise level’ may not do much to improve the precision of the indicator when comparisons are made over short time periods.
The variation in yields of wheat in the UK is illustrated by the figure below. It will be seen that there is a strong underlying upward trend, which has stabilised in the past 10-15 years. The coefficient of variation of yields over the past 11 years (1999-2009) was 4.5% for wheat, 4.5% for winter barley, 4.2% for spring barley, 8.2% for oilseed rape and 4.3% for potatoes (2004-9 only). The arable N balance is roughly one half of the N offtake in crops. Therefore if fertiliser inputs are stable, the natural variability in yields will result in ca 8-10% variability in the arable N balance year on year. The P balance is very small (negative if manure inputs are ignored) which means the impact of these natural variations will be even greater.

The variability of the balance from year to year could be reduced by use of a ‘moving average’ yield over say 5 years.

**Nutrient content of products: Grain N content**

Nutrient offtake in crops constitutes the dominant output of the Farm Gate balance, and grain comprises the dominant crop output. Its importance is of course greatest in England.

Cereal grain N contents, and statistical data, are reported annually by the Home Grown Cereals Authority (HGCA), for Great Britain (HGCA 2004, 2008, [http://www.hgca.com](http://www.hgca.com)) (No data are reported for Northern Ireland, where production is in any case very small). The national values are 0.16 overall for Scotland, and 0.18 for GB. There is a little regional variation, with greater N content in Scotland than in Eastern England for example, but for the main cereal growing areas in England results are fairly similar. The average standard errors for Great Britain are 0.05% of the mean for wheat and 0.1% of the mean for barley. Variability is greater for the regions and for Scotland because of the smaller sample size and no data are available for Wales and Northern Ireland. The standard error on the moisture content is much smaller than that of the N content, and therefore adds little to the overall error.
GB mean data were used in the balance, for simplicity. If political decisions are to be made on the basis of the individual national balances, use of regional or national composition data instead of the GB value should be considered.

The high precision of the N composition data for cereals should be set in the context of the year-to-year variability, since this will affect the confidence with which underlying changes in the balance can be detected. The coefficient of variation between years (for the period 1979 to 2009) was 7% of the mean, over a period with no clear trend. For barley, there was a strong downward trend between about 1980 and 1990 (from about 2.0 to 1.5% N), followed by relative stability. Taking therefore only the period from 1990 to 2009, the coefficient of variation was 4.3% of the mean. The variability in the combined N and yield data (ie in offtake) over the period 1999-2009 was 4.8% of the mean for wheat and 4.7% for barley. Some part of this variation will be due to deliberate economic choices by farmers in relation to their (annually varying) target market, and some will be due to factors outside their control, chiefly the weather.
The year to year variation in both yield and N content is substantially greater than the uncertainty in the annual value. A more stable balance could be achieved by using a moving average nitrogen content of grain rather than the values for individual years. It is likely that the annual variation in offtake per unit area of other crops will be of a similar order to that for cereals (i.e. around 5%).

N content of all crops other than wheat and barley, and P content for all crops, have been based on standard values since no annual surveys are carried out. The data for P are industry standards, agreed between Defra and the Potash Development Association (MAFF 2000, Defra 2010), since they are used for calculation of P offtake in relation to fertiliser requirements. Data for N and P content of fruit and vegetables are published by the Food Standards Agency in nutritional tables (e.g. Food Standards Agency 2002 and other editions). There is no single official data source for N content of other crops. For all crops except cereals therefore the only source of annual variation in calculated offtake is yield variation.

For crops where annual composition data are not available (i.e. most crops) any trends in composition will not be readily detected. Systematic changes in composition may be expected for example in relation to the fluctuating N inputs to crops such as oilseed rape as price regimes change; and in response to the large systematic reductions in P fertiliser inputs to arable crops. The extent of any such bias is not easy to determine.

Livestock products: quantity
Data on milk production for the UK, GB and NI are available from national statistics. Figures are collated from many of the larger UK dairy companies and are then scaled to reflect 100% of deliveries Production data for Scotland and Wales are derived from milk quota data.

Meat production is generally (though not always) reported as dressed carcase weight. The main uncertainty relates to the difference between the carcase which leaves the farm, and the dressed carcase. The differences reflect weights of offal and gut-fill, which need to be accounted for as products removed from the farm. The latter will vary depending on to the breed, size/age of the animal and level of feeding prior to leaving the farm. Gut-fill can account for 5 to 25% of the live weight of cattle, with an average value of 15% (Rohr and Daenicke, 1984), and up to 35% in forage-fed lambs (NRC, 1985). Gut fill/unit empty body
weight tends to decline as animals increase in weight. In the present study, standard values for converting dressed carcass weight to whole body weight have been assumed; to our knowledge, there are no data available that allow a more accurate estimates based on breed, production system etc.

Egg production is expressed as the number of eggs produced for human consumption, rather than the weight, which is affected by the breed, diet and stage of the laying cycle. In this study, a standard egg weight (63 g) has been assumed. However, eggs are graded according to weight, and the use of data on the relative proportions of eggs produced in each category (from small to very large) would reduce the standard deviation of predicted N and P output in eggs.

Sheep wool production is reported for Scotland and Wales, but apparently not for England and Northern Ireland. Estimates of production by advisers are in the range 2-3 kg/sheep depending on type, while the reported yields are 1.6 – 1.8 kg/sheep. Thus, there is potential bias in this value as well as well as substantial uncertainty.

Livestock products: composition
The protein content of milk is reported annually. Milk N content is obtained by dividing protein content by 6.38 since there is little non-protein N present. The P content of milk is not routinely measured. A number of authorities have published estimates of the P content of milk. Food Standards Agency (2002) give a single value of 0.93 g/kg for whole milk, but separate values for pasteurised whole milk for summer and winter (0.91 and 0.96 g/kg, respectively) suggesting a seasonal effect. A study undertaken for MAFF (Withers et al., 2001) reported average milk P content of 0.801 g/kg. Since milk P is most closely associated with the protein fraction, the P concentration, it might be argued that greater accuracy might be achieved if milk P content were linked to the N content, but no relationships have been published in peer-reviewed journals. For this study, a fixed content of 0.9 g/kg has been assumed (Cottrill and Smith, 2010).

For meat from beef cattle sheep, the amount of N and P leaving the farm has been calculated using equations derived from whole-body composition data (ARC 1980). These are very old data, and may not be fully representative of modern genotypes or feeding systems, but to update them would likely be prohibitively expensive.

For pigs, body composition data of de Longe et al (2003) were used. For poultry meat, composition data from for broilers (Wiseman and Lewis, 1998) were also applied to laying hens. These data are relatively recent and the cost of providing new data is unlikely to improve accuracy.

The composition of eggs intended for human consumption are reported by national periodically updated statistics (Food Standards Agency 2002 and other editions)

Manure removed and incinerated
Statistics on broiler litter incinerated are obtained from the power stations concerned. The composition of broiler litter is taken from regularly reviewed Defra coefficients. The uncertainty on these data are not known, but steering group members made an expert estimate of the order of 15%.

Omitted output data
Products consumed by the producer, or sold in farm shops are generally not included in production statistics.

We have not included exported livestock. The quantity of stock is small at UK level.
9.4.3 Summary of uncertainty of components of Farm Gate balance

The following data relevant to a nutrient balance are annually updated and known with good accuracy in the UK:

- Crop areas
- Livestock numbers
- Fertiliser inputs
- Livestock feed quantities
- Production of major crops
- Production of livestock products (meat, milk, eggs; wool is less well reported)
- N content of wheat and barley grain, and of milk
- Atmospheric deposition of N, is now estimated annually

Factors for which reasonably robust data exist, though these are irregularly updated, include:

- Nutrients excreted by livestock (and losses prior to spreading manure)
- Composition of livestock feeds
- Composition of livestock products
- Composition of major crops
- Composition of fruit and vegetables
- Typical yields of minor crops

The least robust data relate to composition of minor crops; nutrients removed in the non-consumed part of livestock carcasses; wastes and other non-fertiliser materials applied to land; and deposition of P.

The overall estimated level of uncertainty of the main balance components, and the impact on the uncertainty of the total input or output, are summarised below.

These comments refer to the UK as a whole. Data for individual countries within the UK vary, such that some items must be inferred from totals reported for UK, Great Britain or England and Wales combined. Data for Northern Ireland is in many cases collected and reported separately.
Table 12. Estimated uncertainty (standard error as % of mean) in components of the Farm Gate balance, and impact on inputs or outputs

<table>
<thead>
<tr>
<th>Component</th>
<th>Item</th>
<th>Standard error, % of mean</th>
<th>% of UK input or output</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2% (N), 5% (P)</td>
<td>1-3%</td>
</tr>
<tr>
<td>Fertiliser</td>
<td></td>
<td>2%</td>
<td>1% (N)</td>
</tr>
<tr>
<td>N fixation</td>
<td>Tonnage</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Livestock feeds</td>
<td>Composition</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>not known</td>
<td>3%</td>
</tr>
<tr>
<td>Atmospheric</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sewage/ wastes</td>
<td>Annual yield variation</td>
<td>4.50%</td>
<td>3%</td>
</tr>
<tr>
<td>Arable crops</td>
<td>Major crop yields</td>
<td>1.50%</td>
<td>1%</td>
</tr>
<tr>
<td></td>
<td>Cereal composition</td>
<td>&lt; 0.1%</td>
<td>&lt;0.1%</td>
</tr>
<tr>
<td></td>
<td>Minor crop yields</td>
<td>5%</td>
<td>0.5%</td>
</tr>
<tr>
<td>Livestock products</td>
<td>Minor crop composition</td>
<td>10%</td>
<td>1%</td>
</tr>
<tr>
<td></td>
<td>Production</td>
<td>? 10%</td>
<td></td>
</tr>
<tr>
<td>Manure incinerated</td>
<td>Composition</td>
<td>? 15%</td>
<td>? 5%</td>
</tr>
<tr>
<td></td>
<td>Overall</td>
<td>? 15%</td>
<td>? 5%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15%</td>
<td>&lt;0.3%</td>
</tr>
</tbody>
</table>

9.4.4 Magnitude of components of the SS balance for the UK

Several of the components of the Soil Surface balance are the same as for the Farm Gate balance.

The main additional data items are:

- Quantity of nutrients excreted to land or applied to land as manure
- Quantity of nutrients ingested as grass and fodder

Both are major components. The first accounts for 38-53% of inputs for N and P respectively, the second for about 60% of outputs.

Manure and excretal returns

The first item is calculated from livestock numbers and coefficients which are updated regularly because of their importance as underpinning to the implementation of environmental schemes on farms. The precision of these estimates is expected to be moderately good. Livestock numbers are derived from June Survey and related statistics, and are annually updated. A comparison of these data for Wales with an entirely independent source, the Cattle Tracing Scheme, during the period when both sources were available, found differences of 1 to 9%, the latter being unexpectedly large. The uncertainty for the UK overall is therefore tentatively set at 1%. The coefficients of excretion are more difficult to determine, but are based on calculations including the
UK Agriculture Nutrient Balances methodology review.

nutrients consumed by stock, and measured manure quantities produced and composition. The uncertainty is estimated as perhaps 10% for any single item, but 5% overall.

The second item, offtake in grass and fodder consumed, has in previous iterations of the balance been calculated by a variety of means, usually based on an estimated yield per unit area of grass, by analogy with the method of estimating arable crop yields. The yields have been estimated by advisors. Experimental data summarised in Defra (2000) indicate yield potentials of 10-11 t/ha under grazing and 13-14 t/ha dry matter under cutting for silage. However, most grassland in the UK is stocked at substantially less than the theoretical capacity of the land to carry stock, and is accordingly fertilised at much lower rates than those required to achieve such yields. The recommendation for optimum yield is generally well above 200 kg/ha N (depending on circumstances) although average fertiliser inputs to grass in 2008 across Great Britain were 55 kg/ha N. Yields vary widely between farms and regions.

The result is great uncertainty in the estimate – successive estimates have varied by at least 30% at UK level. Best advisory information is assigned an uncertainty of 20% in the absence of any sound basis for assessment. There is also substantial uncertainty in the average composition of grass eaten, especially as fertiliser inputs of both N and P have declined dramatically in recent years, which has been estimated as 10%.

Table 13 Estimated uncertainty (standard error as % of mean) in components of the Soil Surface balance (as calculated in previous reports). Items preceded by * are those not used in the Farm Gate balance

<table>
<thead>
<tr>
<th>Component</th>
<th>Item</th>
<th>Standard error, % of mean</th>
<th>% of UK input or output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertiliser N fixation</td>
<td></td>
<td>2% (N), 5% (P)</td>
<td>1-3%</td>
</tr>
<tr>
<td>* Manure and Excretal Returns</td>
<td>Livestock numbers</td>
<td>20%</td>
<td>1% (N)</td>
</tr>
<tr>
<td></td>
<td>Coefficients</td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Overall</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Atmospheric</td>
<td>not known</td>
<td>5%</td>
<td>&lt; 0.5%</td>
</tr>
<tr>
<td>Sewage/ wastes</td>
<td>Year-to-year yield variation</td>
<td>4.50%</td>
<td>3%</td>
</tr>
<tr>
<td>Arable crops</td>
<td>Major crop yields</td>
<td>1.50%</td>
<td>0.5%</td>
</tr>
<tr>
<td></td>
<td>Cereal composition</td>
<td>&lt; 0.1%</td>
<td>&lt;0.1%</td>
</tr>
<tr>
<td></td>
<td>Minor crop production</td>
<td>5%</td>
<td>0.5%</td>
</tr>
<tr>
<td></td>
<td>Minor crop composition</td>
<td>10%</td>
<td>1%</td>
</tr>
<tr>
<td>* Grass and fodder eaten</td>
<td>Tonnage</td>
<td>30%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Composition</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Overall</td>
<td>15%</td>
<td>15%</td>
</tr>
<tr>
<td>Manure incinerated</td>
<td></td>
<td></td>
<td>&lt;0.3%</td>
</tr>
</tbody>
</table>
In addition to these uncertainties, the calculation has the disadvantage that it is not sensitive to stock numbers or any other available statistic, but changes according to the best guess of the latest compiler of the balance. The trend in excretal production of grazing stock in recent OECD balances has fallen (as a result of falling livestock numbers) but the estimated offtake in grass consumed has risen at the same time – these trends are inconsistent and biologically impossible.

Under the currently implemented method, the Soil Surface balance has very similar overall level of uncertainty as the Farm Gate balance. It is set equal to the Farm Gate balance minus an adjustment for volatilisation losses from manures prior to spreading, the latter being relatively small. The most uncertain component, grass and fodder consumed, is calculated by difference from the remaining components including the manure applied. Thus, although these components may be uncertain, their combined effect is constrained to be consistent with an overall balance based on best available data. This gives a result that is scientifically more plausible and more useful for international comparison and Policy use.

9.4.5 Spatial uncertainty: National and regional

The balance has been calculated for individual countries of the UK. Some of the data items required are reported only at UK or GB level, and have had to be inferred for the individual countries. In general this is because they are not important in certain countries (e.g. arable crop data are reported in less detail for Wales and Northern Ireland). In some cases (e.g. crop areas), at least some of the data exist and could be used explicitly in the calculation if the improvement in precision was thought worthwhile. (If future balances are calculated by Defra staff, they may find it relatively simpler to obtain such data internally than it was for the authors of this project). Composition data are generally reported only for UK as a whole, and in this work a single coefficient has always been used for the whole UK.

We have developed a method for regionalisation of the balance, based on regional data on crop areas and livestock numbers from the June Survey. The regional maps should be seen as expressing how the impact of the nationally-derived balance is distributed across the country. They do not provide any additional information as regards local practices. A high balance locally simply means that the June Survey data indicate that there is a high concentration of those types of agricultural system that were identified (at national level) as having a large nutrient balance per ha.

The precision of the regional balance values will be severely limited, for reasons which relate to both the June Survey data and the coefficients used for regionalisation:

June Survey data: These results become less reliable as the area of interest becomes smaller. For very small regions, much of the data may be considered ‘disclosive’ and is either not reported, or reported in a form which has smoothed out the disclosive elements. This issue was found to be a particular problem with the NUTS3 regions used for England, many of which were dominantly urban, with very small areas of agricultural land. In very small areas, it is possible to generate somewhat implausible balances, for example there may be more manure generated by local pig and poultry units than could be accepted by local land, and in practice the surplus is exported. Large farming conglomerates may report all their results to a single office, such that there may be more agricultural land reported locally than the regional surface area. The June Survey data cannot take account of such issues, and locally anomalous results are increasingly likely, the smaller the reporting area.
We suggest that this problem could be reduced by combining all regions with less than a specified area of agricultural land into a single, delocalised region.

In this context we reproduce parts of an excellent summary of the situation from the Welsh Digest of Small Area Statistics for 2007:

**Recommendations for using agricultural small area statistics**

It is not possible to produce hard and fast rules on the use of such complicated datasets. However, extensive analysis of the Agricultural Survey suggests that there are seven key observations.

- The Welsh Agricultural Survey provides statistical estimates.
- The Agricultural Survey is a source that is good at giving a broad overview of agriculture in Wales. More detail almost always equates to less accuracy.
- The survey is good at demonstrating trends in the aggregate estimates over time.
- The survey is good at showing the mix of activities on holdings and constructing farm typologies.
- In general the Agricultural Survey produces robust estimates for most of the variables in the survey at national and regional levels.
- The nature of the data source means that we can be confident that on average the small area estimates are reasonably robust over a wide range of variables. This means that it would be reasonable to consider a map of the distribution of a variable across Wales (for example splitting the small areas into “high”, “medium” and “low” groups).
- The fact that we have robustness for small areas on average does not imply that any specific small area must also be robust. Applications that require accurate estimates for specific localities are extremely likely to be compromised by data quality issues.

**Data quality issues**

The following key points should always be remembered.

- The Welsh Agricultural Survey is actually a sample survey not a census.
- The figures thus contain estimates.
  (In general around 45% of the total for most variables comes from actual responses. The remaining 55% will be imputed and so subject to a degree of sampling error.)
- The results are not definitive or comprehensive.
- Where we have an actual response then the values will be generally accurate.
- The accuracy of the estimates for missing data depends very largely on the number of actual responses on which the estimate is based.
- The register of farms on which the survey is based is not a compulsory register and so can only be our best estimate of the true population.
- The survey is based on farm holdings as a building block. These holdings are not geographically compact units. We can make estimates for geographical areas but these will contain additional errors because of location issues.

**Specific issues**

For holdings outside the subsidy system there are four key types of holding that are known to have coverage problems.
- Specialist poultry producers.
- Specialist pig producers.
- Specialist horticulturists.
- The very smallest holdings including non-commercial concerns.

The specialist producers are a particular concern because there tend to be few of these in Wales and these sectors are dominated by a small number of holdings. The most extreme is for chicken producers where more than 90% of the birds are on less than 1% of the holdings with chickens.
Geographical location of holdings

The Welsh Agricultural Survey collects information at the level of the individual farm holding. These holdings are collections of land farmed together as a unit. They are not necessarily contiguous sets of fields.

The fields on a holding may be scattered over a wide area. Therefore, while we will know the number of animals on a holding we do not know where the animals graze (or where their manure is applied). Similarly while we know the total area of crops we do not know where the crops are grown. It is possible to make an estimate of the general location of a holding. These estimates can use the digital field boundaries where these are available and address information otherwise. We can then build up geographical estimates by assuming that all the activity on a holding takes place at this estimated location. Clearly this is a great simplification of reality. The accuracy of the geographical estimates depends mainly on using areas that contain a sufficiently large number of holdings. With a large number of holdings the overall net error will decrease as a false inclusion on one holding is balanced by a false exclusion on another. However, for very specific location, with small numbers of holdings involved, the level of error because of the location issues must be significant.

The significance of this problem can be seen in map 2. This uses the individual field registrations from the subsidy payments system. The map shows all the registered fields that belong to farms that are thought to fall within the single Small Area

![Map of Small Area 173](image.png)

Figure 6. Map relating to boxed quotation above, showing actual location of land attributed to a specified Small Area within Wales. Source: Wales.Gov.UK

Regional coefficients: The regional coefficients were generated by sectorising the balance, and then dividing the individual sector balances by the total national area of an
indicative livestock or land use statistic. This process was shown to give reasonable results consistent with advisory expectation, but necessarily introduces additional assumptions and approximations. For example the apportionment of certain feeds such as on-farm-fed grain between different livestock sectors (dairy, beef, pigs and poultry) is uncertain. It does not affect the total balance, but will affect the balance of those individual sectors. Thus the individual sector balances will have greater uncertainty than the overall total balance. They provide a useful way of identifying the major contributors to the balance, and we believe them to present a broadly correct picture for the test year of 2004. However the apportionment may require revision in future years, to ensure it remains realistic.

9.4.6 Variation caused by change in definitions

The result of the balance calculation is sensitive to the definition used. In the UK, the greatest sources of this variation in the balance are:

- atmospheric deposition, especially of N. Inclusion of this considerably increases the balance
- inclusion or exclusion of rough grazing land. In the present calculation, agricultural land has been defined as managed grass plus tilled land. Inclusion of rough grazing will
  - increase the total balance if atmospheric deposition is included
  - decrease the balance per ha

These differences are sufficiently large to invalidate comparisons with other countries that use different rules.

9.5 Potential improvements to the balance calculation

The balance development, and particularly the review of uncertainty has identified several ways in which the accuracy of the balance could be increased.

Improvements in data

The main areas where improvement could be made or where more regular review of the data would increase confidence (in approximate priority order) were identified as:

- Livestock feed composition data
- Crop composition (other than cereal N content)
- Livestock product composition and live weight: dead weight ratios
- Non-agricultural materials applied to land.
- N fixation is imprecisely known, and potentially increasing in grassland systems, but improvement of the current estimate would be a major undertaking.

The reduction in inputs due to economic and environmental drivers means that it is possible that nutrient composition of products could be changing. Other environmental pressures (e.g. avoidance of land fill) are likely to increase non-agricultural materials
applied to land in future, though their quantity is currently small. The drive to bio-fuel use is a counter-pressure, since it creates a demand for agricultural crop residues that hitherto have been returned to land, directly or via livestock feed.

**Omitted components**
It is known that the data are incomplete in many ways. In some cases the required data are uncertain or missing, but in others the calculation could be added.

Items for which data are available include:
Seed for planting (this is currently included in the OECD soil surface balance, and could easily be added.). The quantity is small, roughly constant for a given crop, and not affected by policy change.
Protected crops and nursery stock. These are currently omitted. The area concerned is small, and the activities highly variable. It is included in principle in the OECD balance, but the data are not always entered.

**Incomplete data**
It is known that many of the input and output data sets are incomplete, and these are reviewed under the Uncertainty section. Some of these omissions could be rectified by improved data, for example Defra have recently stopped compiling the statistics on home-fed grain.

Production statistics for other crops and livestock may omit or underestimate production sold direct from the farm. Reported wool yields are considerably smaller than would be estimated from advisory data on likely yield per sheep.

**Existing data that are not readily available**
There are a number of data sets which are known to exist but are not readily available e.g. on the web in appropriate form, and in some cases could not be obtained for this calculation. This includes:
Composition of feed
Fine detail of census returns on minor crops and stock, at both national and regional level – necessitating considerable interpolation and estimation.
Yields of minor crops, and wool

10 Calculation of sector balances

10.1 **Purpose of sector balances**

There are two main reasons for calculating the balance by agricultural sectors.

- First, comparison of balances between very different farming systems is unhelpful – for example arable balances are typically smaller than those for grassland, but losses to water are often greater from the former.

- Second, sector balances are necessary for regionalisation of the balance. The components of balance are available only at national or even GB/UK level. At regional level, the main source data available is the June Survey of crop areas and livestock numbers. Therefore, a regional balance is calculated by apportioning the balance for different sectors according to the survey data.
10.2 **Approach to sector balances**

For the present purpose, the sectors were harvested crops (arable excluding fodder); grassland systems; pigs and poultry. The balance at this level was calculated directly from the national data.

Each sector balance was then subdivided. In the case of harvested crops, the division was to individual crop level since this is simple to determine from the data. The livestock sectors were subdivided into system subsectors: Dairy, beef/other cattle, sheep, and other grazing livestock; pig breeders and pig fatteners; layers, broilers, other hens and other poultry. The livestock subdivisions were made on the basis of the relative quantities of excreta from each subsector, on the principle that the balance is equal to excretion for pigs and poultry; and is likely to be well correlated with it for ruminants.

The harvested crops balance was taken for simplicity as the balance excluding livestock manures. In this form, the Farm Gate and Soil Surface balances are equivalent. The balances for the livestock sectors were calculated independently.

The balances for the pig and poultry sectors were calculated by assigning all feeds and products to a sector (breeding pigs, fattening pigs, layers, broilers, other hens and other poultry). This was relatively simple with regard to products, but involved a certain amount of judgement with regard to feeds. The boundaries between the sectors are therefore not precise but the total will be correct. The balances for the grassland sectors were calculated in the same way, with the addition of fertiliser inputs to grassland and fodder crops.

Other inputs to land (atmospheric deposition, sewage etc) and export of manure for incineration were excluded from the sector balances for this purpose. This was partly a matter of convenience, and partly because these factors are not closely related to how the farmer manages the system. For example the N balance as an indicator of livestock feed efficiency should be calculated independently of the fate of the manure (9ncineration or land application). Atmospheric inputs are not under the farmer’s direct control. The other inputs to land (wastes) are not always efficiently utilised within the system, and were therefore ignored, but it is possible that this component might in future be brought within the balance.

It should be noted that the method of sectorising the balance described here, for the purpose of mapping the balance, is still a little simplistic. There is interaction both between sectors, and between each sector and the other components. For example, there is increasing evidence that farmers reduce fertiliser inputs to allow for nutrients in manure. The latest data suggest that this reduction is of the order of 20% of the total N content of manures applied, in arable systems (Lord et al., 2008, from the British Survey of Fertiliser Practice), and probably even greater for P. Indeed when manure inputs are ignored, the balance for the harvested crops sector is negative. Because of these adjustments, fertiliser inputs in areas with livestock will be smaller than in areas without, and the latter will appear (unfairly) to have a greater nutrient balance. In principle therefore the national arable balance should be increased to allow for the substitution of fertiliser by manure nutrients, and the livestock sector balance decreased. While a methodology was developed within the project to take this into account, it was considered perhaps too complex for the automated, updatable system, which was the objective of the project, and was not implemented.

The problem relates particularly to manures from pigs and poultry, which are produced in large localised quantities. Manure from grazing stock is applied either to grassland, or to arable land in the immediate vicinity. Its impact is taken into account within the total
grassland sector balances, and the quantities applied are constrained by grassland stocking density limits. The net effect on P of an improved adjustment for the contributions of manure would be an harvested crops sector balance close to zero (instead of negative) with a corresponding increase in the pig and poultry sector balance. For the grassland sector, the effect would be small because manure is largely used within the grassland area. The effects on N would be smaller than on P, estimated as a 6% increase in the harvested crops sector balance, with a corresponding quantity of N deducted from the pig and poultry sector balance.

### 10.3 Harvested crops sector and subsector balances

The harvested crops sector balance was the difference between inputs (as fertiliser and N fixation) and outputs (as harvested product removed from the field). The P balance was negative for arable crops overall, reflecting the recent reductions in P fertiliser. However, the balance was positive if manure inputs to arable land were taken into account, indicating that farmers probably adjust their fertiliser inputs to take account of P provided by manure.

We have here counted fodder crops as part of the grassland systems. The fertiliser input to them is therefore part of the livestock balance, and it is not necessary to calculate the fodder crop offtake (except for the purpose of populating the Soil Surface balance spreadsheets) as this remains within the livestock sector.

<table>
<thead>
<tr>
<th>Table 14. Harvested crops sector balance 2004</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td><strong>England</strong></td>
</tr>
<tr>
<td>kT N</td>
</tr>
<tr>
<td>kT P</td>
</tr>
</tbody>
</table>

The sector balance was also expressed in terms of individual crops and crop groups. Fertiliser input, N fixation and yield of arable crops are all provided as national statistics for individual major crops. Calculation of a balance per ha of crop is therefore natural and simple, and is equivalent for Farm Gate and Soil Surface balance.

The individual crop balances have more meaning for N than for P. Nitrogen fertiliser inputs are determined largely by the current crop. The fertiliser input in the current year is an important determinant of N loss potential. A substantial proportion of any surplus N is likely to be lost over winter. For this reason, the N surplus calculated for a single cropping year is a significant indicator of N loss potential. N surpluses can be meaningfully calculated per crop as the difference between fertiliser input and product removed. For P, which is better retained in the soil, it is common practice to apply additional fertiliser to the most responsive crops in the rotation (such as potatoes) and reduced quantities to the rest of the rotation (e.g. Cereals). A per-crop balance therefore has little meaning, and the mean balance per ha of arable land may be the better indicator of environmental risk.

It will be seen that the greatest N balance accrues to cereals and oilseed rape, and that the P balance for most crops apart from potatoes is negative, reflecting both rotational manuring (P is applied to the most responsive crop in the rotation, and this serves for the remainder) and the fact that manures, which are not part of this calculation, supply significant quantities of P.
Table 15. Individual crop balances by country, for N and P, excluding manure inputs. 2004

<table>
<thead>
<tr>
<th>Crop</th>
<th>England</th>
<th>Wales</th>
<th>Scotland</th>
<th>N Ireland</th>
<th>UK</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nitrogen balance kT N</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td>48.80</td>
<td>0.40</td>
<td>-0.05</td>
<td>-0.43</td>
<td>48.73</td>
</tr>
<tr>
<td>Winter barley</td>
<td>16.14</td>
<td>0.44</td>
<td>4.63</td>
<td>0.06</td>
<td>21.27</td>
</tr>
<tr>
<td>Spring barley</td>
<td>8.43</td>
<td>0.61</td>
<td>5.31</td>
<td>1.00</td>
<td>15.36</td>
</tr>
<tr>
<td>Oats</td>
<td>0.30</td>
<td>0.13</td>
<td>-0.01</td>
<td>0.06</td>
<td>0.48</td>
</tr>
<tr>
<td>Triticale and other grain</td>
<td>-0.15</td>
<td>0.00</td>
<td>0.01</td>
<td>0.01</td>
<td>-0.13</td>
</tr>
<tr>
<td>Potato</td>
<td>5.24</td>
<td>0.15</td>
<td>0.42</td>
<td>0.04</td>
<td>5.84</td>
</tr>
<tr>
<td>Sugar Beet</td>
<td>-0.76</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>-0.76</td>
</tr>
<tr>
<td>Oilseed rape</td>
<td>45.77</td>
<td>-0.60</td>
<td>4.30</td>
<td>0.01</td>
<td>49.47</td>
</tr>
<tr>
<td>Linseed</td>
<td>-0.09</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>-0.08</td>
</tr>
<tr>
<td>Peas-dried for animal consumption</td>
<td>8.99</td>
<td>0.00</td>
<td>0.17</td>
<td>0.00</td>
<td>9.16</td>
</tr>
<tr>
<td>Field beans for animal consumption</td>
<td>22.25</td>
<td>0.00</td>
<td>0.36</td>
<td>0.00</td>
<td>22.61</td>
</tr>
<tr>
<td>Other arable crops</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.16</td>
<td>0.16</td>
</tr>
<tr>
<td>Total peas and beans as veg</td>
<td>1.70</td>
<td>0.00</td>
<td>0.16</td>
<td>0.01</td>
<td>1.87</td>
</tr>
<tr>
<td>Vegetable brassicas</td>
<td>3.60</td>
<td>0.02</td>
<td>0.22</td>
<td>0.03</td>
<td>3.88</td>
</tr>
<tr>
<td>All other veg and salad</td>
<td>1.26</td>
<td>0.01</td>
<td>-0.04</td>
<td>0.04</td>
<td>1.26</td>
</tr>
<tr>
<td>Orchard fruit</td>
<td>0.89</td>
<td>0.00</td>
<td>0.00</td>
<td>0.13</td>
<td>1.02</td>
</tr>
<tr>
<td>Soft fruit</td>
<td>0.39</td>
<td>0.00</td>
<td>0.03</td>
<td>0.04</td>
<td>0.46</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Crop</th>
<th>England</th>
<th>Wales</th>
<th>Scotland</th>
<th>N Ireland</th>
<th>UK</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phosphorus balance kT P</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td>-19.32</td>
<td>-0.15</td>
<td>-0.18</td>
<td>-0.08</td>
<td>-19.73</td>
</tr>
<tr>
<td>Winter barley</td>
<td>-1.06</td>
<td>-0.02</td>
<td>0.44</td>
<td>-0.03</td>
<td>-0.68</td>
</tr>
<tr>
<td>Spring barley</td>
<td>-1.02</td>
<td>-0.02</td>
<td>1.65</td>
<td>0.01</td>
<td>0.61</td>
</tr>
<tr>
<td>Oats</td>
<td>-0.28</td>
<td>0.01</td>
<td>0.06</td>
<td>-0.01</td>
<td>-0.21</td>
</tr>
<tr>
<td>Triticale and other grain</td>
<td>-0.10</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>-0.11</td>
</tr>
<tr>
<td>Potato</td>
<td>4.20</td>
<td>0.08</td>
<td>1.20</td>
<td>-0.01</td>
<td>5.48</td>
</tr>
<tr>
<td>Sugar Beet</td>
<td>-0.74</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>-0.74</td>
</tr>
<tr>
<td>Oilseed rape</td>
<td>-1.56</td>
<td>-0.12</td>
<td>0.26</td>
<td>0.00</td>
<td>-1.42</td>
</tr>
<tr>
<td>Linseed</td>
<td>-0.08</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>-0.08</td>
</tr>
<tr>
<td>Peas-dried for animal consumption</td>
<td>-0.18</td>
<td>0.00</td>
<td>-0.01</td>
<td>0.00</td>
<td>-0.19</td>
</tr>
<tr>
<td>Field beans for animal consumption</td>
<td>-1.35</td>
<td>0.00</td>
<td>-0.02</td>
<td>0.00</td>
<td>-1.37</td>
</tr>
<tr>
<td>Other arable crops</td>
<td>-0.04</td>
<td>-0.01</td>
<td>-0.01</td>
<td>0.02</td>
<td>-0.04</td>
</tr>
<tr>
<td>Total peas and beans as veg</td>
<td>0.23</td>
<td>0.00</td>
<td>-0.03</td>
<td>0.00</td>
<td>0.20</td>
</tr>
<tr>
<td>Vegetable brassicas</td>
<td>0.50</td>
<td>0.00</td>
<td>0.03</td>
<td>0.01</td>
<td>0.53</td>
</tr>
<tr>
<td>All other veg and salad</td>
<td>0.69</td>
<td>0.00</td>
<td>0.14</td>
<td>0.00</td>
<td>0.84</td>
</tr>
<tr>
<td>Orchard fruit</td>
<td>0.13</td>
<td>0.00</td>
<td>0.00</td>
<td>0.02</td>
<td>0.15</td>
</tr>
<tr>
<td>Soft fruit</td>
<td>0.17</td>
<td>0.00</td>
<td>0.02</td>
<td>0.01</td>
<td>0.20</td>
</tr>
</tbody>
</table>
10.4 Livestock sector balances

From available statistics, it is possible to generate reasonably separate balances for pigs, poultry and the grassland sector. Feeds within the grassland sector, for dairy, beef and sheep systems, can be reasonably well separated also, but fertiliser inputs and N fixation for grass cannot be readily assigned to different stock types. Therefore the national level balance calculates initially 3 main sector balances, for grassland sector, pigs and poultry.

Figure 7. UK 2004 Farm gate N and P balance by sector, kT
Subdividing the balance within these main sectors was carried out on the basis of excretion of nutrients. Thus, if 30% of nutrients excreted by poultry were attributed to layers, it was assumed that they also represent 30% of the balance. These calculations were carried out before adjustments for incineration of broiler litter or volatilisation losses prior to spreading. Under these conditions, the pig and poultry balances are mathematically equivalent to their excretion (subject to uncertainty/ errors in the calculation data).

The estimates of livestock excretion were generated from detailed national census statistics, and associated coefficients developed on behalf of Defra (Cottrill & Smith, 2010).

The required steps for generation of the subsector balances are:

- calculate separate grassland, pig and poultry balances
- calculate total manure excretion by each sector, using standard coefficients and census data
- apportion the total livestock balance within each sector, e.g. between breeding and fattening pigs, according to the relative quantity of excretion from each.
Table 16  Farm gate livestock balance by sector, prior to adjustment for manure incineration.  UK 2004

<table>
<thead>
<tr>
<th>Sector</th>
<th>$kT\ N$</th>
<th>Wales</th>
<th>Scotland</th>
<th>N Ireland</th>
<th>UK</th>
<th>$kT\ P$</th>
<th>Wales</th>
<th>Scotland</th>
<th>N Ireland</th>
<th>UK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grassland</td>
<td>353.3</td>
<td>98.0</td>
<td>133.5</td>
<td>113.8</td>
<td>698.7</td>
<td>33.9</td>
<td>9.6</td>
<td>16.8</td>
<td>10.2</td>
<td>70.5</td>
</tr>
<tr>
<td>Pigs</td>
<td>54.6</td>
<td>0.5</td>
<td>6.0</td>
<td>4.6</td>
<td>65.7</td>
<td>9.5</td>
<td>0.1</td>
<td>1.0</td>
<td>0.8</td>
<td>11.4</td>
</tr>
<tr>
<td>Poultry</td>
<td>106.4</td>
<td>5.4</td>
<td>11.3</td>
<td>14.0</td>
<td>137.0</td>
<td>23.5</td>
<td>1.2</td>
<td>2.4</td>
<td>3.1</td>
<td>30.2</td>
</tr>
</tbody>
</table>

Table 17.  Nutrient excretion by livestock.  UK 2004

<table>
<thead>
<tr>
<th>Sector</th>
<th>$kT\ N$</th>
<th>Wales</th>
<th>Scotland</th>
<th>N Ireland</th>
<th>UK</th>
<th>$kT\ P$</th>
<th>Wales</th>
<th>Scotland</th>
<th>N Ireland</th>
<th>UK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grassland</td>
<td>492.0</td>
<td>145.0</td>
<td>167.1</td>
<td>122.0</td>
<td>926.2</td>
<td>78.3</td>
<td>22.8</td>
<td>25.8</td>
<td>19.0</td>
<td>146.0</td>
</tr>
<tr>
<td>Pigs</td>
<td>47.3</td>
<td>0.3</td>
<td>5.2</td>
<td>4.8</td>
<td>57.7</td>
<td>9.6</td>
<td>0.1</td>
<td>1.1</td>
<td>1.0</td>
<td>11.6</td>
</tr>
<tr>
<td>Poultry</td>
<td>93.5</td>
<td>4.6</td>
<td>9.4</td>
<td>12.7</td>
<td>120.1</td>
<td>24.5</td>
<td>1.2</td>
<td>2.5</td>
<td>3.3</td>
<td>31.6</td>
</tr>
</tbody>
</table>
Table 18. Proportion of nutrients excreted by each stock type (subsector) within each sector, UK, 2004.

<table>
<thead>
<tr>
<th>Stock Type</th>
<th>Proportion of Nutrients Excreted</th>
<th>UK Agriculture Nutrient Balances methodology review.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$N$ Excretion by subsector as proportion of sector</td>
<td>$P$ Excretion by subsector as proportion of sector</td>
</tr>
<tr>
<td></td>
<td>England</td>
<td>Wales</td>
</tr>
<tr>
<td>Grassland</td>
<td>Beef breeder</td>
<td>0.17</td>
</tr>
<tr>
<td>Grassland</td>
<td>Dairy breeder</td>
<td>0.41</td>
</tr>
<tr>
<td>Grassland</td>
<td>Other cattle &amp; calves</td>
<td>0.24</td>
</tr>
<tr>
<td>Grassland</td>
<td>Other stock</td>
<td>0.01</td>
</tr>
<tr>
<td>Grassland</td>
<td>Sheep</td>
<td>0.17</td>
</tr>
<tr>
<td>Pigs</td>
<td>Pig breeder</td>
<td>0.22</td>
</tr>
<tr>
<td>Pigs</td>
<td>Pig fattener</td>
<td>0.78</td>
</tr>
<tr>
<td>Poultry</td>
<td>Broilers and other hens</td>
<td>0.55</td>
</tr>
<tr>
<td>Poultry</td>
<td>Layers</td>
<td>0.22</td>
</tr>
<tr>
<td>Poultry</td>
<td>Other Poultry</td>
<td>0.23</td>
</tr>
</tbody>
</table>
10.5 Discussion of sector balances

The majority of the livestock balance in all UK countries is attributed to the grassland sector, representing 78% of the livestock N balance and 63% of the livestock P balance.

These sectorised balances formed the basis of disaggregation of the balance between regions. Thus the nutrient balance attributed to dairy cows was distributed pro rata according to the location of dairy cows within each country.

Relationship of balance to excretion

The calculated balances for pigs and poultry were similar to the calculated excretion of N and P, within the limits of accuracy of the method. For the grassland sector, the N balance significantly exceeded calculated excretion, while the P balance was substantially smaller. These discrepancies reflect the fact that this sector includes interaction with the land. Even if the farm gate balance were zero, the stock would still excrete nutrients – the excretion being balanced by nutrient intake from grass grazed. (This is the basis of the Soil Surface balance approach). In the method of calculation of Farm Gate sector balances within this project, inputs of manures other than those derived from grazing stock are not counted. Inclusion of these (i.e. pig and poultry manures) would increase the balance in the grazing sector. Some manures are transferred from the grazing sector to the arable sector. The N or P balance and excretion are therefore not identical within the grassland sector.

The partitioning of the balance into subsectors showed the dominance of dairying within the grassland sector, broilers within the poultry sector and fattening pigs within the pig sector.

Relationship of balance to expected livestock system efficiency

The results were compared with measured data from a range of livestock systems. In these systems, both excreta and ‘retained N’ (N converted to product) are positively correlated with N intake.

The average N utilisation efficiency for measured fattening pig systems was 50%, but the range was wide. The average efficiency derived from the balance at national level was around 36%, which is significantly smaller, but within the range of measured values. National averages often indicate a smaller efficiency than would be inferred from experimental data.
Within the dairy sector, measured N efficiencies vary with the N intake in feed. N output in milk increases only slightly with increased N input, the surplus N being largely excreted (Figure 10). Typical efficiencies observed for individual measured herds vary widely, most falling in the range 15-35%, with a mean of 26%. Observed efficiencies are smaller in the meat sector, at around 10-15%. The average N efficiency (offtake from farm as a proportion of total inputs) for the grassland sector was calculated from the UK N balance to be 17%, which is consistent with these data.
11 Spatial disaggregation (mapping) of balance

11.1 Approach

The sectorised balance developed above was apportioned between regions using indicative data from each country’s small area statistics. For example, the dairy nutrient surplus was divided by the total number of dairy cows recorded for that country, to give a value of surplus per dairy cow. If a region contained 1% of the national dairy herd, it was assumed to contain 1% of the national nutrient balance associated with dairying. The small area statistics were sometimes less detailed than national statistics, such that the indicator stock numbers might not represent the whole of the stock within a sector. The balance per head of stock should not therefore be taken literally, but rather as a value linked to the indicator statistic for the purpose of apportioning the balance.
11.2 Spatial data available

The small area statistics provided by Defra and the Devolved Administrations were less detailed than June Survey data, partly for reasons of avoiding disclosure. This was particularly true for Wales and Northern Ireland, especially as regards arable land uses.

The different levels of detail in each country necessitated aggregating the sector and crop balances in different ways. For simplicity two forms were used – detailed for England and Scotland, and less detailed for Wales and Northern Ireland.

Table 19. National totals of spatial data provided for regional balance estimation. 2004 (thousands). Note that Wales and N Ireland present certain data (e.g. total pigs) as grouped categories only.

<table>
<thead>
<tr>
<th>Census group</th>
<th>England</th>
<th>Wales</th>
<th>Scotland</th>
<th>N Ireland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy breeder</td>
<td>1374</td>
<td>380</td>
<td>197</td>
<td>288</td>
</tr>
<tr>
<td>Beef breeder</td>
<td>730</td>
<td>288</td>
<td>496</td>
<td>296</td>
</tr>
<tr>
<td>Other cattle and calves</td>
<td>3575</td>
<td>613</td>
<td>1271</td>
<td>1093</td>
</tr>
<tr>
<td>Sheep</td>
<td>15873</td>
<td>9737</td>
<td>8055</td>
<td>2225</td>
</tr>
<tr>
<td>Other Stock</td>
<td>78</td>
<td>37</td>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total pigs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pig breeder</td>
<td>425</td>
<td>49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pig fattener</td>
<td>3811</td>
<td>472</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total poultry</strong></td>
<td></td>
<td>8688</td>
<td>20509</td>
<td></td>
</tr>
<tr>
<td>Layers</td>
<td>29695</td>
<td>2945</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Broilers and other hens</td>
<td>87700</td>
<td>10721</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other poultry</td>
<td>3054</td>
<td>80</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total cereals</strong></td>
<td>40</td>
<td>38</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td>1865</td>
<td>102</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barley</td>
<td>643</td>
<td>316</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oats</td>
<td>80</td>
<td>21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Triticale and other grain</td>
<td>22</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potato</td>
<td>112</td>
<td>2</td>
<td>29</td>
<td>6</td>
</tr>
<tr>
<td><strong>Total other crops</strong></td>
<td>7</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sugar Beet</td>
<td>154</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oilseed rape</td>
<td>456</td>
<td>39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linseed</td>
<td>29</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peas-dried for animal consumption</td>
<td>61</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Field beans for animal consumption</td>
<td>175</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other arable crops</td>
<td>24</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total veg and fruit</strong></td>
<td></td>
<td>1</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Vegetables</td>
<td>112</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orchard fruit</td>
<td>22</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soft fruit</td>
<td>7</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Managed grass</td>
<td>3686</td>
<td>1117</td>
<td>1225</td>
<td>838</td>
</tr>
</tbody>
</table>

The sector and crop balances were divided by the corresponding number of stock or area of crop, to give a balance per head or per ha. These balances are indicative.
only, and depend on the way in which dairy cows, or laying hens, for example, were defined by those generating the regional statistics. In some cases – notably ‘other stock’, the types of stock reported varied between countries, and not all stock were represented. The coefficients in this case are necessarily somewhat arbitrary, since a balance calculated from all stock reported in the national June Survey data, is being shared among only a proportion of those stock.

11.3 Regional coefficients
The resulting coefficients are shown in the table below. Blanks indicate that that census group is not used in that country. Data are reported at a different level of detail. For example total pigs are used in Wales, but not in England, where instead pig breeders and pig fatteners are separately reported.
<table>
<thead>
<tr>
<th>Census Group</th>
<th>England</th>
<th>Wales</th>
<th>Scotland</th>
<th>N Ireland</th>
<th>England</th>
<th>Wales</th>
<th>Scotland</th>
<th>N Ireland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy breeder</td>
<td>104.2</td>
<td>68.3</td>
<td>117.4</td>
<td>134.6</td>
<td>10.3</td>
<td>7.0</td>
<td>15.7</td>
<td>12.7</td>
</tr>
<tr>
<td>Beef breeder</td>
<td>82.4</td>
<td>57.6</td>
<td>85.6</td>
<td>98.4</td>
<td>7.8</td>
<td>5.6</td>
<td>10.8</td>
<td>8.6</td>
</tr>
<tr>
<td>Other cattle and calves</td>
<td>23.4</td>
<td>29.2</td>
<td>25.3</td>
<td>31.4</td>
<td>2.0</td>
<td>2.7</td>
<td>3.0</td>
<td>2.7</td>
</tr>
<tr>
<td>Sheep</td>
<td>3.9</td>
<td>3.8</td>
<td>4.4</td>
<td>5.1</td>
<td>0.4</td>
<td>0.4</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td>Other Stock</td>
<td>65.6</td>
<td>17.1</td>
<td>15.9</td>
<td>0.0</td>
<td>13.7</td>
<td>3.9</td>
<td>4.4</td>
<td>0.0</td>
</tr>
<tr>
<td>Pigs</td>
<td>31.2</td>
<td>21.9</td>
<td>5.7</td>
<td>3.7</td>
<td>13.7</td>
<td>3.9</td>
<td>4.4</td>
<td>0.0</td>
</tr>
<tr>
<td>Pig breeder</td>
<td>28.7</td>
<td>0.0</td>
<td>27.1</td>
<td>0.0</td>
<td>6.5</td>
<td>0.0</td>
<td>6.3</td>
<td>0.0</td>
</tr>
<tr>
<td>Pig fattener</td>
<td>11.1</td>
<td>0.0</td>
<td>9.8</td>
<td>0.0</td>
<td>1.8</td>
<td>0.0</td>
<td>1.5</td>
<td>0.0</td>
</tr>
<tr>
<td>Poultry</td>
<td>1.9</td>
<td>2.0</td>
<td>0.4</td>
<td>0.5</td>
<td>1.8</td>
<td>0.0</td>
<td>0.4</td>
<td>0.0</td>
</tr>
<tr>
<td>Layers</td>
<td>0.8</td>
<td>0.0</td>
<td>1.0</td>
<td>0.0</td>
<td>0.2</td>
<td>0.0</td>
<td>0.2</td>
<td>0.0</td>
</tr>
<tr>
<td>Broilers and other hens</td>
<td>0.5</td>
<td>0.0</td>
<td>0.5</td>
<td>0.0</td>
<td>0.2</td>
<td>0.0</td>
<td>0.1</td>
<td>0.0</td>
</tr>
<tr>
<td>Other poultry</td>
<td>8.1</td>
<td>0.0</td>
<td>1.9</td>
<td>0.0</td>
<td>1.8</td>
<td>0.0</td>
<td>0.4</td>
<td>0.0</td>
</tr>
<tr>
<td>Total cereals</td>
<td>0.0</td>
<td>39.9</td>
<td>0.0</td>
<td>18.0</td>
<td>0.0</td>
<td>-4.7</td>
<td>0.0</td>
<td>-2.8</td>
</tr>
<tr>
<td>Wheat</td>
<td>26.2</td>
<td>0.0</td>
<td>-0.5</td>
<td>0.0</td>
<td>-10.4</td>
<td>0.0</td>
<td>-1.8</td>
<td>0.0</td>
</tr>
<tr>
<td>Barley</td>
<td>38.2</td>
<td>0.0</td>
<td>31.4</td>
<td>0.0</td>
<td>-3.2</td>
<td>0.0</td>
<td>6.6</td>
<td>0.0</td>
</tr>
<tr>
<td>Oats</td>
<td>3.8</td>
<td>0.0</td>
<td>-0.6</td>
<td>0.0</td>
<td>-3.5</td>
<td>0.0</td>
<td>2.9</td>
<td>0.0</td>
</tr>
<tr>
<td>Triticale and other grain</td>
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<td>0.0</td>
<td>5.7</td>
<td>0.0</td>
<td>-4.8</td>
<td>0.0</td>
<td>-1.9</td>
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<td>14.2</td>
<td>6.2</td>
<td>37.7</td>
<td>39.7</td>
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<td>0.0</td>
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<td>-18.2</td>
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<td>Sugar Beet</td>
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<td>109.1</td>
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<td>Linseed</td>
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<tr>
<td>Peas-dried for animal</td>
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<td>0.0</td>
<td>77.4</td>
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<td>0.0</td>
<td>-5.3</td>
<td>0.0</td>
</tr>
<tr>
<td>consumption</td>
<td></td>
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<td></td>
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<td></td>
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</tr>
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</table>
### N, kg per head or per ha

<table>
<thead>
<tr>
<th>Census Group</th>
<th>England</th>
<th>Wales</th>
<th>Scotland</th>
<th>N Ireland</th>
<th>England</th>
<th>Wales</th>
<th>Scotland</th>
<th>N Ireland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field beans for animal consumption</td>
<td>127.0</td>
<td>0.0</td>
<td>165.3</td>
<td>0.0</td>
<td>-7.7</td>
<td>0.0</td>
<td>-9.6</td>
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</tr>
<tr>
<td>Other arable crops</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>-1.7</td>
<td>0.0</td>
<td>-0.9</td>
<td>0.0</td>
</tr>
<tr>
<td>Total veg and fruit</td>
<td>0.0</td>
<td>25.5</td>
<td>0.0</td>
<td>79.4</td>
<td>0.0</td>
<td>5.4</td>
<td>0.0</td>
<td>10.7</td>
</tr>
<tr>
<td>Vegetables</td>
<td>58.4</td>
<td>0.0</td>
<td>31.9</td>
<td>0.0</td>
<td>12.6</td>
<td>0.0</td>
<td>13.6</td>
<td>0.0</td>
</tr>
<tr>
<td>Orchard fruit</td>
<td>39.9</td>
<td>0.0</td>
<td>0.9</td>
<td>0.0</td>
<td>6.0</td>
<td>0.0</td>
<td>0.1</td>
<td>0.0</td>
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<tr>
<td>Soft fruit</td>
<td>52.0</td>
<td>0.0</td>
<td>5.3</td>
<td>0.0</td>
<td>23.2</td>
<td>0.0</td>
<td>4.1</td>
<td>0.0</td>
</tr>
<tr>
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<td>2.5</td>
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<td>3.1</td>
<td>1.3</td>
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<td>0.2</td>
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### P, kg per head or per ha

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<th>Scotland</th>
<th>N Ireland</th>
<th>England</th>
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<th>Scotland</th>
<th>N Ireland</th>
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</thead>
<tbody>
<tr>
<td>Field beans for animal consumption</td>
<td>127.0</td>
<td>0.0</td>
<td>165.3</td>
<td>0.0</td>
<td>-7.7</td>
<td>0.0</td>
<td>-9.6</td>
<td>0.0</td>
</tr>
<tr>
<td>Other arable crops</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>-1.7</td>
<td>0.0</td>
<td>-0.9</td>
<td>0.0</td>
</tr>
<tr>
<td>Total veg and fruit</td>
<td>0.0</td>
<td>25.5</td>
<td>0.0</td>
<td>79.4</td>
<td>0.0</td>
<td>5.4</td>
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<td>10.7</td>
</tr>
<tr>
<td>Vegetables</td>
<td>58.4</td>
<td>0.0</td>
<td>31.9</td>
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<td>12.6</td>
<td>0.0</td>
<td>13.6</td>
<td>0.0</td>
</tr>
<tr>
<td>Orchard fruit</td>
<td>39.9</td>
<td>0.0</td>
<td>0.9</td>
<td>0.0</td>
<td>6.0</td>
<td>0.0</td>
<td>0.1</td>
<td>0.0</td>
</tr>
<tr>
<td>Soft fruit</td>
<td>52.0</td>
<td>0.0</td>
<td>5.3</td>
<td>0.0</td>
<td>23.2</td>
<td>0.0</td>
<td>4.1</td>
<td>0.0</td>
</tr>
<tr>
<td>Total managed agricultural land</td>
<td>4.8</td>
<td>2.3</td>
<td>2.5</td>
<td>0.8</td>
<td>3.1</td>
<td>1.3</td>
<td>1.4</td>
<td>0.2</td>
</tr>
</tbody>
</table>
11.4 Results and discussion

The results are shown by the maps below, reported per ha of managed agricultural land.

The regional maps illustrate the greater nutrient balance in areas of livestock farming. The balance is greater in lowland grazing systems than in arable areas. Balances are particularly great in Northern Ireland and in other areas with substantial dairying (Figure 14) reflecting the higher stocking densities (as kg/ha of excretal N or P) in dairy compared to beef or sheep systems. Pig and poultry systems have similar impact, where they occur, but the areas of concentrated pig or poultry production do not relate so clearly to agroclimatic zones.

The nutrient balance is generally small in upland areas because of the small inputs and low stocking densities. However, in some areas with substantial rough grazing, the balance per ha of managed agricultural land can be misleadingly large, since the stock which roam the upland rough grazing are all attributed to the limited area of managed land.

The national balances are based largely, although not entirely, on nationally reported data, although the coefficients are all generated at UK level. The regional balances are based solely on the national balance data, apportioned via regional land use and livestock numbers – they do not take account of any likely variation in practice between regions, chiefly because no data currently exist to make such adjustments. Even where regional data on, for example, yields exist, corresponding data on inputs do not. Adjusting only one component of the balance for regional variation would not necessarily improve accuracy, and might indeed create spurious variation. The regionalised balances should therefore be seen solely as aids to understanding regional variation in pressure on the environment arising from the relative amounts of different agricultural systems present.

Accuracy and precision

The disaggregated results are necessarily less precise than the national data, which, in turn, are less precise than the UK data. This is because of the many assumptions that have been made in order to distribute the balance spatially. (See section 8 for a fuller discussion of these issues).

The NUTS3 regions used for England are very small in urban areas. This leads to results that should not be taken at face value, since the disaggregation of agricultural statistics to very small areas is not robust. For example the offices of large pig or poultry holdings may be within an urban area with very little agricultural land, leading to misleadingly large values of the balance, when in reality the manure will be applied to agricultural land in the surrounding areas.

It would probably be preferable to amalgamate such very small areas into a national urban zone, the resulting coefficient being applied to all the spatially dispersed small areas, for mapping purposes. Agreement on this approach was however not reached within the project timespan.
Figure 12. Mapped regional N and P balance per ha of managed agricultural land across the UK, 2004.
Figure 13. Land use in the UK 2004. Harvested crops, Managed grassland and Total managed agricultural land, proportion.
Figure 14. Livestock densities in the UK 2004. Dairy breeders, Pigs and Poultry per ha managed agricultural land.
12 Relationship of balance to other environmental indicators

12.1 Commonality of source data and methodology

The core data sources used within these balance calculations are the same as those used for the majority of environmental models used for policy evidence within the UK. In particular, they are the same as those used within ADAS to run the policy-relevant models NEAP-N for nitrate (Lord & Anthony, 2000), PSYCHIC for P (Davison et al., 2008) and NARSES for ammonia (Webb & Misselbrook, 2004). The cropping and livestock data are based on Defra statistics, and integrated with other spatial data to provide a common agricultural land use map; and the manure and excretal coefficients are taken from the acknowledged sources used in support of policy. Thus, the results should be directly comparable with other policy evidence.

The environmental models take account of a number of factors and processes that the nutrient balances ignore – this is both a strength and a weakness of using such a balance. By intention balances are simple indicators, which are therefore less susceptible than model results to uncertainty caused by our incomplete understanding, and variation due to individual interpretations and assumptions. The balance can inform interpretation of water quality data and model outputs, and can indicate the extent to which one of the most readily measurable indicators of environmental risk is changing in the desired direction. However nutrient balances should ideally be used and interpreted in the context of other data, including cropping and livestock numbers, and climate; and with the outputs of the environmental models.

At field scale, within a given system, there is a clear relationship between nutrient inputs and nutrient emissions to the environment. Greater inputs create greater risk both of immediate loss (to air or water); and of subsequent loss due to enriched nutrient supply in the soil.

However the relationship between the balance and loss varies greatly between systems (Lord et al., 2002). Comparison of annual nutrient balance between different locations is not a reliable guide to magnitude of environmental problems such as gaseous emissions, nitrate concentrations in water, or P loss to water.

Arable crop systems generally have a smaller balance (N and P) than grassland systems; yet their losses of N and P to water are often greater, within a given climatic zone and soil type (e.g. Figure 15). Furthermore, concentrations of nitrate are greater in areas of lower rainfall, which are typical of arable systems. For this reason, nitrate concentrations in waters are greatest in the drier eastern areas of England and Scotland, despite the fact that the balance is greater in the intensive grazing areas of the wetter west. Nitrate Vulnerable Zone designations reflect this pattern (Figure 16).

Figure 16. Nitrate vulnerable zones, 2004.
The relationship between nutrient balance and loss to the environment is usually non-linear. Within a given system, the loss from land with a large balance is likely to be greater, per unit of balance, than from low balance farms. High-input systems tend to be less efficient, in terms of unit of output per unit of nutrient applied, than low-input systems. For example, in arable systems the rate of increase of nitrate loss with increase in N inputs is steepest at high inputs, while at inputs substantially below crop requirement, the gradient is generally small or negligible. Figure 18 shows the relationship developed from a large number of field experiments on cereal crops and grass. The points marked on the lines indicate the balances at zero input and at typical inputs for these two land uses. The graph shows how the same pattern occurs within livestock systems, and how at average inputs the balance is greater under grass than cereals, but the nitrate loss is smaller.
The net effect of all these confounding factors was explored for nitrate loss by Lord et al., (2002). Measured nitrate concentrations or loads in streams selected as being in agriculturally dominated catchments were found to show no correlation with the calculated nitrogen balance. The N balance was positively correlated with the proportion of grassland in the catchment while nitrate concentrations were positively correlated with the proportion of arable land. Within dominantly grassland catchments there was a positive correlation between nitrogen balance and nitrate concentration. This was not found for dominantly arable catchments, perhaps partly because the range of N inputs is narrower in arable than grassland systems.

One of the reasons for the different relationship in grassland and arable systems between balance and nitrate leaching is that substantial quantities of ammonium are lost from livestock excreta, leaving less of the surplus at risk of leaching. Ammonia emissions are in general positively correlated with balance. Ammonia emissions from arable land are generally small unless livestock manures have been applied. The NARSES national ammonia model (Webb & Misselbrook, 2004) shows a clear pattern of greater emissions in western areas, with their greater livestock numbers.
The relationships between P balance and P loss are equally complex. Incidental losses from applications of P fertiliser and, more importantly, manure will increase with inputs and with the balance. Large P balance sustained over many years will increase the P content of soil which increases the P concentrations in both runoff and sediment. However, concentrations in streams tend to be greater in arable land than grassland areas, despite the smaller balance, chiefly because losses of sediment (containing particulate P) are usually greater from arable land, due to cultivation and periods without crop cover. Losses of soluble P may be relatively high from grassland, arising largely from excreta. All these losses are greatly influenced by site and management factors. Since the quantities of P lost are small relative to quantities applied, any change in P loss due to management factors has rather little effect on the balance. Thus, the nutrient balance can affect the risk of loss under a given set of conditions, but site and management factors are often dominant in determining how much P is actually lost.
These examples illustrate the uses and limitations of the nutrient balance. It can identify areas of high general risk for nutrient loss, especially within a given system and set of climatic/soil conditions. It is less reliable in identifying the form of pollution, or the relative pollution risk from different systems. As one of a suite of indicators it can show progress towards reducing pollution risk, but its suitability for making comparisons between regions or countries is less certain.
13 Conclusions

The project has developed a general, updateable method for calculation of nutrient balances for UK agriculture. This work has drawn on several previous studies. The main improvements or innovations in this project include:

- Calculation method based on Farm Gate balance, to increase accuracy and responsiveness to changing practice
- The most detailed P balance to date
- Method provided for conversion to Soil Surface balance as required by OECD & Eurostat
- Calculation at national level (as well as UK totals)
- Regionalisation and mapping of the nutrient balance within countries
- Data entry, calculation and GIS systems, with documentation, created to facilitate future updating
- Assessment of uncertainty and bias
- Assessment of priorities for improvement
- Review of policy uses of the balance, and its relationship to other environmental indicators

We hope and intend that this provides a sound foundation for future improvements to the nutrient balance calculations.
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