Scoping Study to Determine Feasibility of Populating the Land Use Component of the LULUCF GHG Inventory

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Executive Summary

Project objectives

There is a need to protect and enhance the vast stocks of carbon (>10 billion tonnes) stored in UK soils, both to mitigate climate change through increased carbon sequestration in soils and to prevent potential climate change impacts resulting from soil carbon loss. To do this we need to be able to quantify, verify and report the emissions and removals of greenhouse gases (GHG) from soils as a result of land management practices and land use change.

The main tool used to (calculate and) report the greenhouse gas emissions and removals associated with changes in soil carbon is the Land Use, Land Use Change and Forestry (LULUCF) component of the UK GHG Inventory. The coverage of soil carbon fluxes in the inventory, particularly with respect to land management rather than land use change, is currently limited.

The aim of the project is to determine the feasibility of populating the land use component of the LULUCF GHG inventory. The research needs for this project are divided into four tasks:

1. Scoping the feasibility of populating the land use/management component of the LULUCF inventory in order to capture soil carbon fluxes associated with land management and associated greenhouse gas emissions and removals. This is the main focus of the project.
2. Exploration of the methodology for calculating emissions from the management and use of peatlands.
3. Improving the robustness and transparency of the methodology for calculating emissions from the extraction of peat for horticultural use.
4. Exploration of how to improve the methodology for the Land Use Change component of the inventory to address policy questions

Project methodology

Carbon stock changes and GHG emissions are reported in the LULUCF inventory following Intergovernmental Panel on Climate Change (IPCC) guidance. This is based on the availability of activity data (e.g. data on land areas and management system) and 'emission factors' (coefficients that relate the activity data to the amount of GHG emissions, e.g. carbon stock change per unit area). The IPCC guidance provides three methodological tiers: Tier 1 uses coarse activity data and default emission factors (EFs), Tier 2 uses higher-resolution activity data and country-specific EFs, and Tier 3 uses models and inventory measurement systems.

The data requirements and availability were assessed for each land management option for the three tiers. These are reported in a spreadsheet accompanying this report. This spreadsheet identifies existing activity data and emission factors (including default emission factors), describes data requirements where there is a lack of data, and identifies Tier 3 model options. It classifies each management option by priority and ease of inclusion, and identifies where inventory development is already in progress in the LULUCF inventory project or the Agricultural GHG Inventory Research Platform. The spreadsheet also identifies data for reporting land management activities which may be significant in the UK context (e.g. wetland restoration) but are not currently covered in the IPCC guidelines or where the guidelines do not take into account all greenhouse gas sources and sinks.

Options for reporting emissions from land management (Tasks 1 and 2)

123 land management options are listed and described in the spreadsheet. Only ten of these options are already reported in the inventory, with another two in progress (development under the current LULUCF inventory project).

The currently unreported options with the highest priority for inclusion (having potentially large fluxes affecting all countries of the UK) in the LULUCF inventory are:

- cropland and grassland management affecting carbon stock changes in mineral and organic soils, and
- wetland restoration from other land use types.

The cropland/grassland management options would take moderate effort to incorporate into the inventory at Tier 1 or 2 (meaning that 1-3 weeks' work is required to develop either activity data or emission factors). There is no default method for wetland restoration, and development of Tier 2 methods applicable to all countries of the UK would require significant additional work to process both activity data and emission factors, and possibly field data collection in some cases.

The options that would be easiest to incorporate into the inventory (where suitable activity data and emission factors already exist) are those affecting carbon stocks in woody biomass on croplands, e.g. orchards and perennial biomass crops, and grasslands, e.g. heather moorland and scrub. These options are of low to medium priority based on their size.

It was estimated that about half (59) of the currently unreported land management options could be reported at Tier 1 or 2 level given moderate effort to fill the data gaps, and an additional five options already reported could move to Tier 2 level with moderate effort. Besides the wetland restoration options, those concerned with Settlements and Flooded Lands will be most difficult to incorporate into inventory reporting, as UK research and data in these areas is limited. A move to Tier 3 reporting was generally considered to be more difficult, as it requires higher resolution data and detailed process understanding.

Not all land use activities that produce GHG emissions are covered by the IPCC guidance, but these may be of interest in the UK context. There is the potential to develop reporting for some non-CO2 emissions (N_2O emissions from N mineralisation on drained organic grassland soils, CH_4/N_2O emissions from re-wetting of organic soils and Removal of CH_4 from the atmosphere through management induced changes in grassland soils) with moderate effort.

Emissions from the management and use of peatlands (Task 2)

Management activities affecting wetlands/peatlands are not well-covered by the IPCC guidance. In the past two years there has been extensive compilation and analysis of research into peatlands in the context of climate change (both in terms of their resilience and their potential to act as GHG sources or sinks). This research is reviewed for its potential to contribute to improved reporting of peatland management emissions and removals in the LULUCF inventory.

A number of key problems still exist in estimating the GHG budget of UK peatlands, mostly due to the uncertainty surrounding the extent and state of peatlands and a lack of long term monitoring data investigating all aspects of the GHG budget (gaseous and fluvial fluxes and biomass transfer through livestock or harvesting). Emission factors specific to UK peatland types and management activities are currently lacking but research is underway to address this.

A literature review of peatland drainage was also undertaken, as this common land management activity on peatlands is known to generally produce large GHG emissions but is not well represented in the LULUCF inventory. Information on the past and current drainage status of all types of UK peatlands is patchy and regionalised. Evidence to allow the compilation of emission factors is similar patchy, as different fluxes vary in importance across drained and undrained peatlands of different types and management. This makes it difficult to quantify the potential GHG mitigation benefits of wetland restoration at local, regional and national scales. A measurement/monitoring programme of the type proposed by Evans *et al.* (2011) would address these gaps in evidence for UK contexts.

A new method for reporting on-site and off-site emissions from peat extraction in the UK (Task 3)

A new approach to reporting on-site and off-site emissions from commercial peat extraction has been developed for the UK (at the individual country level). This was used to produce the emissions reported in the most recent 1990-2009 LULUCF inventory. A number of data sources were explored for constructing a robust dataset on the location, extent and type of peat extraction in Great Britain and Northern Ireland. Three data sources were then used in combination to produce an activity dataset with areas of active peat extraction.

- The British Geological Survey (BGS) supplied the set of Great Britain peat extraction site records from the Directory of Mines and Quarries: this gives location, name, operator and council for currently active commercial extraction sites in England (54 sites), Scotland (26 sites) and Wales (2 sites). This Directory does not record the extent of the extraction area. It is updated every three to four years.

- Areas of peat extraction can be clearly seen on Google Earth satellite imagery (using the BGS point locations). The imagery has been taken at varying (but known) dates and coverage is not consistent across the UK.
- There is good information on peat extraction (for both horticultural and fuel use) in Northern Ireland from papers published in the scientific literature.

The total UK emissions reported for the UK in 2009 were 7.4 Gg CO_2 from on-site emissions, 274.6 Gg CO_2 from off-site emissions and 0.002 Gg N_2O from drainage on peat extraction sites. These numbers have declined considerably since 1990, due to the decline in the area of peat extraction. There was insufficient data on the extent of peat extraction for domestic use (in Scotland and Northern Ireland) to allow GHG estimates to be made for this activity. Domestic extraction could be significant in much localised areas, but ground survey would be required to estimate its extent. Further work is required to assess the extent and associated emissions of post-extraction restoration of cut-over peat to other land use types.

As part of the project, measurements were made of the carbon content of horticultural peat produced from the UK and Ireland which turned out to be higher than previous measurements used in inventory calculations. These will result in an increase on estimated off-site emissions. This will be used to refine the emission factors in subsequent inventories.

Land Use Change

The fourth task of the project was concerned with an exploration of how to improve the methodology for the land use change component of the LULUCF inventory to better account for land use changes. The following questions were considered: How can we track land parcels undergoing a series of land use changes in succession? What is the potential for moving to a geo-referenced tool? Does urbanisation really equate to a total loss of soil carbon? How can we include small scale land use changes that may be encouraged as mitigation measures, .e.g. buffer strips and field margins?

As this task was not intended as the main focus of the project, it is addressed by summarising relevant work in existing and completed projects and discussing issues to be taken into consideration in the development of further work in this area. The various options for more detailed representation of land use change in the LULUCF inventory are considered. A data assimilation approach of all available land use datasets is required to develop sufficient temporal and spatial resolution in tracking historic and present-day land use change, as no single dataset has sufficient resolution and coverage. A land use vector approach (using data assimilation) is in development, which will be able to represent the range of land use histories across an area over time (including crop-grass rotational land use).

Synergies with the Agriculture Sector inventory and the Agriculture GHG Research Platform are discussed: potentially these will increase consistency in the use of activity data between the two sectors and emissions from land management being estimated and reported in a more consistent way.

The fate of soil carbon after urbanisation was also reviewed: there is mixed evidence on the extent of loss but broad agreement that soil carbon stocks decline. It is difficult to derive large-scale estimates of soil C loss due to urbanisation as there is limited consensus on the C content of urban soils, and it is likely that the C content of suburban/garden soils has been underestimated. Soil sealing (where 100% loss could be assumed if all normal soil functions are removed) and topsoil removal/translocation also contribute to total losses, but further investigation is needed into the extent of such practices in a UK context.

1 Contents

2 Introduction

2.1 Context of project

There is a need to protect and enhance the vast stocks of carbon (>10 billion tonnes) stored in UK soils, both to mitigate climate change through increased carbon sequestration in soils and to prevent potential climate change impacts resulting from soil carbon loss. To do this we need to be able to quantify, verify and report the emissions and removals of greenhouse gases (GHG) from soils as a result of land management practices and land use change.

The main tool used to (calculate and) report the GHG emissions and removals associated with changes in soil carbon is the Land Use, Land Use Change and Forestry (LULUCF) component of the UK Greenhouse Gas Inventory. Whilst this has been designed to meet the UK's reporting obligations to the United Nations Framework Convention on Climate Change (UNFCCC) and to comply with Intergovernmental Panel on Climate Change (IPCC) guidelines, the inventory is now being adapted to function as a policy tool. However, the coverage of soil carbon fluxes in the inventory, particularly with respect to land management rather than land use change, is currently limited. There are many issues which need to be explored and overcome, such as the permanence of changes in soil carbon due to land management practices and the availability of data (particularly high resolution activity data).

2.2 Project objectives

The aim of the project is to determine the feasibility of populating the land use component of the Land Use, Land Use Change and Forestry (LULUCF) greenhouse gas inventory. The research needs for this project are divided into four tasks:

1. Scoping the feasibility of populating the land use/management component of the LULUCF inventory in order to capture soil carbon fluxes associated with land management and associated GHG emissions and removals. This is the main focus of the project.
2. Exploration of the methodology for calculating emissions from the management and use of peatlands.
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2.3 The IPCC and national greenhouse gas inventory reporting

There are many processes on land that can lead to emissions and removals of greenhouse gases, and these can be governed by both natural and anthropogenic factors. National GHG inventories are only concerned with anthropogenic emissions and removals, defined by the IPCC as those occurring on 'managed land' (in the LULUCF sector). Managed land is defined as 'land where human interventions and practices have been applied to perform production, ecological or social functions'.

The calculation of GHG emissions and removals is based on activity data and emission factors.

- Activity data: data on the magnitude of human activity resulting in emissions or removals taking place during a given period of time, e.g. data on land areas, management systems, fertilizer use
- Emission factor: a co-efficient that relates the activity data to the amount of chemical compound which is the source of later emissions, e.g. net carbon stock change in kg C ha^{-1} a^{-1}

The IPCC is responsible for the development of guidance on the calculation and reporting of national greenhouse gas emissions and removals. Guidance is developed by groups of nominated scientific experts from all over the world, which is then extensively reviewed before approval by the IPCC. When preparing inventory guidance, authors review the latest science and technological knowledge for the best methodologies and emission factors (which should be globally applicable). These are referred to as the default methods or emission factors. Where a better national method/emission factor is available for a specific sector the IPCC recommends it be used, provided that the national method is transparent and documented. The IPCC guidance assists countries in filling in the Common Reporting Format (CRF) tables used for reporting national emissions and removals for every year since 1990. Countries reporting annual GHG inventories to the UNFCCC are obliged to follow the IPCC guidance and inventories are regularly reviewed to ensure this.

There are six sectors used for reporting GHG emissions and removals in the national GHG inventory:

1. Energy
2. Industrial Processes
3. Solvent and Other Product Use
4. Agriculture
5. Land Use, Land Use Change and Forestry (LULUCF)
6. Waste.

The Agriculture and LULUCF sectors are closely linked (Table 1) but the LULUCF sector is the only sector where removals of carbon dioxide can be reported, as well as emissions of GHGs.

The Good Practice Guidance for LULUCF (2003) is currently followed when producing the LULUCF inventory. There are also the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. These contain similar methods but a different reporting structure, in which the LULUCF and Agriculture Sectors are brought together into the Agriculture, Forest and Other Land Use (AFOLU) sector. The 2006 Guidelines are not yet formally used, as the accompanying CRF tables are not yet operational, but inventory compilers are encouraged to make use of their updated methods and emission factors.

Net carbon stock changes (assumed to result in the emission or removal of carbon dioxide from the atmosphere) are calculated for the living biomass (above and below ground), dead organic matter (dead wood and litter) and soils carbon pools.

Table 1: Categories and gases in the Agriculture and LULUCF inventory sectors

Agriculture (CRF sector 4)	LULUCF (CRF sector 5)
4A Enteric Fermentation	*5A Forest Land*
CH_4 emissions from agricultural livestock	Carbon stock changes on forest land and emissions from fertilization, drainage and biomass burning
4B Manure Management	*5B Cropland*
CH_4 from animal manure and N_2O from manure storage	Carbon stock changes on cropland and emissions from land use conversion, liming and biomass burning.
4C Rice Cultivation	*5C Grassland*
Not relevant in the UK	Carbon stock changes on grassland and emissions from liming and biomass burning.
4D Agricultural Soils	*5D Wetlands*
Direct and indirect emissions of N_2O from agricultural soils	Carbon stock changes and emissions from peat production and areas converted to permanently flooded land (reservoirs)
4E Prescribed Burning of Savannas	*5E Settlements*
Not relevant in the UK	Carbon stock changes on settlement land and emissions from biomass burning.
4F Field Burning of Agricultural Residues	*5F Other Land*
Non-CO_2 emissions from on-site burning of crop residues and agricultural waste	Areas that do not fall into the other land categories (no emissions are reported in the UK)
4G Other	*5G Other*
No emissions reported in the UK under this category	Changes in carbon stocks in harvested wood products

The IPCC guidance provides three methodological tiers for estimating greenhouse gas emissions and removals:

- Tier 1 employs the basic method and default emission factors (global or biome-level) published in the IPCC Good Practice Guidance for LULUCF (2003). Tier 1 methodologies usually use activity data that are spatially coarse, i.e. national or global level estimates.
- Tier 2 use the same methodological approaches as Tier 1 but applies region- or country-specific emission factors and higher-resolution activity data.
- Tier 3 methods use models and inventory measurement systems tailored to national circumstances, repeated over time, driven by high-resolution activity data and disaggregated to sub-national level.

In general, moving to higher tiers improves inventory accuracy and reduces uncertainty but the complexity and resources required also increases. A combination of tiers can be used in inventory reporting.

2 Options for reporting emissions from land management (Task 1)

2.1 Current inventory coverage of land management options

There are six land use categories in the LULUCF sector: Forest Land (F), Cropland (C), Grassland (G), Wetlands (W), Settlements (S) and Other Land (O). Each category is split into an *xLand* remaining *xLand* category and a Land converted to *xLand* category. These are denoted as Cropland remaining Cropland (CC) etc. or Grassland converted to Cropland (GC) etc. The key gaps (where there are no estimates of emissions) in current inventory reporting are listed below. There are also some geographical gaps in activity data, principally for Northern Ireland.

- Carbon stock changes in non-forest living biomass (perennial woody biomass) in CC, GG and SS categories
- Carbon stock changes in non-forest dead organic matter
- Carbon stock changes in soils due to land use management in CC, GG and SS categories
- Separate reporting of carbon stock changes in organic soils under land use change
- Greenhouse gas emissions from drainage (Forests and Wetlands, as drainage of agricultural land is reported in the Agricultural sector)
- N_2O emissions from disturbance associated with land use conversion to Cropland[1]
- Greenhouse gas emissions from non-forest biomass burning (e.g. moorland burning)
- Greenhouse gas emissions from land converted to Wetland for peat extraction[2]
- Greenhouse gas emissions from Wetland converted to other land uses (restoration)

[1] Now included in the LULUCF inventory (from 2009 inventory onwards)
[2] Now included in the LULUCF inventory from 2009 inventory onwards, based on work undertaken in this project

- Greenhouse gas emissions associated with flooded land (reservoirs, gravel pits, managed coastal retreat)

There is an ongoing development programme under the existing LULUCF inventory project funded by DECC (2009-2012). This allows for the integration of new data, methods and activities. The programme for development work is agreed by the project scientific steering committee (composed of stakeholders, inventory compilers and invited scientific experts), based on external reviews and stakeholder priorities.

In the 1990-2009 national GHG inventory (MacCarthy *et al.* 2011) the Forest Land category was split between Land converted to Forest Land, and Forest remaining Forest Land using a 20 year conversion period (as recommended by a UN expert review team). We intend to use the same approach for the Cropland, Grassland and Settlement categories in the 1990-2010 inventory[3]. There will be no overall change in the emissions reported at the category level. Such an approach will make it easier to separate out the effects of historical land use change and to reconcile area information between the inventory and those reported in agricultural surveys. It will also be conceptually simpler to report the effects of land use management in e.g. the Cropland remaining Cropland category than in the Land converted to Cropland category (which included all land converted to Cropland since 1950).

Gaps in the IPCC methodologies were also identified during the assessment of gaps in the current LULUCF inventory. These include:

- Removal of N_2O and CH_4 from the atmosphere by land management activities
- N_2O emissions from land management activities other than fertilisation and drainage
- Rewetting of previously drained wetlands for restoration purposes
- The fate of soil carbon entering water courses: at present it is assumed to be emitted back to the atmosphere as CO_2, but may be transferred or deposited elsewhere.
- Emissions resulting from wind farm construction (agreement is needed on whether this is a conversion to Settlement, Other Land or even Grassland (if the majority of the area is still used for grazing).
- Carbon stock changes in soils due to rotational land management practices, i.e. where the management practice involves regular land use change between cropland and grassland within the 20 year conversion period.

These gaps may exist because the scientific understanding of the area is still developing or the activity is only significant over a small area at the global scale. In the case of wetlands, the IPCC is preparing supplementary guidance which will be published in 2013.

2.2 Methodology for task 1

The data requirements and availability are assessed for each land management option for the three tiers. These are reported in a spreadsheet accompanying this report. This spreadsheet identifies existing activity data and emission factors (including default emission factors), describes data requirements where there is a lack of data, and identifies Tier 3

[3] This was implemented for the 1990-2010 inventory

model options. It identifies where inventory development is already in progress in the LULUCF inventory project or the Agricultural UK GHG Platform project. Each management option is classified according to how easy it would be to include in the LULUCF inventory and by priority for inclusion (based on the estimated size of emissions/removals compared to those from activities already included in the LULUCF inventory).

For each of the reporting tiers the following are identified:

- The feasibility of populating the land use component of the inventory, and the method that could be used.
- Methodological development requirements, including data collection and model requirements
- Significant gaps in scientific knowledge and whether there is already UK relevant research in place to address them.
- Data requirements (including scale) and whether this data is available and how key gaps could be filled (including the potential for using earth observation data).
- Data requirements for generating UK or regional specific emission factors.
- Associated risks and sources of uncertainty.

In addition to the 3 methodological tiers described above, a fourth scenario investigates the feasibility of reporting land management activities which may be significant in the UK context (e.g. peatland restoration) but are not currently covered in the IPCC guidelines or where the guidelines do not take into account all greenhouse gas sources and sinks.

2.2.1 The Options spreadsheet

The land management options considered under the project are listed in the Microsoft Excel workbook accompanying this report. Land management activities which can be reported in the LULUCF inventory (i.e. IPCC guidance exists) are described on the 'IPCC activities' sheet. The attributes of these land management options are described in Table 2.

Table 2 : Attribute descriptions of the land management options

Column heading	Description
Option ID	Each option is numbered and these are cross-referenced in section 2.3.
Peatland management	Whether this activity also comes under Task 2 (management and use of peatlands)
Land use category	Top-level CRF category, e.g. 5B Cropland
Sub-category	CRF Sub-category, e.g. Cropland remaining Cropland
Activity	Inventory activity category, e.g. carbon stock changes in mineral soils

Default method exists?	Is a Tier 1 default method described in the GPG-LULUCF (2003) or IPCC 2006 Guidelines?
Reported?	Is this activity reported in latest inventory (1990-2009)?
Land management option	Option name e.g. crop yield improvement
Tier 1 default emission factors	Emission factor described in GPG-LULUCF (2003) or IPCC 2006 Guidelines
Tier 2 emission factors	UK-specific emission factors (may be split by region, management type and specialised land-use category) with reference.
Existing Tier 1 activity data	Dataset name, spatial/temporal scales, time period (e.g. since 1990?), level of detail. e.g. areas of crop types in the June Agricultural Survey, published annually since before 1990, publically available at DA level
Tier 1 activity data requirements if not already used	Description of dataset requirements: Scale (national/DA-level), units (area or volume), frequency of collection
Existing Tier 2 activity data	Scales, time period, level of detail. e.g. regional level statistics
Tier 2 activity data requirements	Scale (regional), units (area or volume), frequency of collection
Existing Tier 3 activity data	Scales, time period, level of detail. e.g. soil databases, Countryside Survey, IACS
Tier 3 activity data requirements	Scale (high-resolution parcel or raster), units, regular collection, detailed categorisation
Tier 3 model modifications required	Which models are available? How much modification would be required to calculate emissions?
Additional comments	Any changes between GPG-LULUCF and IPCC 2006 Guidelines, other comments
Priority (size and sign)	Priority for inclusion in the inventory: • High (large GHG flux, affecting all DAs) • Medium (medium-high GHG flux, affecting some DAs) • Low (minor GHG flux) • + (generally a source)

	• - (generally a sink) • +/-(variable, can be source or sink) • ~ (unknown)
Priority (inclusion)	• Not currently reported • In progress (under development programme of current LULUCF inventory project) • Already reported
Ease of inclusion (for each Tier)	How much work is required to include the land management option in inventory reporting at each Tier level: • No default method (Tier 1 only) • Assumed zero carbon stock change (Tier 1 only) • Easy - activity data and EFs already exist and only require minor processing (< 1 week's work) • Moderate - significant additional work required to process activity data or EFs for inclusion (1-3 weeks' work) • Difficult - significant additional work required to process both activity data and EFs (>3 weeks work) • Very difficult – activity data or EFs do not currently exist and require collection (>6 months work) • In progress (under development programme of current LULUCF project) • Already reported at that Tier level

The activities described on the 'Non-IPCC activities' sheet are:

1. Non-CO_2 emissions from organic soils
   - N_2O emissions from organic nitrogen mineralisation on drained grassland soils
   - CH_4/N_2O emissions from re-wetting of organic soils (incl. drain blocking)
2. Removal of CH_4 from the atmosphere through management induced changes in grassland soils
3. CO_2 emissions from liming of non-agricultural land
4. Soil carbon entering water courses
5. Emissions from wind farm construction

These are described in section 2.3.24.

2.3 Summary of land management options

2.3.1 Forest carbon stock changes in living biomass/dead biomass (options 1, 2).

Priority (size): High (-)

Priority (inclusion): Already reported

Ease of inclusion:

- *Tier 3- Already reported and further development in progress*

These activities are currently reported in detail using a Tier 3 model (CFlow). More detailed modelling of species and management options is being developed by Forest Research under the existing LULUCF inventory development programme.

2.3.2 Forest carbon stock changes in mineral and organic soils (options 3, 4).

Priority (size): High (+/-)

Priority (inclusion): Already reported

Ease of inclusion:

- *Tier 3- Already reported*

Soil carbon stock changes are currently estimated using the CFlow model (Tier 3), which takes account of fluxes caused by (i) soil disturbance during planting and harvesting and (ii) carbon flows from the trees through the soil. More detailed information is required on the effects of afforestation on different soil types and the role of previous land use history on soil carbon stock changes. The CFlow model currently assumes that, after the initial disturbance caused by afforestation, inputs to the soil carbon stock pool exceed losses, resulting in a net gain of soil carbon. Estimates of soil carbon stock changes could be improved, either by updating the soil carbon modules of CFlow (or the Forest Research model CARBINE) to include the initial soil carbon content and better process modelling, or by linking into other soil carbon models e.g. Roth-C, ECOSSE, and YASSO.

2.3.3 N_2O emissions from forest fertilization (option 20)

Priority (size): Low (+)

Priority (inclusion): Already reported

Ease of inclusion:

- *Already reported at Tier 1*

Nitrogen fertilizer is not applied to established forests in the UK (personal communication, Forestry Commission). Fertilizer is applied to some newly forested land but this is reported under the sub-category ‘Land converted to Forest’ (not considered here as this task is concerned with land management not land conversion).

2.3.4 Forest N_2O emissions due to drainage (options 21, 22)

Priority (size): Medium (+)

Priority (inclusion): In progress

Ease of inclusion:

- *Tier 1-In progress,*
- *Tier 2- Difficult*
- *Tier 3- Very Difficult*

Activity data on the extent of drainage in forest land is required to report at Tier 1. This is being addressed by Forest Research in the existing LULUCF inventory development programme.

2.3.5 Cropland carbon stock changes in living biomass/dead organic matter (options 5a-c, 6a-b)

Priority (size): Low (– or ~) - it is estimated that the GHG flux will be minor compared with fluxes reported already

Priority (inclusion): Not currently reported

Ease of inclusion:

- *Tier 1 Easy- for carbon stock changes in above-ground woody biomass (orchards), zero carbon stock change is assumed for dead organic matter ;*
- *Tier 2 Moderate – for dead organic matters and for other perennial crops e.g. miscanthus grass*
- *Tier 3 Difficult- Tier 3 models exist for perennial biomass crops but additional research would be required to obtain suitable emission factors*

Carbon stock changes in living biomass due to crop yield increases (agronomy) are already reported at Tier 2 in the LULUCF inventory. This can also generate higher dead organic matter and soil C inputs (see below). Where crop yield increases are due to improved fertilizer nitrogen use efficiency, there can also be associated lower emissions of N_2O, but these changes will be accounted for in the Agriculture sector inventory. The Agricultural Inventory Research Platform (Defra project AC0114 on Data synthesis, modelling and management) is scoping data sources to improve reporting in this area.

There is currently no reporting of carbon stock changes in woody biomass in cropland, e.g. in orchards, although a default IPCC method exists. Tier 1 reporting could be easily implemented for all countries of the UK, using activity data (area under land use published in the June Agricultural Survey) and default factors from the IPCC (aboveground biomass). Tier 2 reporting requires more detailed information on each type of perennial crop grown in each region of the UK, such as information on the area under each crop type, carbon stock changes in different crops and management regimes for the different crop types. These carbon stock changes could be obtainable from the scientific literature and the national inventory reports of other European countries; however literature data may be sparse as this is considered a low priority area.

Carbon stock changes in perennial biomass crops, e.g. miscanthus grass, are not considered in the LULUCF inventory, but could be reported under permanent crops in a similar way to orchards. Energy crops are expected to have biomass carbon sequestration potential (depending on the preceding land use; St Clair et al., 2008; Hillier et al., 2009) but the current area under energy crops is very small. While some activity data exists, as well as Tier 3 models, this is an area where detailed UK estimates could be developed, but it would require an expansion in the number of studies trialling the potential growth and carbon storage of perennial biomass crops across the UK. The emissions associated with the production of energy crops (e.g. petrol emissions during harvesting, GHG emissions associated with fertiliser applications) would be implicitly included in the appropriate sectors of the GHG inventory (e.g. Energy, Agriculture).

2.3.6 Cropland carbon stock changes in mineral soils (options 7a-n)

Priority (size): High (+ or +/-)

Priority (inclusion): Not currently reported

Ease of inclusion:

- *Tier 1/Tier 2 Moderate(requires more detailed land cover information)*
- *Tier 3 Moderate (There are many existing models which are being run spatially at fine resolution for the whole UK. Some model evaluation would be required to demonstrate the adequacy of the models and driving data. Many other countries (e.g. USA, Canada, Australia, Japan) have tier 3 modelling frameworks to track and project soil C change in mineral soils.)*

Carbon stock changes in mineral soils due to cropland management are not currently reported. For Tier 1/ Tier 2 reporting in the LULUCF inventory the activity data (area of land under each land management type) is required and can be obtained from agricultural survey statistics and land management scheme information. Changes in cropland management may also influence N_2O and CH_4 emissions from soils, which require accounting for in the Agriculture sector inventory. The Defra AC0114 project will be assessing the existing evidence and the extent to which such emissions might be accounted for in the Agriculture sector inventory, and will also be scoping data sources for land and manure management practice throughout the UK, which could be used to bring reporting up to Tier 2 level. It is important therefore that common activity data are used across the LULUCF and Agriculture sector inventories to ensure consistent accounting of all GHG emissions associated with cropland management on mineral soils.

Smith *et al.* (2008) reported the per area mitigation potential of different cropland management practices in Great Britain (Table 3). These are based on the mitigation factors derived for cool – moist climatic regions from the IPCC Fourth Assessment Report (Chapter 8: Global Agricultural Mitigation Potential, 2008), and are not UK-specific. The estimates represent annual soil carbon change rate for a 20 year time horizon in the top 30cm of the soil. The factors used were derived from mineral soils (<5% SOC), and in the absence of adequate data for organo-mineral soils (defined here as 5 – 12 % SOC), are assumed also to apply to organo-mineral soils. In general these management practices lead to a reduction in the amount of the three GHG gases released into the atmosphere. Fitton *et al*. (2011) found that in terms of total UK GHG emissions even the highest calculated mitigation strategies will only account for 1.5 % of current emissions, however the GHG savings are significant compared to the current small LULUCF sink in GB.

Inclusion of these different land management practices, which will benefit both the LULUCF and Agriculture Inventory, requires more detailed information on land use and soil type, as for example developed under Defra project SP0567 (Assembling UK-wide data on soils carbon (and greenhouse gas fluxes) in the context of land management, Defra, 2006), although much of this information is not currently available for use due to data licensing conditions. For reporting at Tier 2 level the Defra AC0114 project will be scoping data sources for land and manure management practice throughout the UK, could be used to bring reporting up to Tier 2 level.

Table 3: Per-area annual mitigation potentials for each management practice for individual and all GHGs (Source: Smith *et al*. 2008)

		CO_2 ($t\ CO_2\ ha^{-1}\ y^{-1}$)			CH_4 ($t\ CO_2$-eq. $ha^{-1}\ y^{-1}$)			N_2O ($t\ CO_2$-eq. $ha^{-1}\ y^{-1}$)			All GHG ($t\ CO_2$-eq. $ha^{-1}\ y^{-1}$)		
Activity	**Practice**	*Mean Estimate*	*Low*	*High*	*Mean Estimate*	*Low*	*High*	*Mean Estimate*	*Low*	*High*	*Mean Estimate*	*Low*	*High*
Cropland	Agronomy	0.88	0.51	1.25	n/a	n/a	n/a	0.10	0.00	0.20	0.98	0.51	1.45
Cropland	Nutrient Management	0.55	0.01	1.10	n/a	n/a	n/a	0.07	0.01	0.32	0.62	0.02	1.42
Cropland	Tillage and residue management	0.51	0.00	1.03	n/a	n/a	n/a	0.02	-0.04	0.09	0.53	-0.04	1.12
Cropland	Set-aside	3.04	1.17	4.91	0.02	n/a	n/a	2.30	0.00	4.60	5.36	1.17	9.51
Cropland	Agro-forestry	0.51	0.00	1.03	n/a	n/a	n/a	0.02	-0.04	0.09	0.53	-0.04	1.12
Grassland	Grazing, fertilization, fire	0.81	0.11	1.50	n/a	n/a	n/a	n/a	n/a	n/a	0.80	0.11	1.50

Notes: The estimates represent average change in soil carbon stocks (CO_2) or emissions of N_2O and CH_4 on a per hectare basis. Positive values represent CO_2 uptake which increases the soil carbon stock, or a reduction in emissions of N_2O and CH_4. N/A means mitigation potential is not available.

2.3.7 Cropland carbon stock changes in organic soils (see also section 4) (option 8)

Priority (size): Medium (+)

Priority (inclusion): Not currently reported

Ease of inclusion:

- *Tier 1 Moderate (requires area of land where drainage occurs for Scotland, Wales and Northern Ireland)*
- *Tier 2/Tier 3 Moderate (Currently reported under Tier 2 for England, requires the relevant activity such as detailed land cover information and relevant emission factors for Scotland, Wales and Northern Ireland)*

Emissions from historical drainage of the English fens are reported in the LULUCF inventory (Tier 2); however as there is no matching activity data for Scotland, Wales and Northern Ireland, emissions from historic drainage of organic soils are not reported for these countries. The Natural England peatland condition maps (Natural England, 2010) are a more recent source of information on the extent and state of different peatlands in England, and the current Defra project (SP1210 "Lowland peatland systems in England and Wales-evaluating greenhouse gas fluxes and carbon balances", reporting in 2016) on lowland bogs in England and Wales may also produce information on areas and emissions. However, use of these sources will mainly allow improvements in the reporting of emissions from England. Compiling similar data for Scotland, Wales and Northern Ireland is more difficult, although some relevant information is available, for example Annex 1 sets out an example of information on Scottish lowland bogs in the British Geological Survey library. These data could be used to make an equivalent assessment of condition of cultivated peats to that produced by Natural England. The Defra AC0114 project will be mapping the extent and condition of artificial soil drainage for UK agricultural land, primarily for use in an improved Agriculture sector inventory in which soil drainage status may be a parameter influencing the estimate of N_2O emissions from agricultural soils. However, such data could be combined with soil maps to assess the extent and condition of drainage on cropland organic soils, providing an improved activity data source for the estimate of C stock changes from drained organic soils. Again, this highlights the importance of using common activity data across the LULUCF and Agriculture sector inventories.

The emission factors in this area require improvement. Bradley (1997) reported carbon loss rates from 'thick' and 'thin' cultivated peats in England , which bracket the IPCC default emission factor of 5 tC ha^{-1} yr^{-1}. Natural England is of the opinion that the 'thick' peat emission factor is too high, and the value for England probably lies between the currently used value and the IPCC default value (Thompson 2010). Further work is needed to develop more accurate Tier 2 emissions factors for the UK countries: the Defra-funded SP1210 project aims to report emission factors for lowland bogs and fens for England and Wales in 2016.

2.3.8 Grassland Carbon stock changes in living biomass/dead organic matter (options 9-10)

Priority (size): Medium (- or ~)

Priority (inclusion): Not currently reported

Ease of inclusion:

- *Tier 1 Assumed zero carbon stock change*
- *Tier 2 Easy*
- *Tier 3 Difficult*

No reporting is required at Tier 1 level, as carbon stocks in living biomass and dead organic matter are assumed by the IPCC to remain stable on grassland. There is potential to develop country-specific Tier 2 reporting, taking account of the carbon stocks in perennial vegetation, e.g. heather moorland and scrub, and how these are affected by management, e.g. controlled burning and grazing. The carbon stocks in hedgerows could also be taken into account here (although these do not fall into a single land use category). Further work is required to develop suitable carbon stock change factors, but it is thought that this can be largely done by a desk-based literature review, rather than requiring additional field measurements.

2.3.9 Grassland Carbon stock changes in mineral soils (options 11a-e)

Priority (size): High (+/-)

Priority (inclusion): Not currently reported

Ease of inclusion:

- *Tier 1/Tier 2 Moderate*
- *Tier 3 Difficult*

Carbon stock changes in mineral soils due to grassland management are not currently reported. If suitable activity data could be developed from data assimilation of agricultural survey statistics and land management scheme information then Tier 2 reporting could be established. This would make use of the soil carbon contents and stock changes under different land use types reported by Defra project SP0567 (these stock changes due to LUC were at a more detailed level than the LULUCF inventory). The Defra AC0114 project will be scoping data sources for land and manure management practice throughout the UK, which could be used to bring reporting up to Tier 2 level.

Smith *et al*. (2008) also report annual mitigation potentials for grassland management (Table 3), although these are not UK-specific (see above).

2.3.10 Grassland Carbon stock changes in organic soils (see also section 4) (options 12a-g)

Priority (size): High (+/- or ~)

Priority (inclusion): Not currently reported

Ease of inclusion:

- *Tier 1 Easy (England)/ Moderate (requires area of land where drainage occurs for Scotland, Wales and Northern Ireland)*
- *Tier 2/Tier 3 Very Difficult (additional research required to establish region-specific emission factors)*

Emissions from drainage on organic grassland soils are not currently reported. The Natural England peatland condition maps (Natural England 2010) contain data on the extent of gripped peatlands in England which could be used as activity data for emission calculations. There are not equivalent data for Scotland, Wales and Northern Ireland. The Defra AC0114 project will be mapping the extent and condition of artificial soil drainage for UK agricultural land, which could be combined with soil maps to assess the extent and condition of drainage on lowland grassland organic soils (see section 2.3.7).

Use of the IPCC Tier 1 default emission factor (a constant value of 0.25 tC ha^{-1} yr^{-1}) will either result in (1) an over-estimate of carbon stock changes on organic soils if drainage ditches/grips do not remain in good condition and their efficiency for removing fluvial carbon decreases over time, or (2) an under-estimate if drainage triggers an erosive phase of rapid carbon removal and loss. Evidence exists for both these processes in UK peatlands (Lindsay, 2010), which are dependent on the balance between rainfall and runoff in different parts of the UK. Additional research combining both emission losses to the atmosphere and fluvial losses to the aquatic system is required to establish Tier 2 emission factors (the Defra-funded project SP1205 “Greenhouse gas emissions associated with non-gaseous losses of carbon- fate of particulate and dissolved carbon” will start to address this for England and Wales).

2.3.11 Cropland/Grassland CO_2 emissions from liming (options 27a-b, 28a-b)

Priority (size): Low (+)

Priority (inclusion): Already reported

Ease of inclusion:

- *Tier 1 Already reported*
- *Tier 2 Moderate*

Emissions are reported at Tier 2 level, based on the annual amount of lime sold for agricultural purposes in the UK and UK-specific emission factors for dolomite and limestone. The LULUCF inventory uses lime production statistics from the Annual Minerals Raised Inquiry (ONS 2010) and information from the British Survey of Fertiliser Practice (BSFP 2010) on agricultural areas receiving lime applications. The lime production data are currently aggregated for commercial sensitivity and region-specific reporting could be improved if this region-specific data was made available.

2.3.12 Wetlands[4] (peat extraction) carbon stock changes in living biomass/dead organic matter (options 13-14)

Priority (size): Low (+ or ~)

Priority (inclusion): Not currently reported

Ease of inclusion:

- *Tier 1 Assumed zero carbon stock change*
- *Tier 2 Moderate*

This refers to the changes in biomass carbon stocks after ground clearance for conversion to peat extraction. Through the examination of extraction site directories and aerial photography (see section 5 for details) there is no evidence that anything but very small areas (in the Somerset Levels) have been converted to peat extraction since 1990.Location data could be compared with Land Cover Map (1990 or 2000) to assess the previous ground cover. This would enable reporting at Tier 2 level.

Due to the nature of peat soils, it is not possible to separate dead organic matter from soil in this category. Carbon stock changes in dead organic matter will be implicitly reported with carbon stock changes in soils.

2.3.13 Wetlands (peat extraction) carbon stock changes in soils (option 15)

Priority (size): Medium (+)

Priority (inclusion): Already reported

Ease of inclusion:

[4] The IPCC definition of Wetlands includes any land that is covered or saturated by water for all or part of the year, and that does not fall into the Forest Land, Cropland or Grassland categories. Only emissions from managed wetlands are considered in the GHG inventory, defined as being where the water table has been artificially changed (e.g. drained or raised) or created through human activity (e.g. damming a river). The IPCC provides methodologies for peat extraction and for reservoirs (permanently Flooded Land).

- *Tier 1 Already reported*
- *Tier 2 Moderate*
- *Tier 3 Very Difficult*

This refers to the carbon stock changes in soils as a result of peat extraction activities. On-site emissions (from extraction activities) and off-site emissions (from the decomposition of horticultural peat) are already reported at Tier 1 level. Higher level reporting would require improved country-specific emission factors related to peat extraction methods and site management (e.g. the stockpiling of peat on site), as the activity data on the area of extraction is already largely available.

2.3.14 Wetlands Non-CO_2 GHG emissions from drainage (options 23-24)

Priority (size): Medium (+)

Priority (inclusion): Not currently reported

Ease of inclusion:

- *Tier 1 No default method*
- *Tier 2 Moderate/Difficult*
- *Tier 3 Very Difficult*

Methane is produced during organic matter decomposition under anaerobic conditions (i.e. below the water table), but much of this methane is consumed by methanotrophic bacteria within the soil before it can be emitted to the atmosphere. Vegetation plays an important role in the proportion of CH_4 which reaches the atmosphere. Aerenchymous vegetation provides a transport pathway from below the water table to the atmosphere bypassing the surface aerobic zone. In contrast, *Sphagnum* mosses, through symbiotic methanotrophic bacteria living in the Hyaline cells, are capable of recycling large amounts of CH_4 , therefore a significant amount of the CH_4 produced in the anaerobic zone may be re-used before it ever reaches the atmosphere (Raghoebarsing *et al.* 2005). As with many microbial processes, the rate of methanogenesis and methanotrophy are both influenced by temperature. Hence important factors in the net CH_4 emission include water table depth, water table variability (as methonogens are destroyed by aerobic conditions), temperature and vegetation. The primary effects of drainage are lowered water tables, reducing the anaerobic zone suitable for methanogenesis, increasing the methane oxidising aerobic layer, and changing the vegetation community.

The relationship between CH_4 emissions and water table has in practise been difficult to summarise and although various studies have attempted to model the relationship between CH_4 and water table, most have been based on natural water table variability rather than directly on the effects of artificial drainage. Whether these relationships hold on artificially drained sites is still unclear (see examples within Lindsey 2010) as the time scales over which the water table is drawn-down is likely to have a large impact on the methanogenic community and the subsequent CH_4 emission. Although most studies show a significant reduction in CH_4, the magnitude of this reduction is not always easily predictable. For example, Dinsmore *et al.* (2009) found water table was only a significant factor in CH_4 emission in chambers where aerenchymous vegetation was not present. CH_4 emissions are also extremely variable across sites due to microtopography and much of the total catchment emission may originate from specific hotspots within the landscape. McNamara *et al.* (2008) showed that gullies covering only 9.3% of the catchment area contributed 95.8% of the net CH_4 flux. In a similar way to gullies, drainage ditches are likely to represent significant hotspots within drained catchments. Therefore areal coverage of drains, or drain spacing is likely to be an extremely important factor in predicting total CH_4 emission from drained wetlands.

Natural England (2010) estimate that ~24% of English deep peats and 39% of deep fen peats are currently under cultivation, they also estimate 11% of deep peats are gripped (shallow drains), and mostly on blanket bog (21%). Bussell *et al.* (2010) conducted a review of the literature (not UK specific, only UK site included was Cerrig yr Wyn in Plynlimon, mid-Wales) considering the role of drainage in GHG emissions. They concluded from a total of 13 studies that drained peat had an emission rate ~8 mg CH_4 m^{-2} d^{-1} less than intact peatlands. They also found that this effect correlated well with greater water table depth and pH and that the effect was larger in fens than bogs. They also used 8 studies to consider the effect on N_2O and found a net increase in N_2O emissions of ~133 µg N_2O m^{-2} d^{-1} in drained compared to intact peatlands; no significant difference was observed between bogs and fens. A recent meta-analysis of UK flux chamber measurements for CH_4 emission (21 sites) (Levy *et al. 2012*) calculated an effect of +0.8 (± 0.28 SE) nmol CH_4 m^{-2} s^{-1} (or +0.4 g CH_4 m^{-2} y^{-1}) per cm increase in water table. The potential drawback of the meta-analysis is the assumption that the long-term effect of water table manipulation is the same as the relationship observed in natural variations. Natural England calculated emission factors for gripped blanket bog/raised bog and shallow peaty soils in England of 0.2 and 0.73 t CO_2-eq $ha^{-}1$ yr^{-1} (based on the Durham Carbon Model (Worrall 2010) and IPCC tier 1 emission factors, respectively) and GHG emissions of -0.01 and 0.01 Mt CO_2-eq y^{-1} for English blanket bog/raised bog and shallow peaty soils, respectively. The report also states however that more data is required to develop a more accurate picture of emissions.

Because of the high spatial variability reported in CH_4 emission studies (e.g. Bartlett and Harriss, 1993; Waddington and Roulet, 1996; Dinsmore *et al.*, 2009), upscaling from traditional chamber methods has always been an issue when estimating catchment or landscape scale fluxes of CH_4 and N_2O. Recent technological advances have allowed CH_4 fluxes to be measured using micrometeorological methods which will give a much more spatially integrated emissions estimate and may provide better measurements for future model validation. Hence our ability to devise emission estimates for CH_4 is likely to greatly improve in the future. Current projects looking at CH_4 emissions from drained UK peatlands include GHG-Europe and CEH Carbon Catchments which are jointly funding work in the Forsinard Reserve in Northern Scotland, and a National Trust peat restoration pilot study in Llyn Serw (Wales) run by Centre for Ecology & Hydrology in Bangor. The work being undertaken at the Forsinard Reserve will utilise both micrometeorological and static chamber methods to compare GHG fluxes across unmanaged, drained and restoration catchments over the next 2-3 years. The Llyn Serw study is a five year field experiment to evaluate the effects of peat restoration on the GHG balance.

2.3.15 Wetlands – emissions from flooded lands (options 25-26)

Priority (size): Low (+, affects small area)

Priority (inclusion): Not currently reported

Ease of inclusion:

- *Tier 1 No default method*
- *Tier 2/Tier 3 Very Difficult (would require field-based research to establish suitable UK emission factors as existing research biased towards Canada and Brazil)*

The IPCC discusses emissions from Flooded Lands (see footnote 4 above), defined as 'water bodies where human activities have caused changes in the amount of surface area covered by water, typically through water level regulation'. In the UK context, this refers to reservoirs for hydroelectricity and water storage.

There are 2 main phases in the GHG emissions from flooded land/reservoirs. The initial phase (which lasts up to ~10 years) where recently flooded labile organic matter decomposes, and a second more steady state phase where the reservoir is likely to act in a similar way to that of comparable freshwater lakes. Labile carbon can be sourced from the surrounding catchment, transported via soil water processes or stream discharge, or produced *in situ* via phytoplankton and primary production (Rosa 2004; Abril *et al.* 2005). The transformation of particulate and dissolved organic carbon, as well as direct GHG inputs, lead to water-atmosphere concentration gradients and evasion of GHGs from the water surface. In-situ production, which has been identified as a source of reservoir organic matter in the tropics, is less likely to be important in UK reservoirs where temperatures are much lower; low pH peatland waters may also restrict *in situ* processing. UK reservoirs also tend to be narrow and deep (Lindsey *et al.* 2010) which again may limit primary production.

The emissions during the initial phase are largely dependent on the catchment characteristics prior to flooding. The creation of reservoirs in peatland areas in particular, due to their large store of organic carbon, may lead to significant sources of GHGs (Louis *et* *al.* 2000). The abundance of blanket peat in UK upland areas means much of the carbon processed within UK reservoirs is likely to be of peat origin. A study on Finnish reservoirs (Huttunen *et al.* 2002) found no significant difference between reservoirs created on either a forest mineral soil or peat soil. However, both were old reservoirs (created in early 1970's) and therefore much of the labile carbon was likely to have been decomposed already. The differences between the reservoirs on different soil types are therefore likely to be limited to the year's post-flooding. This illustrates the importance of age-specific emission factors for GHG accounting.

An important factor in both methanogenesis and denitrification is the oxygen content of the reservoir: Fearnside (2005) showed this was influenced by water residence time and the input of fresh oxygenated water. CH_4 emissions increase with greater residence time (Fearnside 2005) and may be temporally dynamic throughout the year because of this, i.e. there will be higher CH_4 emissions during dry seasons (Abril *et al.* 2005).

Pathways for GHG losses include:

a) diffusive emission from the water surface which can be measured *in-situ* using floating chamber methods or calculated from water-atmosphere concentration gradients and gas transfer coefficients;

b) bubble ebullition, which is of particular importance for CH_4 because it has a very low solubility in water; or

c) evasive loss at the outflow or spillway.

Bubble ebullition can be measured using bubble traps though it is difficult to accurately upscale, due to spatial variability and the importance of specific ebullition events (in peatlands these events can be triggered by low air pressure, and a similar mechanism may influence reservoir emissions). Evasive losses at the outflows represent a significant challenge in terms of measurement as traditional chamber methods cannot be deployed in fast moving water and gas transfer coefficients at this water volume are again difficult to measure/estimate. Furthermore, the position of dam outlets far below the water surface means that CH_4 rich hypolimnion water is exported. The sudden pressure drop, low solubility of CH_4 and high turbulence at the outlet leads to significant degassing. Guérin and Abril (2007) estimate two thirds of CH_4 is lost through degassing at the outflow turbine. The Canadian Hydro-Québec study, which considered GHG emissions from Eastman 1 Reservoir, found CH_4 emissions represented < 1% of total GHG emissions (Tremblay *et al.* 2010). The catchment area only contained ~14% peat so this may not be representative of the typical upland catchment for UK reservoirs. N_2O emissions are generally low unless there is a significant source of N from the catchment i.e. through agricultural inputs.

Reservoir emission studies have so far been biased towards Canada and Brazil and no known studies have been carried out within the UK. Factors that may be needed to estimate total reservoir CH_4 and N_2O emissions include: areal extent of UK reservoirs; individual reservoir size, inflow and outflow discharges used to calculate water residence time; time since initial flooding; catchment land-use including N inputs; and catchment soil type which will influence the early stage emissions and the labile carbon inputs. Water temperature, nutrient status and pH of individual reservoirs may also help categorise reservoirs to more specific emission factors. Significant further work is still required to estimate suitable emissions factors for UK reservoirs, which may not be properly represented by current international studies. A current Defra-funded project SP1205 considering the downstream fate of peat derived carbon will begin to consider reservoir carbon dynamics, however as reservoirs make up only a small part of project it will not decisively establish emission factors that can be utilised for upscaled emission estimates.

2.3.16 Settlements Carbon stock changes in living biomass/dead organic matter (options 16-17)

Priority (size): Medium (~)

Priority (inclusion): Not currently reported

Ease of inclusion:

- *Tier 1 No default method*
- *Tier 2 Difficult*
- *Tier 3 Very Difficult*

There is no default method for this activity as the IPCC assumption is that there is no change in carbon stocks in live biomass in long-established settlement land. Some relevant activity data exists at Tier 2 level but additional work would be needed to develop equivalent emission factors (e.g. biomass carbon densities in different UK settlement types).

2.3.17 Settlements carbon stock changes in soils (see also section 7.3) (option 18)

Priority (size): Medium (~)

Priority (inclusion): Not currently reported

Ease of inclusion:

- *Tier 1 No default method*
- *Tier 2 Difficult*
- *Tier 3 Very Difficult*

No emissions are reported for this activity in the inventory (carbon stock changes are assumed to be zero in the IPCC default method). There is potential Tier 2 activity data available on urban tree planting and development on urban/suburban green space but suitable equivalent emission factors are lacking.

2.3.18 Other Land carbon stock changes (option 19)

The IPCC defines the Other Land category as including bare soil, rock, ice and all land areas that do not fall into any of the other five land-use categories. Areas are reported to act as a check on the overall area at a country level, but it is assumed that there are no human-induced GHG emissions associated with the Other Land category.

2.3.19 Restoration after peat extraction (options 34a-r)

Priority (size): Low (+/- or ~)

Priority (inclusion): Not currently reported

Ease of inclusion:

- *Tier 1 Assumed zero carbon stock change*
- *Tier 2 Moderate*
- *Tier 3 Moderate (Forest biomass and dead organic matter)/Difficult/Very Difficult (soils and non-forest biomass)*

Restoration of peat extraction sites will result in carbon stock changes in biomass and soils. Work to enhance the peat extraction activity dataset has established the location of extraction sites that have been active since 2002 (see section 5 for methodology) but it is not possible to consistently extend this data set back to 1990. Those sites that are no longer known to be active could be inferred to be abandoned or restored, in which case their subsequent land use could be established from land cover datasets or remote sensing imagery.

2.3.20 Other wetland restoration (options 35a-o)

Priority (size): Medium/High (~)

Priority (inclusion): Not currently reported

Ease of inclusion:

- *Tier 1 No default method*
- *Tier 2/Tier 3 Difficult/Very Difficult (due to the lack of baseline data on pre-restoration peatlands and large uncertainties regarding the size and direction of change of GHG emissions)*

See review in section 3

2.3.21 GHG emissions from controlled biomass burning (non-peatlands) (options 29a-f)

Priority (size): Low (+)

Priority (inclusion): Not currently reported

Ease of inclusion:

- *Tier 1/Tier 2 Moderate*

Controlled burning for forest management does not occur in the UK. Burning of agricultural residues is reported under the Agriculture sector inventory. Emissions from biomass burning of woody biomass during conversion to settlement are currently reported, but this is being re-examined, as burning is contrary to the UK's forest certification scheme for sustainable woodland management. Emissions from upland heather and grass biomass burning on non-peatlands are included in the discussion in section 2.3.22.

2.3.22 GHG emissions from controlled biomass burning on peatlands (options 31a-f)

Priority (size): Medium (+)

Priority (inclusion): Not currently reported

Ease of inclusion:

- *Tier 1 Moderate (data available for England and Scotland)*
- *Tier 2 Difficult (would require compilation of burn licence data)*
- *Tier 3 Very Difficult*

There is little data available to assess the burn extent either of controlled or wild fire on UK peatlands although Natural England (2010) estimated 16% of all English deep peats are rotationally burnt, including 30% of a blanket bogs (this equates to 1088 km^2 and 1066 km^2 for deep peat and blanket bog, respectively). Burnhill *et al.* (1991) used satellite imagery to estimate that 870 km^2 in Scotland and 1106 km^2 in England were managed for burning (although significant underestimation was likely in Scotland due to poor satellite coverage and cloud cover. This estimate was based on an assumption of heather cover >50% was managed by burning. Merrington *et al.* (2010) estimated 3,150 km^2 of UK peatland was subject to burning.

Current advice on burning regulations are given by 'The Heather and Grass Burning Code 2007 Version' by Natural England, 'The Muirburn Code' by the Scottish Government Rural Affairs Dept., 'The Heather and Grass etc. Burning (Wales) Regulations 2008' and through the Department of Agriculture and Rural Development Northern Ireland. There is potential to utilise these guidelines to determine areas where burning could potentially take place at a national scale; assuming a fixed percent of controlled burn where control burn is legal may produce a reasonable national controlled burn extent estimate. Significant work would be required to calculate this and the uncertainty is still likely to be very large. Further information may be gained from applications for burn licences through Natural England, Scottish Natural Heritage, the Welsh Government or the Northern Ireland Environment Agency.

Carbon losses due to burning are achieved either directly via combustion or indirectly through erosion, vegetation change or reduced carbon accumulation post-fire due to vegetation removal (Turetsky *et al.* 2002; Lindsey 2010). Current studies show contradictory results on CH_4 emissions (Gray, 2006; Farage *et al.,* 2009) and overall loss of carbon (Farage *et al.*, 2009; Ward *et al.* 2007), although studies are generally biased towards the English Pennine peatlands which may not be representative of UK peatlands as a whole. Natural England (2010) have estimated emission factors for GHG emissions from rotationally burnt blanket bog/raised bog of 2.56 t CO_2-eq ha^{-1} yr^{-1} from a simplified version of Durham's Carbon Model (Worrall *et al.* 2010). They also estimate an annual GHG emission of 0.26 Mt CO_2-eq y^{-1} from English rotationally burnt blanket bog/raised peat. Not enough information exists to calculate reliable national emission factors for the UK, but it may be possible to report for individual countries. PhD research on peatland fires in Scotland is currently being carried out by Emily Taylor (University of Edinburgh).

2.3.23 GHG emissions from wildfires biomass burning (options 30a-f, 32a-f, 33a-f)

Priority (size): Medium (+)

Priority (inclusion): Not currently reported

Ease of inclusion:

- *Tier 1 Moderate*
- *Tier 2 Difficult*
- *Tier 3 Very Difficult*

GHG emissions from forest wildfires are already reported at Tier 1 level, but there is no activity data on wildfires in the other land use categories. Work to improve activity data is currently planned under the current DECC-funded LULUCF inventory project. This will be particularly relevant to wildfires on forest land and grassland and controlled burning on grassland (for game or grazing management on moorland). As with controlled biomass burning (section 2.3.22), there is currently insufficient information available on emission factors to accurately assess GHG emissions from wildfires.

2.3.24 Options not covered under the IPCC methodology

The IPCC guidance follows an inflexible hierarchy: there are some emission-producing activities of interest in the UK context that are not included, either because they are not relevant in a global context (occurring in only a few countries) or because there is insufficient understanding of the activity. Consequently, there are no identifiable ‘slots’ for these activities within the existing reporting structure and changes in emissions from these activities will not be recorded in the annual inventories.

Emission-producing activities not covered by the existing structure include:

1. Non-CO_2 emissions from organic soils
    - N_2O emissions from organic nitrogen mineralisation on drained grassland soils
    - CH_4/N_2O emissions from re-wetting of organic soils (incl. drain blocking)
2. Removal of CH_4 from the atmosphere through management induced changes in grassland soils
3. CO_2 emissions from liming of non-agricultural land
4. Soil carbon entering water courses
5. Emissions from wind farm construction

Activity data could be developed for the first two activities from the existing activity data for estimating soil carbon stock changes. Some emission factors for these activities are available from field research, (e.g. from the NitroEurope programme http://www.nitroeurope.eu) but would require further compilation to produce consistent national/regional emission factors. For the third activity, any emissions from liming of non-agricultural land are likely to be very small and already included under emissions from Cropland or Grassland. Defra are currently funding a project relevant to the fourth option: "Greenhouse gas emissions associated with non gaseous losses of carbon from peatlands - fate of particulate and dissolved carbon" (SP1205). Potentially the carbon transferred to water has already been accounted for in the calculation of soil carbon stock changes, but greater understanding of this pathway is required to take account of storage in fluvial or coastal sediments or conversion into methane. Finally, there is the issue of where to record emissions associated with wind farm construction, particularly where these occur on peatlands. The final land use category is likely to fit best under the Settlement category, but the land surrounding the hard standing is likely to have some other land use, e.g. grazing. Work by Nayak et al. (2010) provides a suitable starting point for emissions calculations in this activity.

2.4 Summary

A total of 123 land management options are listed and described in the spreadsheet, 117 of which fall within the IPCC structure. Sixteen of these are already reported or work is in progress on their reporting.

The unreported options with the highest priority for inclusion (having potentially large fluxes affecting all countries of the UK) in the LULUCF inventory are cropland and grassland management options which affect carbon stock changes in mineral and organic soils and wetland restoration options. The cropland/grassland soil carbon stock change options would take moderate effort to incorporate into the inventory at Tier 1 or 2 (meaning that 1-3 weeks' work is required to develop either activity data or emission factors). There is no default method for wetland restoration, and development of Tier 2 methods applicable to all countries of the UK would require significant additional work to process both activity data and emission factors, and possibly field data collection in some cases.

The options that would be easiest to incorporate into the inventory (where suitable activity data and emission factors already exist) are those affecting carbon stocks in woody biomass on croplands, e.g. orchards and perennial biomass crops, and grasslands, e.g. heather moorland and scrub. The options that would be most difficult to incorporate into inventory reporting, besides wetland restoration options, are those concerned with Settlements and Flooded Lands, as UK research and data in these areas is limited.

Half of the land management options (59) could be reported at Tier 1 or 2 level given moderate effort to fill the data gaps. A move to Tier 3 reporting was generally considered to be more difficult, as it requires higher resolution data and detailed process understanding.

3 Review of UK peatland information and greenhouse gas emissions (Task 2)

3.1 Introduction

On a global level it has been estimated that peatlands contain approximately one third of the terrestrial carbon pool (Gorham, 1991). The ability of peatlands to retain their C stores and also remain as a C sink is affected by land management and also climate and therefore has important implications for the UK terrestrial carbon inventory (Billett *et al.*, 2010). Numerous studies, for example the Natural England commissioned report: England's peatlands: Carbon storage and greenhouse gases (Natural England, 2010), have attempted to determine the carbon stock of UK peatlands and establish their sink/source capacity in relation to GHG emissions, however, published estimates are still subject to considerable uncertainty. Peatlands are defined as: 'ecosystems with a peat deposit that may currently support vegetation that is peat forming, may not, or may lack vegetation entirely. Peat is dead and partially decomposed plant remains that have accumulated *in situ* under waterlogged conditions' (Ramsar Convention, 1971). It is estimated that peatlands cover between 17,000 and 18,000 km^2 of the total UK land area and, while this may represent a small proportion of total land area (c. 7%), they are a potentially large store of carbon. The stability of this store is under threat due to pressures such as climate change, atmospheric deposition and disturbance. As a consequence peatlands are subject to intensive study to investigate their carbon stock, sink/source status, condition, extent and the impact of management and restoration activities. This report summarises information relevant to estimations of GHG emissions from reviews by Natural England, the IUCN and JNCC (Natural England, 2010; Worrall *et al*. 2010; Worrall *et al*. 2011; JNCC, 2011) and lists the main information gaps for GHG reporting. A proposed programme to address these evidence gaps was set out by Evans *et al.* (2011) as part of the JNCC review project.

3.2 Carbon stock of UK peatlands

Information on the type and extent of different peatlands are inferred from national surveys of peat soil or vegetation, maps of soil, vegetation, and geology and other environmental function, research experimental sites and monitoring schemes (JNCC, 2011). Peatlands tend to be classified into three types (JNCC, 2011):

- Deep peaty soils: Areas covered with a majority of peat >40cm deep
- Shallow peaty soils: Areas with a majority of soils with peat 10 – 40cm deep
- Soils with peaty pockets: Areas of mostly non-peat soils, supporting smaller pockets of deep peat

These classifications, and subsequent mapping in the UK, have evolved from the Avery soil classification system (1980); however, different thresholds have been applied in the different countries of the UK (Figure 1). This subsequently creates problems in developing a common understanding of the extent of each peatland type and their carbon stock; and making like for like comparisons (Table 4).

Natural England (2010) and Estimating Carbon in Organic Soils Sequestration and Emission report (ECOSSE, Smith *et al*., 2007) attempted to gather current information and derive new estimates for the amount of carbon stored in organic soils in England, Scotland and Wales (Table 4). Northern Ireland is estimated to have approximately 4,298 km^2 of peatlands, containing approximately 0.168 MtC (Cruickshank *et al*., 1998; Bradley *et al*., 2005). However, as well as uncertainty surrounding the area of peatlands, other sources of error in C reporting include estimations of peat depth and bulk density.

Estimates of soil C stock in peatlands have assumed 1m depth of peat, which lead to an underestimation of soil C (Natural England, 2010). The recent ECOSSE report found that soil C estimates for Scotland and Wales increased by over 30% and 20%, respectively when organic material below 1m was included. Many of the UK's peatlands are mosaics of wetland habitats and have gradual transitions between soil types. However, soil maps, which aim to delineate areas that are relatively similar, tend not to have extensive soil sampling (JNCC, 2011). As a consequence measured values such as bulk density, which can change with depth and soil type, can be unrepresentative of an area, producing a large source of error in C stock estimations. Furthermore, where more detailed maps are available, they tend to be at 1:250000 scale and at this scale map units are likely to encompass a variety of peaty and non-peaty soils (JNCC, 2011). Finally, in some cases the data sources are over 25 years old (Natural England, 2010) and there is a need to update information with a comprehensive national survey.

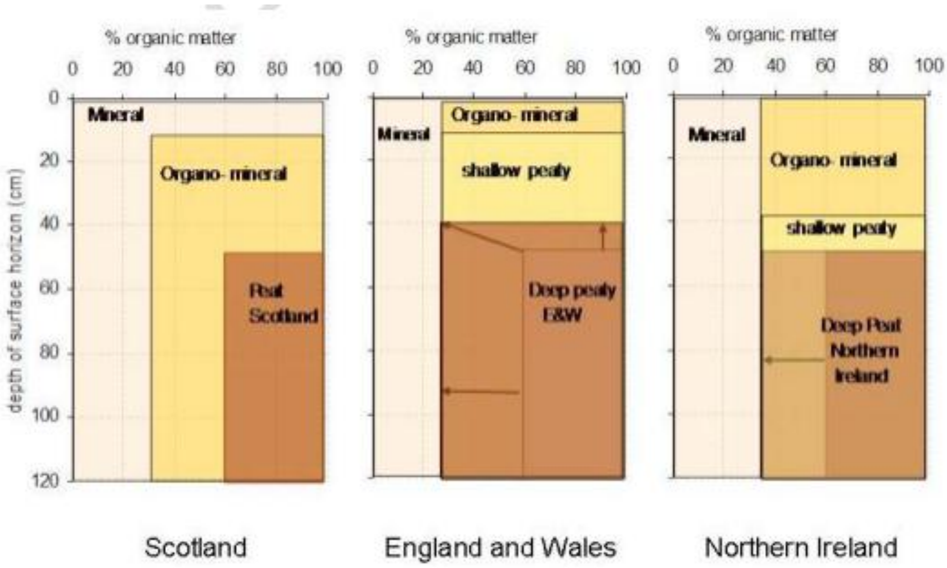


Figure 1: Minimum depth and organic matter content (%) threshold used for differentiation between mineral, peaty (organo-mineral) and peat soil in Scotland, England and Wales, and Northern Ireland soil classification and in the British Geological Survey (BGS) superficial geological material classification (JNCC, 2011).

Table 4: The area and estimated carbon stock of organic and organo-mineral soils for England, Scotland and Wales.

Region	Area km^2	Carbon Stock <1m MtC	Carbon Stock >1m MtC	Total carbon stock MtC
England				
Blanket bog and upland valley mire	3553	n/a	n/a	138
Raised bog (upland and lowland)	357	n/a	n/a	58
Lowland fen (deep)	958	n/a	n/a	144
Lowland fens (waste)	1922	n/a	n/a	186
Shallow peaty soils	5272	n/a	n/a	59
Soils with scattered pockets of deep peat	2114	n/a	n/a	n/a

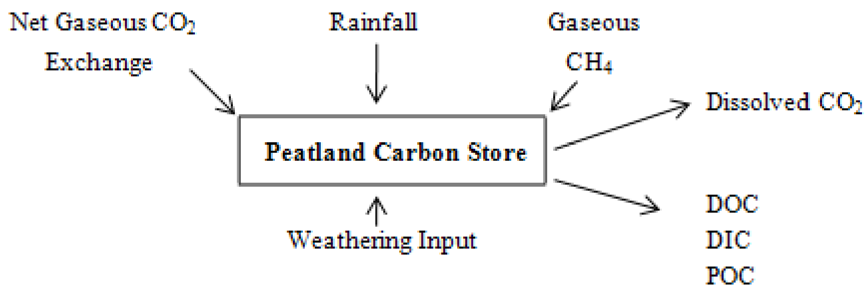
Region	Area km²	Carbon Stock <1m MtC	Carbon Stock >1m MtC	Total carbon stock MtC
Wales				
Peat soils	706	70	52	121
Humic rankers	281	4	0	4
Podzols*	166	5	0	5
Stagnopodzols*	1564	25	0	25
Stagnohumic gleys*	1552	40	0	40
Humic gleys*	29	0.3	0	0.3
Scotland				
Basin peat	838	58	66	124
Blanket peat	7980	799	286	1085
Semi-confined peat	5423	435	134	569
Humus iron podzol*	8495	78	0	78
Peaty podzol*	12240	325	0	325
Subalpine podzol*	3891	79	0	79
Alpine podzol*	516	17	0	17
Peaty gley*	17157	385	0	385
Humic gley*	79	16	0	16
Peaty ranker*	697	35	0	35
Lithosol*	33	3	0	3
Peat alluvium*	n/a	21	0	21

**Indicates that soil type is organo-mineral. Adapted from: JNCC, 2011; Natural England, 2010; Smith et al., 2007; Worrall et al., 2011*

3.3 Greenhouse gas (GHG) budgets

For a peatland ecosystem carbon is cycled between the atmosphere and the vegetation surface through photosynthesis and respiration. Peat accumulates when the input of organic material from the surface exceeds the ability of soil organisms to turn over the new material added from the surface (JNCC, 2011). In general peatlands have two distinct layers: a deep oxygen-poor layer termed the catotelm layer and a near-surface oxygen-rich layer termed the actotelm layer (Charman, 2002). Anaerobic decomposition in the catotelm layer and oxidation in the acrotelm layer leads to the emission of CH_4. Of the principal fluxes from peatland ecosystem (Figure 2) CO_2 fluxes and dissolved organic carbon (DOC) are the best studied, with limited information existing for CH_4, particulate organic carbon (POC), dissolved organic carbon (DIC) and dissolved CO_2 and N_2O. To date there are few studies that have attempted to estimate the complete GHG budget of peatlands. Recent reviews (Worrall *et al*., 2010, 2011) summarise the published and 'grey' literature evidence on the C and GHG budgets of pristine peatlands, in order to provide a baseline against which management impacts can be assessed. Table 5 summarises the studies of GHG budgets of peatlands in the UK; however each study had limitations. Worrall *et al.* (2003; 2009a) constructed a C budget for the Trout Beck blanket peatland catchment at Moor House in the North Pennines. The C budget proposed by Worrall *et al.* (2003) did not consider all uptake and release pathways; in the updated and revised budget Worrall *et al*. (2009) reported that the 13 year average C budget for Trout Beck was -56 tonnes C km^{-2} yr^{-1}, i.e. the catchment was acting as a sink C. However, this catchment has been significantly affected by management.

Figure 2 : Principal fluxes from organic soils for an intact peatland. *Source Worrall et al. 2010*



Other estimations of the C budget of pristine peatlands have been submitted for publication (Rowson *et al*. 2010; Clay *et al*. 2010). Rowson *et al*. (2010) monitored two control plots at Hexhamshire Millstone Grit in north-east England, one dominated by *Eriophorium* sp. and the second dominated by shrubs, which differed in their sink/source status (Table 5). Similarly Clay *et al*. (2010) considered the GHG budget of a peatland dominated by *Calluna vulgaris in the Northern Pennines*, are a considerable source of C. As a consequence, while peatlands are a potentially large store of C they still have the potential to act as a sink or source of C (Worrall *et al.* 2010).

Many northern hemisphere peatlands have suffered from disturbances such as drainage, agricultural improvement, peat cutting and afforestation, burning and increased atmospheric nutrient deposition, which can significantly alter C cycling in peatlands (Roulet *et al*., 2007). Therefore it is important to know the condition and use of peatlands in the UK. Table 6 provides estimates of the extent and trends designated UK Biodiversity Action Plan (BAP) sites, where 3 yearly reporting is required. This survey did not extend to the entire peatland area in the UK and further information has come from different datasets, which were obtained to fill specific policy requirements, making combination problematic. As a consequence there is little direct information on the trends and changes in peatlands (JNCC 2011).

Another significant source of information is the Defra project SP0556 peatland compendium of UK peat restoration and management projects (Table 7; Defra 2008). The compendium contains details on 145 UK restoration and management projects: of these 56 were analysed in detail and include information on the site condition, project objectives, initial site conditions, restoration/management targets and methods and future plans. Approximately half the management projects surveyed in the peatland compendium was involved with one or more peatland types and the dominant peatland type, based on area, was blanket bogs. The presence of a conservation status for peatland sites, such as SSSI's PSA targets, was a major driver of management projects and in general the priority for stakeholders was the restoration of ecological and hydrological function. Carbon storage was used as a justification in 62% of the surveyed sites but in only three cases it was considered extremely important. The peatland compendium also compiled scores on the initial and current site condition (**Table 8**) for each peatland project from 0 for totally for unsuccessful to 100 for completely successful however the perception on peatland condition is dependent on the stakeholders.

Table 5: Estimated C balance for pristine peatlands in the UK. ***Source: Worrall et al. 2011***

Site	**Auchencorth Moss**		**Moor House**		**Moor House (Hard Hill)**			**Bleaklow (a)**[3]		**Bleaklow (b)**	
Source	**Billett *et al.* (2004)**	**Dinsmore *et al.* (2010)**	**Worrall *et al.* (2009)**[1]		**Clay *et al.* (2010)**[2]			**Rowson *et al.* (2010)**			
Year	**1996/8**	**2006/7**	**1998**	**1999**	**2005**	**2006**	**2007**	**2007**	**2008**	**2007**	**2008**
NEE	-28	-115									
PP			-164	-178	-112	-111	-109	-229	-238	-148	-154
NER			52	54	204	176	203	137	118	104	88
CH_4	4.1	0.1	7	6	5.8	5.5	5.7	0.7	0.7	0.7	0.7
DOC	27	25	66	12	49	66	66	13	23	96	96
Rainfall DOC[4]	-3.1	-1.4									
POC	1.4	3.6	16	14	14	18	18	1.9	3.4	21	38
Diss. CO_2	5.5	14	10	5	2.4	3.4	2.2	0.5	2.2	0.5	2.2
Diss. CH_4	0.01	0.01									
Total, t C $km^{-2} yr^{-1}$	7	-70	-13	-87	163	158	186	-76	-90	74	72
Total, t CO_2-e $km^{-2} yr^{-1}$	*97*	*-352*	*88*	*-203*	*291*	*279*	*313*	*-61*	*-75*	*99*	*86*

1 Worrall et al. (2009a) considered 13 years and so maximum and minimum values are given
2 Clay et al. (2010) consider a range of management types, the numbers presented here are from the unmanaged control plots.
3 Rowson et al. (2010) consider two pristine sites where a) us Eriophorium dominated and b) is shrub dominated
4 It is not always necessary to measure rainfall inputs of DOC, if DOC is calculated at source

Table 6: Extent and trend of peat forming vegetation Priority Habitats in UK. ***Source: JNCC 2011.***

UK BAP Priority Habitat	*Area (km²)*	*Summary trend*
Blanket Bog	22085	Declining (slowly)
Lowland Raised Bog	533	Fluctuating
Lowland Fens	258	Declining (slowly)
Upland Flushes, Fens and Swamps	n/a	n/a

Table 7: Number of projects by peatland type and aerial coverage. ***Source: Peatland compendium, Defra 2008***

Peatlands type	*Number of projects*	*Reported restoration/ management area, km² [1]*
Blanket bog	16	151.4
Upland heath	9	15.2
Bog[2]	9	6.3
Lowland heathland	10	1.8
Lowland raised bog	18	11.6
Fen, marsh and swamp	22	7.1
Other	9	6.7

[1] This is an underestimation as a number of projects were not able to give data on aerial coverage of these peatland types and just recorded as present or absent. [2]The classification is based on the BAP classifications. The term 'bog' incorporates blanket bog raised mire and bog habitat and was included to allow respondents the opportunity to provide the classification they use

Table 8: Scores evaluating the initial (A) and current (B) site condition for each peatland project. ***Source: Peatland compendium, Defra, 2008***

Category	***Mean***	***Standard deviation***	***Maximum***	***Minimum***	***Median***
Overall site A	46	25	100	0	50
Overall site B	61	19	100	22	63
Hydrology A	46	26	100	0	50
Hydrology B	67	24	100	0	70
Biodiversity A	60	36	100	5	60
Biodiversity B	63	31	100	5	55
Peat A	70	25	100	10	75
Peat B	71	25	100	20	70
carbon A	50	25	100	0	50
Carbon B	60	25	100	10	60
Overall success	67	26	100	0	75

While there is no definitive estimation on the state of UK peatlands and the extent of different management practices attempts have been made to determine the GHG budget of peatlands under different land management and states. Natural England (2010) compiled available data from different studies (Table 9). They estimate that emissions from degraded peatlands in England could be approximately 2.98 Mt CO_2-e yr^{-1}, suggesting that damaged and degraded peatlands can be a relatively significant source of emissions. Building on this information the JNCC review (2011) provided a meta-analysis to show the probability of C and GHG budget improvements based on available UK studies of different management strategies (Table 10). The review found that certain management practices, such as Afforestation and Revegetation, have a high probability of improving both the C and GHG budgets, while managed burning and deforestation practices will probably degrade peatlands further. However, in both cases the number of studies available to inform the meta-analysis is limited, and as a consequence these conclusions still have a high degree of uncertainty attached. As further information becomes available these estimates will need to be refined and updated.

Table 9: Total estimated GHG emissions from peatlands under a range of uses, land covers and peat condition ($MtCO_2$ -e yr^{-1}). *Source: Natural England, 2010*.

				Fen peatlands	*Shallow*	
Management strategy	***Blanket Bog***	***Raised Bog***	***deep***	***wasted***	***Peaty soils***	***Total***
Cultivated & temporary grass	0.01	0.20	0.96	0.55	0.12	1.83
Improved grassland	0.05	0.04	0.42	n/a	0.10	0.61
Rotationally burnt	0.26	0.00	n/a	n/a	n/a	0.26
Afforested	0.06	0.01	0.00	n/a	0.16	0.24
Restored	0.01	0.00	0.02	n/a	n/a	0.03
Extracted	0.00	0.02	0.00	n/a	n/a	0.02
Overgrazed	0.00	0.00	n/a	n/a	n/a	0.00
Bare peat	0.00	0.00	n/a	n/a	n/a	0.00
Gripped	-0.01	-0.00	n/a	n/a	0.01	-0.00
Hagged and Gullied	-0.01	-0.00	n/a	n/a	n/a	-0.01
Undamaged	-0.02	-0.00	0.00	n/a	n/a	-0.02
Total estimated GHG flux $MtCO_2$ -e yr^{-1}	0.35	0.28	1.40	0.55	0.40	2.98

Table 10: The summary of meta analysis showing the probability of C and GHG budget improvements of different management practices based on available UK studies.

Management	*Probability of C budget improvement*	*Probability of GHG improvement*	*Effective sample size (C)*	*Effective sample size (GHG)*
Afforestation	0.85 (± 0.05)	1.00 (± 0.03)	3.8	4.1
Deforestation	0.10 (± 0.10)	0.07 (± 0.08)	0.9	0.8
Drainage	0.58 (± 0.09)	0.66 (± 0.08)	1.7	2.0
Drain - blocking	0.39 (± 0.06)	0.20 (± 0.07)	1.3	1.6
Grazing removal	0.58 (± 0.04)	0.73 (± 0.03)	5.4	4.9
Managed burning	0.35 (± 0.03)	0.32 (± 0.04)	6.2	5.4
Revegetation	0.75 (± 0.05)	0.52 (± 0.05)	3.8	3.5
Restoration of cutover peat	no data	no data	0.0	0.0

The figures in brackets refer to the variance in the probability estimate. Source: Worrall et al.2011

3.4 Emission factors

As part of their review on the state and extent of peatlands, Natural England (2010) compiled emission factors derived from European peatlands (Byrne *et al*., 2004), IPCC default emission factors (IPCC, 2006) and the Durham Carbon Model (Worrall *et al.*, 2011) (Table 11). This data was used to estimate GHGs from peatlands in England, however, significant information gaps and the lack of relevant studies in the UK means they require refinement (Natural England, 2010). These compiled emission factors differ from those used in the UK GHG inventory (which are based on the IPCC default emission factors) and are not sufficient at present to develop Tier 2 reporting. Consequently, while the emissions estimate are not comparable with the UK GHG inventory estimates Natural England's improved area estimations could be incorporated into the GHG inventory to improve emissions estimates from peatlands.

The JNCC-commissioned review (Worrall *et al*. 2011) also provides emission factors derived for managed peatlands (Table 12) . The emission factors come from the meta-analysis of the literature available for UK peatlands; these are based on modelling and are more detailed in their land management specification. As with the GHG budget estimations there is little UK evidence for the impact of land management on peatlands and therefore these emission factors still have a high degree of uncertainty.

Table 11: Emission factors to estimate GHG fluxes from English peatlands under different management regimes. ***Source: Natural England (2010)***.

Management	*Blanket / Raised Bog*	*Fen peatlands deep*	*Fen peatlands wasted*	*Shallow Peaty soils*
		t CO_2-e $ha^{-1}yr^{-1}$		
Cultivated & temporary grassland	22.42[c]	26.17[e]	4.85[g]	18.32[a]
Improved grassland	8.68[d]	20.58[f]	n/a	0.92[a]
Extracted	4.87[a]	1.57[a]	n/a	n/a
Rotationally burnt	2.56[b]	n/a	n/a	n/a
Afforested	2.49[a]	2.49[a]	n/a	2.49[a]
Restored	2.78[d]	4.2[c]	n/a	n/a
Bare peat	0.06[b]	n/a	n/a	n/a
Gripped	-0.2 [b]	n/a	n/a	0.73[a]
Hagged and Gullied	-0.2 [b]	n/a	n/a	n/a
Overgrazed	0.1[b]	n/a	n/a	n/a
Undamaged	-4.11 [b]	4.2[c]	n/a	n/a

No factors were available for peatlands supporting woodland, scrub, semi-natural vegetation, purple moor grass or with old peat cuttings. Source Natural England (2010) [a] IPCC Tier 1 emission factor; [b] Based on simplified version of Durham Carbon Model (Worrall et al., 2011); [c] Based on data from Couwenberg et al (2008); [d] Emission factors from Byrne et al., (2004); [e] CO_2 and CH_4 factors from Couwenberg et al (2008), N_2O from IPCC Tier 1; [f] CO_2 and CH_4 factors from Couwenberg et al (2008), N_2O from Byrne et al., (2004); [g] CO_2 from Bradley (1997), N_2O from IPCC Tier 1

Table 12: Emission factors to estimate GHG fluxes from modelling (Durham Carbon Model) for UK peatlands under different management

Management		***From modelling*** ***t C ha^{-1}yr^{-1}***
Afforestation	Peat soil	1.94[a]
	Above ground biomass [b]	-3.87
Deforestation		n/a
Drainage	Average	-0.05
	Grazing (present)	0.1
	Grazing (not present)	-0.01
	Burning (present)	0.2
	Burning (not present)	-0.06
Drain blocking		Reverse of drainage
Grazing removal	Average	0.04
	Drainage (present)	-0.09
	No drainage	-0.01
	Burning (present)	-0.01
	Burning (not present)	0.06
Managed burning	Average	0.8
	Grazing (not present)	0.9
	Drainage (present)	0.9
Revegetation [c]		-3.7

[a] Positive number denotes carbon net sink size decrease; b Assumes trees are in maximum growth phase; c Assumes revegetation from 100% bare soil. Source Worrall et al. (2011)

3.5 Discussion and conclusions

This report provides an overview of the potential problems that currently exist in estimating the GHG budget of the UK peatlands. A number of key problems still exist in interpreting the current literature on peatlands to inform the UK GHG Inventory including:

- Estimations on the extent of peatlands are still currently unknown. The different classification systems used by devolved administrations makes it difficult to interpret the country level data on a UK level.
- There is little information on the state of peatlands. Most of the information on the extent and state of peatlands has been collected over many decades to inform specific operational and policy requirements following historically based methodological frameworks. As a result a variety of typologies, classification and mapping systems have been used to describe, measure and report on the soil and vegetation used to define peatlands. This has created difficulties in having a common understanding and language on information about state of peatlands.
- Most studies investigating the transfer of C in the aquatic systems only quantify the DOC flux. However, to complete the total aquatic flux, POC, DIC, dissolved CO_2 and CH_4 should be included. Additionally as peatlands can be complex mosaics of different soil types, N_2O and CH_4 gaseous emissions can be spatially variable.

- Collated evidence in the reviews show that UK peatlands are a large store of C but pristine peatlands can act as a source of C and other GHGs. Natural England presented a similar review process on the impact of land management and restoration practices on the GHG budgets of peatlands. Therefore due to the variation in the C and GHG budgets of both managed and unmanaged peatlands, when stakeholders are considering management changes to peatlands to improve the level of emissions, it must first be considered if pristine peatlands in that area are a natural source of C and GHG's.
- Both reviews highlight that the difficulties in creating a UK wide GHG budget and the appropriate emission factors are due to: the uncertainty surrounding the extent and state of peatlands and lack of long term monitoring data investigating all aspects of the GHG budget.

4 A literature review of peatland drainage (Task 2)

In the UK, drainage of peatlands has been an integral part of their long-term management for agriculture, grazing, sport (grouse moors), afforestation and extraction. Undrained "natural" peatlands are generally regarded as net accumulators of carbon, whereas drained peatlands lead to significant loss of C in gaseous, dissolved and particulate forms to the atmosphere and the fluvial system. Overall the sink strength of peatlands decreases in response to drainage due to large CO_2 emissions (e.g. Dirks, et al. 2000) and fluvial losses.

Much has been written about the drainage of agricultural soils in the UK and significant amounts of inventory data do exist (e.g. National Survey of Drainage Need in 1968/9 carried out by MAFF's Land Drainage Service; grant-aided drainage returns) (Defra Project ES0111 report, ADAS 2002). One of the most extreme examples of drainage for agricultural use, The Fens, has been intensively drained since the 17th Century resulting in much of the original lowland peats being put under cultivation. Drainage of UK lowland and upland peatlands therefore goes back hundreds of years with particular periods of intensive installation of drains. Although the gripping (creation of steep sided, open ditches) of many parts of upland UK started in the 1930s with the development of the Cuthbertson plough (Holden 2004), post-World War Two agricultural intensification led to the gripping of huge areas of moorland throughout the UK. Data on the timing and rate of peatland drainage are unavailable at a national level, although there was strong grant-aided support for drainage schemes in the post World War Two years. In the 1960 and 1970s significant amounts of upland drainage took place in the English Pennines. Peak drainage rates of 100 000 ha yr^{-1} for 1970 have been quoted by Green (1973) and Robinson and Armstrong (1988). Since the early 1990s there has been a significant reduction in drainage rate as subsidies were reduced or removed. Hence over the last 80 years annual peatland drainage rates have fluctuated as pressures on the economy and land have changed.

In the early part of the 21st Century although some drainage systems are becoming less effective due to natural infilling, many are still highly active. Unsurprisingly the research evidence about the effects of drainage on the cycling of carbon is sometimes contradictory reflecting differences in the intensity of drainage, time since initiation and the rainfall-runoff regime (summarised in Worrall *et al*., 2011). Drained (man-made) areas of upland peatlands in the Pennines are typically characterised by increased water colour (associated with high DOC) (Mitchell and McDonald, 1995). Blockage of gullies is known to reduce DOC fluxes (O'Brien et al. 2008), whereas grip blocking is known to have variable impact on DOC and POC fluxes, at least in the short-term. Water colour and DOC data from a 14 km^2 upland peatland catchment in N England showed that drained sites were associated with significantly higher concentrations of DOC compared to undrained sites (Wallage et al. 2006). In contrast, in flatter peatlands aging and poorly maintained drained areas may silt-up (natural blockage) and become vegetated with a mixture of wetland and non-wetland plant species. Given sufficient time some peatland sites on low slopes (<4%), will infill naturally and begin to revert to their previous state (e.g. Holden et al. 2007).

It is now estimated that 18% of UK peatlands are in natural or near-natural condition (Littlewood et al. 2010), with the remaining affected principally by change to agricultural land use (40%), severe erosion (16%), peat cutting (11%) and afforestation (10%). There is sporadic information in the literature about the drainage status of all types of UK peatlands. For example, Cannell *et al.* (1993) state that in total 9% of British peatlands are drained and planted with trees. In upland Britain it has been estimated that 1.5 million ha of blanket peatland have been grip drained (Stewart and Lance, 1983). Afforestation of peatlands has led to intensive drainage of peatland systems and Ratcliffe and Oswald (1988) estimated that 25% of the peatlands of Caithness and Sutherland (mostly occurring at altitudes less than 300m) were affected by differing intensities of drainage; much of this is now being reversed through restoration activities. A report by Natural England (2010) on the status of peatlands states that 11% of all English deep peats are gripped, and most of this occurs on blanket bog (21% affected). The report highlights the "wastage" of English peatlands and states that only 1% of English deep peats remain "undamaged", compared to a UK wide value of 18% (Littlewood et al. 2010). Summary information on past and current drainage status of UK peatlands is therefore patchy and regionalised and we have no UK wide up-to-date information on drainage extent and timing.

In contrast to countries like Finland, the UK therefore lacks a comprehensive inventory of the area of drained peatland. Organisations like the RSPB have developed their own regional GIS-based systems to inform peatland management based upon the GIS desktop mapping application MapInfo. Linked to ground truthing and aerial photography, this has created a powerful tool to map peat drains and direct and manage restoration activities. There is also widespread use of GIS and remote sensing data for individual peat restoration projects (Defra, 2008). There is a need for a UK wide spatial information base on which to calculate emissions associated with peatland management and to provide a mapped, national baseline inventory on peatland drainage so that the potential GHG mitigation benefits of restoration activities can be quantified at local, regional and national scales. National maps of "hydrological condition" could then be developed. A proposed programme to address evidence gaps in UK GHG emission from peatland (including drainage and restoration) was set out by Evans *et al.* (2011).

4.1 Emission Factors Associated with Peatland Drainage

Peatland drainage increases rates of litter and peat decay by orders of magnitude, because of a thickening or deepening of the aerated zone due to a lowering of the water table (Defra, 2009). The net result is a significant increase in CO_2 emissions to the atmosphere. Peatland drainage also effects water quality and leads to significant losses of DOC (dissolved organic carbon) and POC (particulate organic carbon). In a survey of blocked and unblocked drains at 32 sites in the UK Armstrong *et al*. (2010), showed that the mean DOC concentration of water was 28% lower from blocked compared to unblocked drains.

The development of supplementary IPCC guidance for GHG accounting of emissions or removals by wetlands[5] (due 2013) requires that emissions factors be set for drained peatlands, as the guidance will focus on rewetting and restoration of peatlands. This raises several important questions:

(1) Can it be ensured that the baseline GHG emissions (associated with drainage) are of anthropogenic nature?

(2) Are the GHG emission reductions permanent or will they change with time?

(3) Should off-site emissions of CO_2 and CH_4 from the decomposition of eroded peat and fluvial carbon be included in the calculation of emission factors?

While it is recognized that peatland restoration and management intervention may not lead to net GHG benefit in the short-term because of increased methane emissions(Worrall *et al*., 2011), it is generally accepted that in the long term peat re-wetting leads to a net GHG benefit (Natural England, 2010); this however remains to be tested in the UK. Whether or not a peatland managed for forestry has a negative or positive GWP will depend on the intensity of drainage, density of tree planting and the original ground vegetation cover.

Emissions of GHGs will vary according to peat depth and drainage depth. It will also vary in relation to the spacing of drainage within a peatland landscape unit, the wider the spacing the lower the C and GHG losses. Setting acceptable emission factors for drained peatlands therefore needs to consider several key factors.

Research has shown that while annual mean water level is a good indicator of CH_4 emissions in natural systems, the cover of aerenchymous (gas conductive plant tissue) vegetation is a better indicator at the highest water levels (Couwenberg, 2009). In artificially drained

[5] See http://www.ipcc.ch/meetings/session33/doc07_p33_tfi_activities.pdf for further information

systems, where water tables fluctuate more rapidly, the soil-plant system may be disconnected with the change in water table. Hence a combination of proxy measurements will be needed to estimate CH_4 emissions from drained/undrained peatlands. Laboratory based research has also identified significant differences in CO_2 and CH_4 production potential from drained and undrained peat (Glatzel *et al.,* 2004). Subsidence has also been used as a proxy for estimating emissions, although it appears to works well for losses on drainage (i.e. subsidence), and less well for rewetting (i.e. swelling).

At a European level data has been gathered on GHG fluxes associated with different peatland management categories (see Drösler *et al.* 2008). However, since the available data is strongly biased to one or two countries (in particular Finland), it is unrepresentative of peatlands as a whole in Europe. The review by Drösler *et al.* 2008 of the data recommends that the values be used as "indicative orders of magnitude" to show differences between individual peatland types.

5 Estimates of emissions from peat extraction and use in the United Kingdom (Task 3)

5.1 Introduction

This section addresses aspects of task 2 (Exploration of the methodology for calculating emissions from the management and use of peatlands) and task 3 (Improving the robustness and transparency of the methodology for calculating emissions from the extraction of peat for horticultural use) in the project specification.

Section 5.2 describes the IPCC reporting requirements for emissions from peat extraction, section 5.3 describes the development of Tier 1 reporting of on-site emissions from peat extraction (for horticultural and fuel use) and section 5.4 the development of reporting of off-site emissions from horticultural peat use. The final emissions reported in the 1990-2009 inventory are included in Annex 2, and the uncertainties are discussed in section 5.5. The additional work required to develop Tier 2 reporting (section 5.6) is also described.

5.2 Reporting of emissions from peat extraction

Up until the 1990-2008 inventory (published 2010) the UK only prepared estimates of emissions from the extraction of horticultural peat. These were reported under LULUCF category *5C1 Grassland remaining Grassland*, as it was not possible to separate wetlands (as defined by the IPCC guidance) from other semi-natural habitat types in the UK. The guidance and methodologies are clearer in the IPCC 2006 Guidelines than in the 2003 Good Practice Guidance for LULUCF and these have been used to report emissions from peat extraction and peat use in the LULUCF category *5D Wetlands*, for the 1990-2009 inventory onwards. Carbon stock changes in living biomass, dead organic matter and soils can be reported, as well as N_2O and CH_4 emissions from drainage of wetlands.

According to the IPCC 2006 Guidelines, on-site emissions from peat deposits managed for peat extraction (current and abandoned) should be reported in the *5D Wetlands* category, along with off-site emissions from peat used for horticulture (off-site emissions from fuel use are reported under the Energy sector).

The production cycle on a peat extraction site goes through three phases:

1. Land conversion in preparation for peat extraction: construction of drainage ditches or improvement of drainage if land is already drained; removal of surface vegetation.
2. Extraction: milling and air-drying of peat, or block extraction.
3. Abandonment, restoration or conversion to other use.

The Tier 1 default methodology does not distinguish between these production phases and default emission factors for on-site emissions are provided. Emissions are reported under 5D1 Wetlands remaining Wetlands (emissions under 5D2 Land converted to Wetlands are reported as being "Included Elsewhere"). All carbon in horticultural peat is assumed to be emitted off-site during the extraction year[6]. Methane emissions are assumed to be insignificant but N_2O emissions from drainage should be reported (although emissions are considered insignificant on nutrient-poor peatlands).

According to the 2006 IPCC guidance, a Tier 2 methodology uses country-specific emission factors and may sub-divide emission factors and activity data according to extraction practice, peat fertility/composition, use of stockpiles and carbon fraction. Peatlands being converted for peat extraction (reported under 5D2 Land converted to Wetlands) should be separated from those already in production. The recommended default transition period for land being converted for peat extraction is five years. The inclusion of methane emissions from hollows and drainage ditches should be considered.

A Tier 3 approach builds on Tier 2 methodologies and involves a comprehensive representation of the dynamics of CO_2 emissions and removals on managed peatlands.

5.3 Activity data and emission factors for on-site emissions for the UK

The LULUCF inventory uses habitat/landscape surveys to estimate areas of land use and land use change. Areas of peat extraction are not explicitly identified in these surveys (Countryside Survey 1990, 1998 and 2007). They are most likely to fall under the "Inland rock" broad habitat (5G Other) or "Bog" broad habitat (5C Grassland), if some vegetation cover remains (Maskell *et al*. 2008).

This research project explored a number of data sources for constructing a robust dataset on the location, extent and type of peat extraction in Great Britain and Northern Ireland.

[6] The IPCC guidance does not explain this assumption but it is probably for ease of calculation in the absence of missing information on peat use and decay rates. This assumption can be modified at higher tiers.

1. The British Geological Survey (BGS) have supplied an extract of peat extraction site records from the Directory of Mines and Quarries (Cameron *et al.* 2008): this gives location, name, operator and council for currently active commercial extraction sites in England (54 sites), Scotland (26 sites) and Wales (2 sites). This Directory does not record the extent of the extraction area. It is updated every three to four years. BGS also have a GIS dataset of planning permission polygons for peat extraction (current and some inactive) in England, which shows the maximum extent of possible extraction (not actual extraction) and has not been updated since 2005 (some 1995). Further approval (from BGS licensing) would be needed to access this database.
2. An internet search on council planning websites showed that the required information (areas, date of establishment) is mostly not available (Lancashire County Council being an exception). It might be possible to gather this information by contacting each council individually but this would be extremely time-consuming and probably only partially successful (this has been tried in the past-see points 3 and 4). This would not be a realistic option for regular (i.e. annual) update of greenhouse gas inventory estimates.
3. There is a useful list of British peat extraction sites compiled in 2003 available (http://archive.corporatewatch.org/publications/peat/peat.htm), which gives areas of planning consent and consent dates. This was compiled by the Corporate Watch NGO: the data looks well referenced and could be cross-referenced with the more current BGS list but is not a sufficient dataset in itself.
4. Scottish Natural Heritage (Andrew Coupar) has provided a copy of their 2003 database on commercial peat extraction in Scotland and the accompanying report. This gives point locations, working status (active/dormant/intermittent/in restoration/unknown), consent dates and areas, and after-use. The dataset is not comprehensive as some sites are known to be missing (Andrew Coupar- personal communication).
5. There is good information on peat extraction (for both horticultural and fuel use) in Northern Ireland from papers by Tomlinson (2010) and Cruickshank and Tomlinson (1997). The research described in these papers was funded by Defra under previous LULUCF inventory development projects.
6. The Land Cover Map 2000 data[7] was investigated to see whether it would be possible to obtain areas of extraction. LCM class 26 (Inland rock and bare ground) was overlaid with LCM class 8 (Bog incl. deep peat) and 10 (Fen/marsh/swamp) but there appeared to be little coincidence with the BGS point locations.
7. Areas of peat extraction can be clearly seen on Google Earth satellite imagery (using the BGS point locations). Areas can be measured using the Google Earth Pro software (alternative software, such as Feature Manipulation Engine, could also be used). However, the imagery has been taken at varying (but known) dates and coverage is not consistent across the UK.

Three data sources were then used in combination to produce an activity dataset with areas of active peat extraction: the BGS peat extraction site records, Google Earth satellite imagery and the Northern Ireland peat research.

[7] The Land Cover Map 2007 data was published too late to be included in this project.

Surveys of peat extraction in Northern Ireland (Tomlinson 2010, Cruickshank and Tomlinson 1997) provide estimates of the extent in 1990-1991 and 2007-2008 by different methods (mechanical extraction, sod-cutting and hand-cutting) and by different end uses (fuel or horticultural peat) (Table 13). Estimates of areas for 1992-2006 were interpolated and the area for 2009 was assumed to be the same as that for 2008.

Table 13: Activity data for peat extraction sites in Northern Ireland

End use	*Method*	*Area in 1990-1991, ha*	*Area in 2007-2008, ha*
Fuel	Mechanical	3855	329
Fuel	Hand-cutting	107	16
Horticultural	57% vacuum harvesting, 22% mechanical extraction, 18% sod cutting, 3% turfs	576	
Horticultural	95% vacuum harvesting, 5% mechanical extraction		689

Similar information is not available for Great Britain. Most commercial extraction is undertaken using the vacuum harvesting method. The bare surface of the peat is scarified to 5-10 cm depth, the resulting loose peat is left to dry and then removed. Areas undergoing such extraction are clearly visible on aerial/satellite imagery (Figure 3). It is inferred that that the areas of existing extraction do not vary in extent from year to year. If a site could not be identified on the Google Earth imagery then it was not included (some areas may not actually be undergoing extraction, or the photographs may not be up-to-date).

For Great Britain areas undergoing peat extraction in 1991 were calculated using the GB area of peat with planning permission (7598 ha) and splitting it between the three countries in proportion to their production volume in 1991 (for both horticultural and fuel peat). Areas of extraction in 2009 (Table 14) were estimated using the Directory of Mines and Quarries point locations with Google Earth imagery. All sites in England and Wales were assumed to be horticultural peat production. Sites in southern Scotland were assumed to be horticultural, and those in northern Scotland were assumed to be fuel peat production (based on peat type and ownership of sites in several cases indicated that the peat was used for whisky production). A time series was constructed using linear interpolation between the two points. Areas of extraction declined between 1991 and 2009 by 22% in England and 13% on horticultural sites and 52% on fuel sites in Scotland. There is no reported peat production in Wales but two sites are recorded in the Directory of Mines and Quarries. The area of these sites was used for the whole of the time period.

Figure 3: Peat extraction site visible on Google Earth imagery

Table 14: Activity data for peat extraction sites in Great Britain

Country	Area in 1991, ha	Area in 2009, ha
England	5854	4573
Scotland	1734	1290
Horticultural	*1174*	*1021*
Fuel	*560*	*269*
Wales	479	479

No information has been found on the extent of peat extraction for domestic use except in Northern Ireland. Such small-scale extraction could be quite widespread in certain areas, particularly north-west Scotland. Peat cuttings for domestic extraction are not clearly identifiable on aerial photographs, and ground survey would probably be required to estimate the extent of such activity.

Default emission factors for Tier 1 reporting are published in the IPCC guidance (2006). Peat extracted for horticultural use is inferred to be from oligotrophic (nutrient-poor) bogs, with a default EF of 0.2 tonnes C ha^{-1} yr^{-1} (uncertainty 0 – 0.63). Peat for fuel is inferred to be from mineratrophic (nutrient-rich) fens or bogs, with an EF of 1.1 tonnes C/ha/yr (uncertainty 0.06 to 7.0). The default EF for N_2O from drained wetlands (nutrient-rich) is 1.8 kg N_2O-N ha^{-1} yr^{-1}.

5.4 Activity data and emission factors for off-site emissions

Annual production is highly variable because extraction methods depend on suitable summer weather for drying peat. Annual production in Great Britain is inferred from extractor sales by volume as published in the "Annual Minerals Raised Inquiry" report (DCLG website). This gives a breakdown for horticultural and other uses of peat (assumed to be fuel) for English regions and for Scotland (no peat extraction is reported in Wales in the inquiry report) (Table 15).

A value of 0.0557 tonnes C m^{-3} is used for Great Britain to estimate emissions from extracted volumes based on previous work by Cruikshank and Tomlinson (1997). This is slightly lower than the default emission factor of 0.07 tonnes C m^{-3} air-dry peat for nutrient-poor peats. Carbon densities of peat products have been re-assessed as part of this project (section 6).

Table 15: Annual peat production (m^3) for England and Scotland (from Annual Minerals Raised Inquiry/Mineral Extraction in Great Britain reports).

Year	England		Scotland	
	Horticultural	Fuel	Horticultural	Fuel
1990	1,116,940	2,727	293,170	93,163
1991	1,202,000	2,000	241,000	115,000
1992	1,079,000	4,000	332,000	91,000
1993	1,069,820	2,180	306,511	73,489
1994	1,375,000	1,000	498,000	108,000
1995	1,578,000	2,000	657,000	44,000
1996	1,313,000	2,000	517,000	53,000

Year	England Horticultural	Fuel	Scotland Horticultural	Fuel
1997	1,227,000	2,000	332,000	59,000
1998	936,000	0	107,000	32,000
1999	1,224,000	0	392,000	37,000
2000	1,258,000	1,000	336,000	31,000
2001	1,459,000	1,000	325,000	30,000
2002	856,000	1,000	107,000	10,000
2003	1,227,000	1,000	741,000	38,000
2004	902,000	1,000	338,000	21,000
2005	927,000	1,000	556,000	21,000
2006	856,000	1,000	712,000	24,000
2007	654,000	0	221,000	10,000
2008	496,000[1]	0	243,000	21,000
2009[2]	476,000	0	390,000	21,000

1 41,000 m3 used in mushroom casings were assigned to the "Other uses" category in error in the 2008 Mineral Extraction report, and are included here in the "Horticultural uses" category. [2] The 2009 Mineral Extraction report was not published in time to use the latest production volumes in the 1990-2009 inventory.

Tomlinson (2010) gives production estimates of horticultural and fuel peat production under different extraction methods for Northern Ireland for 1990/91 and 2007/2008. These have been interpolated to produce a time series. The total emission from horticultural peat production is the sum of emissions from vacuum harvesting production, sod extraction production and mechanical extraction production.

Emissions from vacuum harvesting production =

area x annual depth of extraction x carbon fraction by volume

where

Annual depth of extraction by vacuum harvesting, m/ha = 0.1

Carbon fraction of air-dry peat by volume, tonnes C/m^3 air-dry peat = 0.0508

Emissions from sod extraction production =

area x sod extraction rate x % dry matter for sods x mean % C

where

Sod extraction rate, tonnes/ha/yr = 200

Sod extraction, mean % dry matter = 35%

Mean % carbon = 49%

Emissions from mechanical extraction production =

area x extraction rate x % dry matter for mechanical extraction x mean % C

where

The mechanical extraction rate was estimated to be 206.45 tonnes/ha in 1990/91 and 243.06 tonnes/ha in 2007/08 (Tomlinson 2010).

Mechanical extraction, mean % dry matter = 67%

Mean % carbon = 49%

Note that the carbon-fraction of air-dry peat by volume for Northern Ireland has changed from 0.0441 tonnes C/m^3 (used in previous inventories) to 0.0508 tonnes C/m^3 based on the recent work by Tomlinson (2010).

5.5 Uncertainty and verification of the activity data and parameters

Uncertainties for the activity data are estimated to be >100% in 1990 and 50% in 2009. Uncertainties in the emission factors are the default IPCC values given in the 2006 Guidelines: -100% to 315% for peat extracted for horticultural use and -98% to 600% for peat extracted for fuel use. A more detailed uncertainty analysis is required, and will be taken forward under the LULUCF inventory project development programme.

The extraction rates of horticultural peat for Northern Ireland are equivalent to the rate of 100 tonnes ha^{-1} $year^{-1}$ given in the IPCC 2006 Guidelines and the moisture content of air-dried peat is within the range given of 35-55%. There is no directly comparable information for extraction rates in England and Scotland as production is reported by volume rather than weight.

The extraction area activity dataset was partially verified by comparing the measured areas with reported areas of planning permission (which were available for some extraction sites in England and Scotland). The measured areas either matched or were smaller than the planning permission areas, which is to be expected as it is known that not all areas with planning permission are undergoing active extraction.

5.6 Potential development of more detailed estimates

Work is in progress to develop the time series of areas undergoing peat extraction and post-extraction restoration, as suitable data is known to be available in Scotland and Wales. It may be possible to develop a Tier 2 methodology for peat extraction emissions that separates peatlands being converted for peat extraction from those already in production. The method combining site locations with Google Earth imagery could be extended to Northern Ireland if a similar register of commercial extraction sites is available.

The classification of types of peatland (nutrient-poor vs. nutrient rich) could be improved and country-specific emission factors developed. For example, Denmark uses a soil emission factor of 0.5 tonnes C ha^{-1} $year^{-1}$ for its nutrient-poor peatlands in its National Inventory Report as the IPCC default value of 0.2 tonnes C ha^{-1} $year^{-1}$ is mostly based on Finnish data.

This is in accordance with the difference in temperatures between Denmark and Finland. The Danish method could be extended to the UK.

Further work on volume conversion factors for off-site emissions from horticultural peat (see following section) has been undertaken and will be included in the next inventory submission.

6 Carbon content of horticultural peat from the UK and Ireland (Task 3)

6.1 Introduction

This section is concerned with what bulk density should be used when estimating off-site emissions from horticultural peat, given that calculations are based on the volume of peat sold (in the Annual Minerals Raised Inquiry (ONS 2010)) and this peat has been partially dried and compressed before its volume is measured.

A previous report by Cruikshank and Tomlinson (1997) estimated annual UK emissions of carbon from peat extraction to be 0.2 ± 0.05 Mt. Their estimate combined peat extraction data and laboratory analysis of the carbon content of peat samples. Peat extraction for horticulture accounted for 92% of the emissions estimate for Great Britain (GB) and only 23% for Northern Ireland (NI) where extraction for fuel was proportionally much greater. The carbon content of horticultural peat was calculated from bulk density measurements made on the packed peat (which is sold by volume rather than weight) and loss-on-ignition (LOI) analysis of percent carbon.

Here we repeat the analysis carried out by Cruikshank and Tomlinson (1997) to re-analyse the carbon content of peat sold for horticulture by volume. We also compare the carbon content of peat extracted from Ireland (ROI) and GB sites as the original analysis produced different values for each (GB 55.7 ± 12.3 g C $litre^{-1}$; NI 44.1 ± 9.1 g C $litre^{-1}$). As Northern Ireland producers source peat from both north and south of the border the following analysis treats NI and ROI together (IRE) and compares this to GB sourced products.

6.2 Method

Bags of 100% horticultural peat were purchased from a range of sources. The majority of garden suppliers contacted (15 in total) did not supply 100% peat products and of those which did five only supplied peat extracted from ROI sites; one supplier only sold Latvian sourced peat products. The brands which we were able to purchase are listed in Table 16. Two of each product listed was purchased and four replicate samples from each were analysed giving a total sample size of 40. Dry bulk density was calculated by drying a known volume of peat at 105°C until the weight remained constant (approximately 48 hours). Volumes of bagged peat samples were collected using a 200 cm^3 cutting ring; the peat blocks were cut into rectangular samples with volumes ranging from 92 to 208 cm^3. Carbon content was calculated using the LOI method described in Ball (1964) assuming that all carbon was in organic form.

Table 16: Description of peat products analysed; volume of Dows blocks estimated from average size of 16” x 5” x 5” Unless stated otherwise peat was machine cut.

Product	Source Country	Form product sold	Volume (L)
Shamrock	ROI	Bagged	100
Bullrush	NI + ROI	Bagged	100
Arthur Bowes	GB	Bagged	100
Dows	GB	Hand-cut Bagged	80
Dows	GB	Hand-cut Blocks	6.55

6.3 Results

Mean dry bulk density of both IRE and GB sourced peats was 0.15 g cm^{-3} (Table 17; Figure 4). No significant difference was seen between dry bulk density estimates of peats sourced in IRE and GB though brand was a significant factor. Brand specific differences are illustrated in Table 17. The hand cut peat (Dows) had a similar dry bulk density to the Shamrock brand, both of which were significantly lower than the other commercially bagged brands.

The mean (± SD) percent carbon of the horticultural peat was 42.8 ± 1.88% (Figure 5); smaller than literature estimates of peatland soils which converge around a value of approximately 52% (Lindsey, 2010). The percent carbon across all samples covered a narrow range of 38-45%, however brand was still a significant factor explaining 66.7% of the variation ($P < 0.01$) (Figure 5); source country (GB or IRE) was not significant.

Table 17: Summary of results from horticultural peat analysis

Brand	Dry Bulk Density (g cm^{-3})	% Carbon	Carbon Density g C L^{-1}
Arthur Bowers	0.17 ± 0.01	39.8 ± 0.79	70.1 ± 4.12
Dows Bags	0.12 ± 0.02	43.1 ± 0.75	52.2 ± 7.08
Dows Blocks	0.15 ± 0.02	44.7 ± 0.27	66.7 ± 8.95
Shamrock	0.12 ± 0.01	43.4 ± 2.12	53.0 ± 4.43
Bullrush	0.19 ± 0.01	42.8 ± 0.32	79.5 ± 19.3

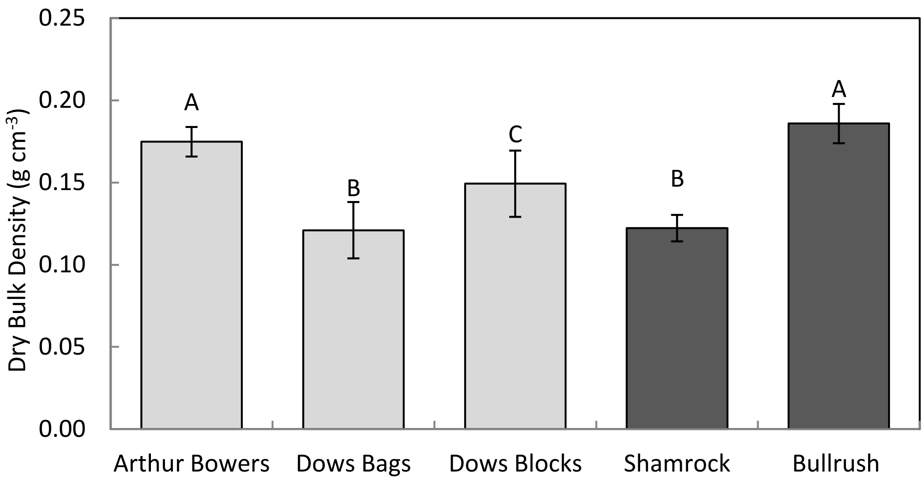


Figure 4: Dry bulk densities of horticultural peat brands. Common letters indicate similarities using Tukeys test statistic. Light grey bars represent GB sourced peats, dark grey represents Ireland (NI + ROI) sourced peats.

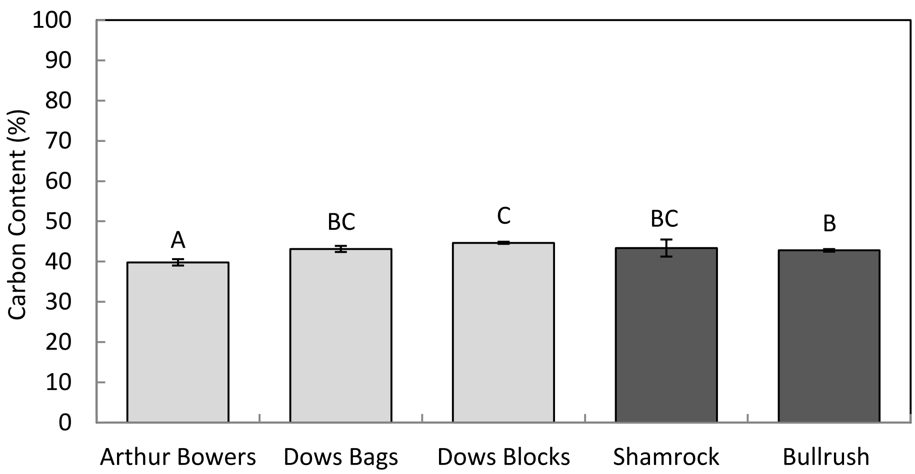


Figure 5: Percent carbon of horticultural peat brands. Common letters indicate similarities using Tukeys test statistic. Light grey bars represent GB sourced peats, dark grey represents Ireland (NI + ROI) sourced peats.

The mean (± SD) carbon density of across all samples was 64.1 ± 12.2 g C litre^{-1} (Figure 6), higher than the original estimates of 55.7 ± 12.3 g C litre^{-1} (GB) and 44.1 ± 9.1 g C litre^{-1} (NI) made by Cruikshank and Tomlinson (1997). Brand explained 73.7% of the variability ($P < 0.01$); source country (GB or IRE) was again non-significant. The highest carbon density (and greatest range) was in the 'Bullrush' samples sourced from both NI and ROI with the lowest in the hand-cut 'Dows' bags and 'Shamrock' Irish peat moss. As the percent carbon was relatively consistent among samples, the primary difference in carbon density originates from differences in dry bulk density.

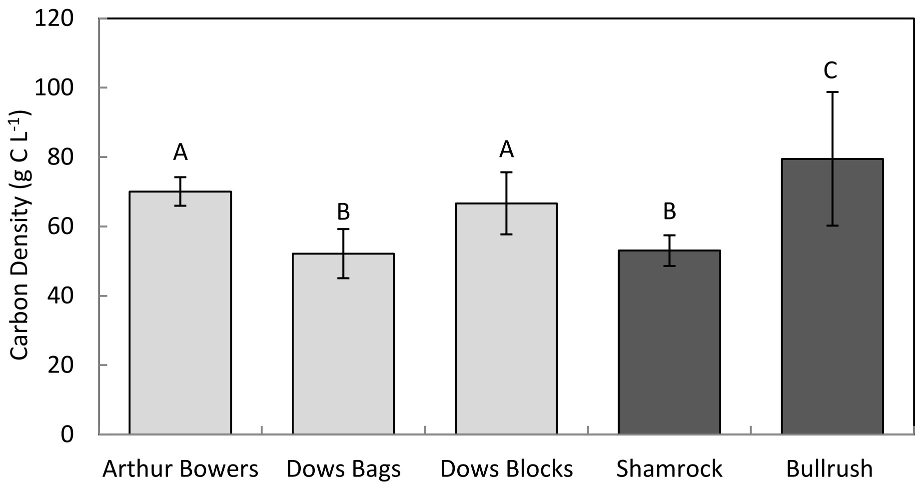


Figure 6: Carbon density of horticultural peat brands. Common letters indicate similarities using Tukeys test statistic. Light grey bars represent GB sourced peats, dark grey represents Ireland (NI + ROI) sourced peats.

6.4 Conclusions

Higher average bulk densities were recorded in bagged horticultural peat than in the original study by Cruikshank and Tomlinson (1997). The use of these bulk densities would result in an increase in off-site emissions of 13% for England and Scotland and 11-27% in Northern Ireland (where the mix of extraction methods has changed over time). The results of this study will be brought before the LULUCF inventory project steering committee, who will consider whether these results should be used instead of those in the Cruikshank and Tomlinson study in the horticultural peat emission estimates.

7 Land Use Change

7.1 Introduction

This section is concerned with the fourth task of the project: an exploration of how to improve the methodology for the land use change component of the LULUCF inventory to better account for land use changes. Consideration was given to the work required to address the following questions, as in the project specification:

1. How can we track land parcels undergoing a series of land use changes in succession?
2. What is the potential for moving to a geo-referenced tool?
3. Does urbanisation really equate to a total loss of soil carbon?
4. How can we include small scale land use changes that may be encouraged as mitigation measures, .e.g. buffer strips and field margins?

This task was not intended to be the main focus of the project so it is addressed by summarising relevant work in existing and completed projects and discussing issues to be taken into consideration in the development of further work in this area. Several of the questions will be addressed in the 2012-2015 LULUCF inventory project. Questions 1, 2 and 4 are considered in section 7.2, and question 3 specifically in section 7.4. Section 7.3 summarises synergies between the current Agricultural GHG Research Platform and the LULUCF inventory.

7.2 Land use change tracking

At present in the LULUCF inventory, carbon stock changes arising from land use since 1950 (or from 1921 for afforestation) are considered. The approach used is based on national land use change matrices developed from land cover surveys (the Monitoring Landscape Change project for 1950-1980) and the Countryside Surveys (1980-2007)). This approach does not differentiate between individual parcels of land (as it based on stratified sampling surveys). Conceptually, it does not take into account situations where land may undergo multiple land use changes in succession (so each land use change will be tracked to completion rather than arrested part-way), for example, short-term grass-crop rotations. Although the impacts of this on soil carbon stock changes will be balanced at the national level, imbalances will occur at regional levels and over short time scales. The activity data on land use change is also the biggest source of uncertainty in the LULUCF inventory.

At present, there are no single land cover datasets that will provide us with sufficient temporal and spatial resolution to track historic and present-day land use change to the level required by the IPCC methodology. The PIACS project (see 7.2.1) examined the potential of the IACS (Integrated Administration and Control System) agricultural data for LULUCF inventory reporting and concluded that it had potential, but the methodology is not UK-wide in scope and does not extend back in time beyond 2000. The way forward will be in the assimilation of all available land cover data sets to ensure complete coverage of land in the UK (including non-agricultural land), the inclusion of historic land use change (where soil carbon stock changes are still contributing to the overall soil carbon flux) and the ability to report annually. The 2012-2015 LULUCF inventory project will implement a land use vector approach, which will be able to represent the range of land use histories across an area over time. The use of all available data sources will constrain the areas of land use change and reduce uncertainty in the LULUCF inventory. This approach will also be able to represent rotational land use patterns. The feasibility of the land use vector approach has already been demonstrated during uncertainty analysis in the current LULUCF inventory project.

On the second point, moving the inventory to a georeferenced tool would require considerable resource input in order to develop an operational system while maintaining existing inventory functionality. A provisional estimate is that resources would need to be at least doubled, with additional resource requirements during the development phase of the georeferenced tool. As discussed above, assimilation of different datasets would be required in order to attain complete coverage of the UK. This may give rise to additional uncertainty, particularly where non-spatial input data is disaggregated to smaller scales. To counter-balance the pressures to increase spatial resolution with the pressure to reduce uncertainty in inventory estimates, the 2012-2015 LULUCF inventory project will analyse how uncertainty changes with the spatial scale of disaggregation. This relationship will be different in each of the land use categories, depending upon the mix of contributing datasets, and the most appropriate reporting scale will vary.

Theoretically, remote sensing (RS) products would provide a data resource at the field scale for inventory reporting. However, RS products still need substantial processing to produce data suitable for use in inventory calculations: for field-level data this could be difficult to do operationally on the annual basis required for reporting. There is also the risk that remote-sensing platforms (satellites) and instruments can fail unexpectedly, leaving a data gap (likewise data collection and statistical publications can also be discontinued, although there is generally some warning of this).

It would be difficult to include small-scale land use changes for mitigation purposes into the LULUCF inventory as it stands, as the IPCC reporting structure is not infinitely scalable. A possible approach would be to estimate the impacts of land management GHG mitigation in a separate tool and to supply the total areas and emissions or removals to the LULUCF inventory as a single 'land management' reporting line. A comprehensive quality assurance process would be required to ensure that there was no double-counting of emissions and removals.

Originally, it was proposed to assess the potential of Land Cover Map 2007 to contribute to the assessment of land use and land use change in the LULUCF inventory. However, the release of Land Cover Map 2007 was delayed due to data licensing issues until July 2011 (http://www.countrysidesurvey.org.uk/); therefore it has not been possible to assess it as part of this project.

7.2.1 Summary of the PIACS Project (Scottish Government-funded, led by University of Aberdeen with CEH and Macaulay Institute)

One of the key requirements for moving LULUCF reporting from Tier 1 to higher Tier 2/Tier 3 reporting is the availability of detailed land use information which can clearly distinguish areas under different management types. The PIACS project was a "Pilot Project to determine the suitability of Integrated Administration and Control System (IACS) data to provide Land Use Change data for Annual Greenhouse Gas Emission Estimates" and aimed to integrate the more detailed land cover information provided by IACS for use with the ECOSSE soil carbon model. This report was funded by the Scottish Government and has now been published (Smith *et al.* (2011)). .

Currently for the LULUCF sector in the UK, data is derived from the Countryside Surveys (CS) which have been undertaken on a ten yearly basis since 1978. Carbon fluxes from the soil are determined using the CFlow model and the LULUCF inventory dynamic soil carbon model (see Annex 3.7 in MacCarthy et al 2011 for further details), for the forest land use category and other LU categories respectively. In Scotland the land use sector accounts for approximately 15% of Scotland's total GHG emissions, the most recent greenhouse gas inventory for Scotland (Sneddon *et al.* 2010) estimated Scotland's LULUCF sector to be a net sink of -4.48 Mt CO_2 in 2008. Net emissions/removals in Scotland are dominated by the large Forest Land sink (-9.16 Mt CO_2 in 2008), although the Cropland source is also significant at 6.64 Mt CO_2. The Grassland and Settlement fluxes were smaller (-2.73 and 1.68 Mt CO_2 respectively). The majority of these emissions/removals arise from soil carbon changes as a result of land use change between categories. These figures compare to the total GHG emissions in Scotland of 53.7 Mt CO_2 in 2008.

The PIACs project sought to evaluate the use of annual IACS data for LUC in the Scottish agricultural sector alongside the ECOSSE model to simulate carbon sources and sinks from soils and associated vegetation and compares the outputs with the current inventory used in Scotland. Below is a brief summary of the IACS data and the ECOSSE model.

IACS is the Integrated Accounting and Control System and is maintained by the Rural Payments and Inspection Directorate of the Scottish Government. Land use information for both permanent and seasonal land is derived from land managers submitting claims for support schemes such as the single farm payment (SFP). For use in the ECOSSE model, land use is broadly defined in five broad categories; a) semi-natural, b) grassland, c) forestry d) cropping and e) other. The coverage of each land use type is dependent on reporting levels; however, from 2000 to 2009 coverage has increased from 4.4 million ha to 5.7 million ha. Coverage is most complete in the lowlands, the south and eastern Scotland; however woodland is under-reported, and needs to be supplemented by other data sources.

Scotland's soils are carbon rich and are potentially a large source of GHG emissions when subjected to climate change, previous models could not examine the impacts of land use change on some organo-mineral soils. Funded by the Scottish Executive and the Welsh Assembly Government, ECOSSE was developed to simulate the impacts of land-use change in mineral, organic and organ-mineral soils (including peaty podzols and peaty gleys).

In brief the ECOSSE model uses a pool type approach, describing soil organic matter as pools of inert organic matter, humus, biomass, resistant plant material and decomposable plant material. Material is exchanged between these pools according to first order rate equations, characterised by a specific rate constant for each pool, and modified according to rate modifiers dependent on temperature, moisture and pH of the soil. Driven by commonly available meteorological data and soil descriptions, the model predicts the impacts of land-use change and climate change on C and N stores in organic soils in Scotland and Wales.

The main conclusions of the PIACS report were that:

1. It is feasible to use IACS land use change data along with the ECOSSE model to simulate changes in soil C stock for Scotland, and to compare these with estimates using the current method which uses Countryside Survey (CS) land use change data and the carbon flow (CFlow) model to simulate net emissions
2. The spatial and temporal resolution of IACS land use data is higher than data obtained from the Countryside Survey (CS), improving spatial resolution by a factor of 40,000 and temporal resolution by a factor of 10. CS data was never designed to provide annual land use change data on a sufficiently accurate spatial scale for GHG inventory purposes hence it is collected every 10 years on a large 10km grid
3. Limitations in the reliability of IACS data are associated with data gaps (due to all land not being reported under IACS), and classification creep (due to changing payments causing systematic changes in the way the land use is classified).
4. Problems with classification creep will be reduced as classifications become more stable. By accounting for land use in successive years, the definition of more uncertain land use categories (such as grassland and semi-natural) can be resolved.
5. Future cross-checking IACS data against other available information on land use change will validate and improve confidence in IACS data whilst maintaining the higher resolution.

7.3 Synergies with the Agriculture Sector Inventory and the Agricultural GHG Inventory Research Platform

Reporting of emissions from the LULUCF and Agriculture sectors under the UNFCCC IPCC Guidelines will come together under a single sector, most likely termed Agriculture, Forestry and Other Land Use (AFOLU). The GHG emission sources to be reported under AFOLU are given as:

Total Agriculture, Forestry and Other Land Use

- **A. Livestock**
  1. Enteric fermentation
  2. Manure management
- **B. Land**
  1. Forest land
  2. Cropland
  3. Grassland
  4. Wetlands
  5. Settlements
  6. Other Land
- **C. Aggregate sources and non-CO_2 emission sources on land**
  1. Biomass burning
  2. Liming
  3. Urea application
  4. Direct N_2O emissions from managed soils

5. Indirect N_2O emissions from managed soils
6. Indirect N_2O emissions from manure management
7. Rice cultivations
8. Other

D. Other

1. Harvested wood products
2. Other

This reorganisation of the reporting of emissions from the LULUCF and Agriculture sectors will have few operational implications, as the emission sources previously reported as Agriculture or LULUCF are still distinct within AFOLU. However, the reporting as a single sector will further highlight the importance of using common activity data in estimating emissions from sources within the previous LULUCF and Agriculture sectors as appropriate, in using consistent approaches to CO_2 and non-CO_2 GHG emissions from particular sources and in reflecting the effects of potential mitigation practices across both CO_2 and non-CO_2 gases as appropriate.

A programme of planned improvements to inventory methodology for estimating UK GHG emissions from the Agriculture sector is currently in progress. The Agriculture Greenhouse Gas Inventory Research Platform (UK Government funded, Defra projects AC0114, AC0115 and AC0116) aims to develop data that will enable emissions of N_2O and CH_4 from agricultural sources to be reported at the Tier 2 or Tier 3 level, through development of country-specific emission factors, inclusion of country-specific agricultural practices and management options and identification and development of improved sources of activity data. There will be synergies between these activities and the development of an improved LULUCF inventory, particularly with respect to emissions from *Land Use*. Specific areas identified where such synergies exist include the Cropland Management component, where improved sources of activity data relating to specific crop management practices (tillage operations, fertilizer management, crop residue management) will be developed in AC0114 and relevant to LULUCF, and Soil Drainage, where improved estimates of the areas of different soil types subject to artificial drainage will be derived.

Members of the current project (SP1105) team are currently responsible for the respective LULUCF (Amanda Thomson) and Agriculture (Tom Misselbrook) inventories and are also members of the AC0114 project team. Links with work undertaken as part of AC0114 have been noted in the Options spreadsheet and in the report where relevant. This final report will be shared with both inventory project teams and steering committees and with the AC0114 project team, to ensure that the synergies between inventory improvement programmes are recognised and made use of.

7.4 Fate of soil carbon due to urbanisation and in urban environments

The rate of urbanisation is increasing world-wide and in most cases the effect on soil carbon storage and soil functioning is negative. One of the most obvious effects of urbanisation is “soil sealing”, the covering of soil with materials like concrete, stone and tarmac, caused by the construction of buildings and urban transport infrastructure. Urbanisation, which also includes other areas like public and private spaces, reduces or prevents natural soil functions and ecosystem services on both the immediate area affected by development/sealing and the surrounding soils. In the urban environment soil C cycling and long-term C pools will also be affected indirectly by a range of other factors including warming (urban heat island affect), disturbance/removal of soil, rainfall patterns, drainage, pollution and urban landscaping.

Urban soils are different from natural soils, typically being more variable, compact, poorly drained, nutrient and pollutant enriched, and warmer (Craul, 1985). Unless topsoil is removed urbanisation will either lead to the long-term burial of soil C if it becomes sealed from the atmosphere, its loss in drainage as dissolved or particulate forms, or if exposed, direct gaseous loss to the atmosphere. In 2006 the European Commission adopted a Soil Thematic Strategy (COM (2006)231) which embodies soil protection measures applicable to areas such as urban development, and proposed a Soil Framework Directive (COM (2006) 232) to regulate these soil protection measures.

There are, however, exceptions to the rule that urbanisation is “bad” for soil carbon. For example, amendment of urban soils with organic waste will lead to an increase in soil C content. Enhanced C sequestration due to the planting of trees may also lead to long-term increase in soil C storage. In an evaluation of the potential for soil C sequestration in the US, Lal *et al.* (2003) identified that urban forests and urban land management had the potential to store an additional 0 to 6 Tg C yr^{-1}.

In Britain, Cannell *et al.* (1999) estimated that about 1.5 M ha of land is currently covered with buildings, roads and other forms of development. The rate of urbanisation increased from 13,000 ha yr^{-1} (1947–1980) to 19,000 ha yr^{-1} (1984–1990). In many parts of the UK rates of urbanisation have recently been decreasing. In England the proportion of land changing from agricultural to residential use has decreased from 36 to 27% between 1999 and 2005 (Department for Communities and Local Government, 2006). In addition residential development in England has increasingly used previously developed land rather than agricultural land. Assuming that all ground converted to urban land loses C towards an equilibrium value of 1 kg C m^{-2} (value based on the average soil C density of arable and uncultivated land that became unmanaged over time, Milne and Brown, 1997), large losses of organic C will result from urbanisation of cultivated, uncultivated and woodland areas. Overall the carbon loss rate for soils due to urbanisation in the UK was estimated by Cannell *et al.* (1999) to be as high as 1.6 Mt C yr^{-1}. Uncertainty in both the amount of C stored in urban soils and the rate of soil carbon loss due to urbanisation is of the order ca. 50%.

In the Republic of Ireland between 1851 and 2000 the extent of suburban lands of the total land area has been estimated to have increased from 0.18% to 1.26% and urban lands from 0.05% to 0.40% (Eaton *et al.* 2008). Although land cover change to urban/suburban areas is a net source of C to the atmosphere, the overall increase in suburban land area has lead to an estimated increase in the SOC stock of these soils is from 1.0 Tg in 1851 to 7.0 Tg in 2000.

In the USA, Imhoff *et al.* (2004) used satellite data and a terrestrial C model to estimate the effect of urbanisation on NPP. Urban land covers less than 3% of the land area of the United States. They found that conversion to urban land reduced photosynthetic C fixation by 0.04 Pg per year or 1.6% compared to the previous land-use. The effect of a lowering of the carbon fixation potential in urban areas will be to decrease long-term soil C storage in the urban landscape.

One of the main issues in deriving large-scale estimates of soil C loss due to urbanisation is getting consensus on the C content of urban soils. Some authors (e.g. Howard *et al.* 1995, Bradley *et al.* 2005) have assumed that urban soils have a C store of zero, whereas Cannell *et al.* (1999) used a value of 1 kg C m^{-2}. Deacon and Billett (1998) showed that the median content of stockpiled, urban forest and "other" urban soils (to a depth of 50 cm) was 12.3, 32.4 and 36.1 kg C m^{-2}. These values are at the lower end of the soil C content of many natural UK soil types. If we assume that urban areas consist of 50% open soil, the median C content of urban areas would be 6-16 kg C m^{-2}. Bradley *et al.* (2005) assumed urban land to contain zero C; garden soils (0-100 cm) were estimated to contain 7 kg C m^{-2}. A study of urban soil C in Coventry, Glasgow and Stoke-on-Trent (Rawlins *et al.* 2008) showed that the assumption by Bradley *et al.* (2005) that suburban soils had half the organic C content of the equivalent soil under pasture was an underestimate of the measured labile SOC content and hence soil carbon stocks. The British Geological Survey's Geochemical Surveys of Urban Environments (GSUE) project measured loss on ignition in soil samples as an indicator of organic matter content, but analytical results do not seem to be available. Although these examples demonstrate the difficulty in making large-scale estimates of soil C loss, they do show that urban soils are likely to have an organic C content >1 kg C m^{-2}.

In conclusion, there is mixed evidence as to the extent of soil carbon loss following urbanisation, but broad agreement that soil carbon stocks decline. The extent of loss also depends on the extent of total soil sealing (where 100% loss could be assumed as the normal soil functions have been removed) and whether top soil is removed and used elsewhere: it would be interesting to know how far this practice occurs in the UK. The evidence from studies in the UK is that soil carbon stocks in suburban settings (parks and residential areas) are likely to be higher than they are currently estimated to be in the LULUCF inventory.

8 Final Conclusions / Key Points

The aim of the project was to determine the feasibility of populating the land use component of the LULUCF GHG inventory. The research needs for this project are divided into four tasks:

1. Scoping the feasibility of populating the land use/management component of the LULUCF inventory in order to capture soil carbon fluxes associated with land management and associated GHG emissions and removals. This is the main focus of the project.
2. Exploration of the methodology for calculating emissions from the management and use of peatlands.
3. Improving the robustness and transparency of the methodology for calculating emissions from the extraction of peat for horticultural use.
4. Exploration of how to improve the methodology for the Land Use Change component of the inventory to address policy questions.

The LULUCF inventory was originally designed as a reporting tool that conforms to the IPCC guidance and can be used to fulfil the UK's statutory obligations under the UNFCCC and the Kyoto Protocol. Increasingly, following the introduction of national GHG emission targets, there is a desire to use the inventory for tracking the impact of mitigation policies and there is a tension between the continuing requirement for international reporting and the requirement for a more flexible, responsive tool for policy analysis. There is a development programme in the LULUCF inventory project that is addressing many of the points raised by policy makers, but the international reporting requirement will continue to be the key priority. It may be that separate policy-responsive tools should be developed that work in synergy with the existing LULUCF inventory reporting, rather than trying to make the LULUCF inventory be 'all things to all men'.

8.1 Options for reporting emissions from land management

123 land management options were identified and described according to their data requirements and whether this data already exists, their priority for inclusion in the LULUCF inventory and the work required to achieve inclusion. These options include those covered by the IPCC reporting structure and land management activities which may be significant in a UK context but are not currently fully covered by the IPCC guidance.

The unreported land management activities that have the highest priority for inclusion (having potentially large fluxes affecting all countries of the UK) in the LULUCF inventory are cropland and grassland management options which affect soil carbon stock changes in mineral and organic soils, and wetland restoration options. The cropland/grassland soil carbon stock change options would take moderate effort to incorporate into the inventory at Tier 1 or 2 (meaning that 1-3 weeks' work is required to develop either activity data or emission factors). The development of reporting for wetland restoration would be more difficult and would require significant additional work to process both activity data and emission factors, and possibly field data collection in some cases. There is also a query over whether/where wetland restoration fits into the current IPCC reporting structure, although this will hopefully be addressed by the supplementary guidance to be published in 2013.

The options that would be easiest to incorporate into the inventory (where suitable activity data and emission factors already exist) are those affecting carbon stocks in woody biomass on croplands, e.g. orchards, and grasslands, e.g. heather moorland and scrub. The options that would be most difficult to incorporate into inventory reporting, besides wetland restoration options, are those concerned with Settlements and Flooded Lands, as UK research and data in these areas is limited.

8.2 Emissions from the management and use of peatlands

In the past two years there has been extensive compilation and analysis of research into peatlands in the context of climate change (both in terms of their resilience and their potential to act as GHG sources or sinks). This research is reviewed for its potential to contribute to improved reporting of peatland management emissions and removals in the LULUCF inventory. A number of key problems still exist in estimating the GHG budget of UK peatlands, mostly due to the uncertainty surrounding the extent and state of peatlands and a lack of long term monitoring data investigating all aspects of the GHG budget. A literature review of peatland drainage was also undertaken, as this common land management activity on peatlands is known to generally produce large GHG emissions but is not well represented in the LULUCF inventory. Information on the past and current drainage status of all types of UK peatlands is patchy and regionalised. Evidence to allow the compilation of emission factors is similar patchy, as different fluxes vary in importance across drained and undrained peatlands of different types and management. This makes it difficult to quantify the potential GHG mitigation benefits of wetland restoration at local, regional and national scales. A measurement/monitoring programme of the type proposed by Evans *et al.* (2011) would address these gaps in evidence for UK contexts.

8.3 Improving the robustness and transparency of the methodology for calculating emissions from the extraction of peat for horticultural use

A new operational methodology has been developed for reporting on-site emissions from peat extraction and off-site emissions from horticultural peat use. This method was based on the latest IPCC 2006 guidance and was used for reporting in the 1990-2009 inventory (published 2011). The method is based upon publicly available datasets and the activity data have been verified by comparison with comparable data sources. The estimated emissions from peat extraction activities have declined considerably since 1990 as the UK peat extraction industry has contracted.

8.4 Exploration of how to improve the methodology for the Land Use Change component of the inventory

This task was not the main focus of the project and has been addressed by summarising relevant work in existing and completed projects and discussing issues to be taken into consideration in the development of further work in this area. The various options for more detailed representation of land use change in the LULUCF inventory are considered. Synergies with the Agriculture Sector inventory and the Agriculture GHG Research Platform are discussed: potentially these will increase consistency in the use of activity data between the two sectors and emissions from land management being estimated and reported in a more consistent way. The fate of soil carbon after urbanisation was also reviewed, with the conclusion being that the current assumption of total loss could be modified if there was more information on the extent of soil sealing and top soil translocation in the UK context- a topic for further investigation.

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10 Annex 1: Information held on peatland resources by the BGS library – Flanders Moss case-study

10.1 Introduction

The British Geological Survey (BGS) is known to hold information on peat deposits throughout Great Britain. The Edinburgh BGS library was visited to assess the availability of information on lowland peatlands in Scotland. A case study of Flanders Moss in Stirlingshire is given below (Figure 7). This illustrates that a large amount of information is available but it requires collation and analysis to be a useful data resource. Information that could be extracted and collated includes:

- The existing carbon stock in lowland peats (from depth and areal extent estimates)
- Land use history affecting historical and present greenhouse gas emissions, particularly from peat extraction and drainage.

10.2 Information in geological maps

Figure 7 contains information noted on the 'Solid and Drift Edition' map. The acronyms DAS and BUS and symbols are described below

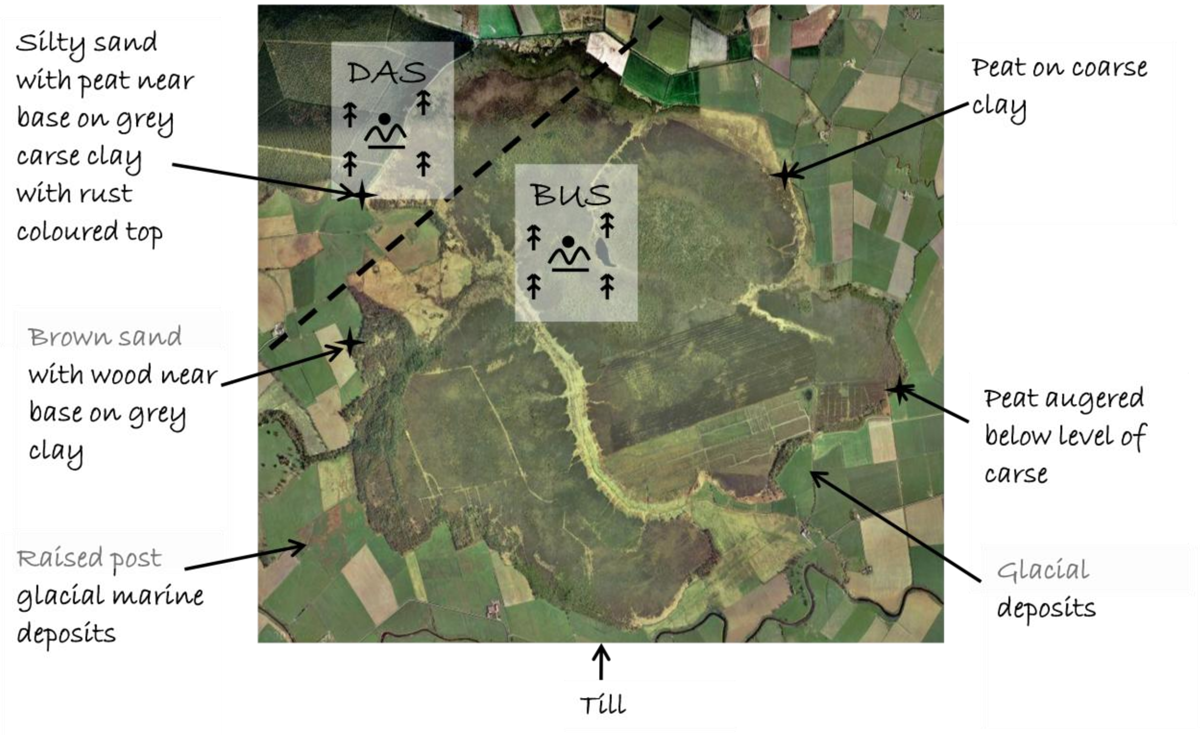

Figure 7: Diagram of Flanders Moss peatland annotated with information from 'BGS FM 150015 NS95NE Solid and Drift Edition map for Flanders Moss and Dykehead'.

DAS – Dalmary sandstone member chiefly greenish grey cross-bedded sandstones locally with plant remains and some beds of siltstone. Reddish grey beds towards base

BUS – Buchlyvie sandstone member mainly red and grey cross-bedded sandstones with chocolate brown to brick-red and green siltstone and silty mudstone beds

– Coniferous forest

– Peat

10.3 Information contained in 'Geology of the Stirling District' 1970, Geological Society Scotland (39)

- The Original 1" map is not accompanied by a sheet explanation but listings of other information sources include a memoir from 1932 entitled 'The economic geology of the Stirling and Clackmannan coalfield' by C.H. Dinham and D. Haldane and a further two coalfield papers by E.H. Francis (1956) and W.A. Read (1959)

- Description of site's geological history
    - By Boreal times the sea had fallen below present level, the newly exposed land developed vegetation cover, which is now locally preserved as layer of peat beneath younger ('carse') clays (laid down during marine transgression during Atlantic times)
    - Pre-Boreal peat exists at Flanders Moss; as a result of sea level fall the sub-peat surface emerged to form part of the land-surface before peat growth began. The emergence probably culminated ~8500 years ago
    - The Atlantic period was characterised by extensive marine transgression although the sea appears to have been excluded from Flanders Moss as the peat growth continued without any detectable break (elsewhere boreal peat removed by erosion or covered by silts and clays).
    - Peats above and below the deposits were laid down between 8421 ± 157 before present (BP) and 5481 ± 130 BP
    - The sub-carse (flat alluvial plain) rests on a surface between 30-36 ft above Ordnance Datum (OD)

- Description of peat extent
    - Hill peat covers wide expanses of high ground in Fintry and Gargunnock hills, in Ochil Hills and between Callander and Braco
    - At lower levels many poorly drained areas are occupied by deposits of basin peat, the largest of which lies on carse lands by the River Forth; this includes Flanders Moss, Ochtertyre, Dunmore and Letham. The basin peat would have been more extensive before the peat was stripped in the 18th and 19th centuries.
    - There is possible peat of Allerød age in the district. Pollen analysis from Ochtertyre Moss showed sub-Boreal and sub-Atlantic aged peat; Radiocarbon analysis from Flanders Moss gave a peat range from 5492 ± 130 to 1854 to 1858 ± 110 years B.P.
    - The peat base at Flanders Moss is ~30ft above OD (lower than carse layer in area).

- Economic Geology
    - NW of Stathallan between Uamh Bheag and Cromlet the average peat thickness is at least 6 ft over 18 sq. miles
    - Lesser but still considerable peat mosses also exist in Keltie Valley, in Gleann an Dubh Choirein, on Meall Leathan Dhail, on Lennieston Muir, on Meall a 'Choire Odhair and at Red Moss NW of Langside
    - The peat has been worked in at least two localities

- In Strathallan peat of Shelforkie Moss, west of Carsebreck, has been extensively worked although the bulk of deposit remains
- Extensive deposits of peat are also found in Ochill, Fintry, Gargunnock and the Touch hills, although there has been little or no exploitation in these relatively inaccessible areas.
- Peat was stripped in the 18^{th} century to create suitable land for agriculture and sold as fuel
- In recent times there has been peat cutting on Dunmore Moss and Letham Moss

* Specific information on the Eastern Part of Flanders Moss was examined in detail by the Moss Survey Group of the Scottish Peat Committee
    - Peat depth is fairly uniform and averages 4.5 m (14.8 ft); exceptions include a hollow in NE with a depth of < 7.5 m and the edges where consolidation has taken place as result of drainage and the depth is ~ 3 m
    - The total net amount of peat is 39 776 000 tons
    - Taking the mean moisture content as 92.7%, the total amount of soils is ~2 900 000 tons
    - Humification varies from H_2 to H_8 on Von Post's scale and the bulk of peat is H_4 to H_5

10.4 Information contained in 'Peat Surveys of Scotland'

* The peat surveys are a series of surveys of peat deposits in Scotland carried out by Peat Section of the Department of Agriculture and Fisheries for Scotland, under the general direction of the Scottish Peat Committee during the years 1949 to 1961. See Appendix I (as reproduced below) for full list of surveyed peats

* Flanders Moss East and Flanders Moss West form the largest peat deposit in the Midland Valley of Scotland covering ~ 3925 acres (1586 ha) and containing about four million tons of dry peat solids. Gartur bog, adjacent to Flanders Moss East, covers 1592 acres much of which is shallow

* The in depth the report contains information under the following headings: situation and access, area, proprietors (1950), geology, rainfall, surface features (topography, vegetation, firmness of surface, drainage), field records and analytical data (size and disposition of bog, peat botanical origin, humification, moisture content, bulk density, ash content, fibre content, chemical composition, basal soil description), classification, and utilisation (general, agriculture, afforestation, fuel, moss litter)

10.5 Appendix I: List of peatlands described by 'Peat Surveys of Scotland'

National Grid References were added using the Ordnance Survey 1:50 000 gazetteer.

DUMFRIESHIRE

Lochar Moss NY 041 720

WIGTOWNSHIRE

Blairderry (NX2661) , Grennan (NX2561) and Dergoals Mosses (NX2560)

Dirskelpin (NX2658), Mark of Luce (NX2959) and Knocketie Mosses (NX2858)

Moss of Cree NX4360

Knock Moss (NX2657)

Mindork Moss (NX3057)

Flow of Dergoals (NX2358) and Dirnean Fell (NX2557)

Annabaglish (NX2856), Drumdow (NX2956) and Ch**a**llochglass Mosses (NX2955) and Challochglass Moor (NX2955)

PERTHSHIRE

Flanders Moss East NS 6398

Gartur Bog NS5798 or NS7692

STIRLINGSHIRE

Flanders Moss West NS 6398

Gardrum NS 8975 and Darnrig Mosses NS 8675

AYRSHIRE

Airds Moss NS6024

MORAYSHIRE

Dava Moss NJ0038?

LANARKSHIRE

Ryeflat Moss NS9548

Cranley Moss NS9347

ARGYLLSHIRE

Achnacress Moss

Moine Mhor NR8293

MIDLOTHIAN

Harburn-Cobbinshaw Bogs NT0158?

CAITHNESS

Altnabreac Area NH4256

Achairn Bog ND3050
Shielton Bog ND2050

SHETLAND

Kame Bog HU3414?
Island of Yell HU4890

ORKNEY

White Moss HY4805
Glims Moss HY3122

RECONNAISANCE REPORTS:-

ORKNEY

Kame of Corrigall HY3320
Keelylang Hill HY3710
Veness Hill HY3705
Hobbister Hill HY3806

11 Annex 2: Emissions from peat extraction in the 1990-2009 inventory

Emissions for this category have been developed on the basis of the Tier 1 default methodology, which does not distinguish between peat extraction production phases (i.e. it includes conversion and vegetation clearing). Emissions are reported under 5.D.1 Wetlands remaining Wetlands (emissions under 5.D.2 Land converted to Wetlands are reported as being "Included Elsewhere"). All carbon in horticultural peat is assumed to be emitted off-site during the extraction year. Methane emissions are assumed to be insignificant but N_2O emissions from drainage are reported (although emissions are considered insignificant on nutrient-poor peatlands).

Table 18: Emissions from peat extraction in England 1990-2009

Year	Area undergoing peat extraction, ha[a]	On-site emissions, Gg C/yr	Offsite emissions from horticultural peat, Gg C/yr
1990	*5926*	-1.185	-62.21
1991	5854	-1.171	- 66.95
1992	*5783*	-1.157	-60.10
1993	*5712*	-1.142	-59.59
1994	*5641*	-1.128	-76.59
1995	*5570*	-1.114	-87.89
1996	*5498*	-1.100	-73.13
1997	*5427*	-1.085	-68.34
1998	*5356*	-1.071	-52.14
1999	*5285*	-1.057	-68.18
2000	*5214*	-1.043	-70.07
2001	*5142*	-1.028	-81.27
2002	*5071*	-1.014	-47.68
2003	*5000*	-1.000	-68.34
2004	*4929*	-0.986	-50.24
2005	*4858*	-0.972	-51.63
2006	*4787*	-0.957	-47.68
2007	*4715*	-0.943	-36.43
2008	*4644*	-0.929	- 25.34[b]
2009	4573	-0.915	-25.34[c]

[a] *Areas in italics are interpolated*

[b] *The value reported in the inventory did not take account of the corrected volumes, so this should be -27.63 Gg C*

[c] *Using the latest volumes reported in the 2009 Mineral Extraction report, this value would be -26.51 Gg C*

Table 19: Emissions from peat extraction in Scotland 1990-2009

Year	Area undergoing horticultural peat extraction, ha [a]	Area undergoing fuel peat extraction, ha [a]	On-site emissions from horticultural peat production, Gg C/yr	On-site emissions from fuel peat production, Gg C/yr	Offsite emissions from horticultural peat, Gg C/yr
1990	*1182.299*	*576.287*	-0.2365	-0.634	-16.330
1991	1173.794	560.109	-0.2348	-0.616	-13.424
1992	*1165.288*	*543.931*	-0.2331	-0.598	-18.492
1993	*1156.783*	*527.752*	-0.2314	-0.581	-17.073
1994	*1148.278*	*511.574*	-0.2297	-0.563	-27.739
1995	*1139.773*	*495.396*	-0.2280	-0.545	-36.595
1996	*1131.268*	*479.218*	-0.2263	-0.527	-28.797
1997	*1122.762*	*463.039*	-0.2246	-0.509	-18.492
1998	*1114.257*	*446.861*	-0.2229	-0.492	-5.960
1999	*1105.752*	*430.683*	-0.2212	-0.474	-21.834
2000	*1097.247*	*414.504*	-0.2194	-0.456	-18.715
2001	*1088.742*	*398.326*	-0.2177	-0.438	-18.103
2002	*1080.236*	*382.148*	-0.2160	-0.420	-5.960
2003	*1071.731*	*365.970*	-0.2143	-0.403	-41.274
2004	*1063.226*	*349.791*	-0.2126	-0.385	-18.827
2005	*1054.721*	*333.613*	-0.2109	-0.367	-30.969
2006	*1046.216*	*317.435*	-0.2092	-0.349	-39.658
2007	*1037.710*	*301.257*	-0.2075	-0.331	-12.310
2008	*1029.205*	*285.078*	-0.2058	-0.314	-13.535
2009	1020.7	268.9	-0.2041	-0.296	-13.535[b]

[a]*Areas in italics are interpolated*

[b] *Using the latest volumes reported in the 2009 Mineral Extraction report, this value would be -21.72 Gg C*

Table 20: Emissions from peat extraction in Wales 1990-2009

Year	Area undergoing peat extraction, ha [a]	On-site emissions, Gg C/yr	Offsite emissions from horticultural peat, Gg C/yr
1990	*479*	-0.0958	0
1991	*479*	-0.0958	0
1992	*479*	-0.0958	0
1993	*479*	-0.0958	0
1994	*479*	-0.0958	0
1995	*479*	-0.0958	0
1996	*479*	-0.0958	0
1997	*479*	-0.0958	0
1998	*479*	-0.0958	0
1999	*479*	-0.0958	0
2000	*479*	-0.0958	0
2001	*479*	-0.0958	0
2002	*479*	-0.0958	0
2003	*479*	-0.0958	0
2004	*479*	-0.0958	0
2005	*479*	-0.0958	0
2006	*479*	-0.0958	0
2007	*479*	-0.0958	0
2008	*479*	-0.0958	0
2009	479	-0.0958	0

[a] *Areas in italics are interpolated*

Table 21: Emissions from peat extraction in Northern Ireland 1990-2009

Year	Area undergoing horticultural peat extraction, ha [a]	Area undergoing fuel peat extraction, ha [a]	On-site emissions from horticultural peat production, Gg C/yr	On-site emissions from fuel peat production, Gg C/yr	Offsite emissions from horticultural peat, Gg C/yr
1990	576	3962	-0.115	-4.358	-29.995
1991	576	3962	-0.115	-4.358	-29.995
1992	*583*	*3736*	-0.117	-4.110	-30.451
1993	*590*	*3510*	-0.118	-3.861	-30.899
1994	*597*	*3284*	-0.119	-3.612	-31.337
1995	*604*	*3058*	-0.121	-3.364	-31.765
1996	*611*	*2832*	-0.122	-3.115	-32.183
1997	*618*	*2606*	-0.124	-2.866	-32.591
1998	*625*	*2380*	-0.125	-2.618	-32.988
1999	*633*	*2154*	-0.127	-2.369	-33.373
2000	*640*	*1928*	-0.128	-2.120	-33.747
2001	*647*	*1701*	-0.129	-1.872	-34.108
2002	*654*	*1475*	-0.131	-1.623	-34.457
2003	*661*	*1249*	-0.132	-1.374	-34.793
2004	*668*	*1023*	-0.134	-1.126	-35.116
2005	*675*	*797*	-0.135	-0.877	-35.425
2006	*682*	*571*	-0.136	-0.628	-35.720
2007	689	345.15	-0.138	-0.380	-36.000
2008	689	345.15	-0.138	-0.380	-36.000
2009	*689*	*345.15*	-0.138	*-0.379665*	-36.000

[a] *Areas in italics are interpolated*

Table 22: Emissions from peat extraction in the UK 1990-2009

Year	Area undergoing peat extraction, ha	On-site emissions, Gg C/yr	Offsite emissions from horticultural peat, Gg C/yr	Direct N_2O emissions , Gg N_2O/yr
1990	12.701	-6.625	-108.54	0.012837
1991	12.605	-6.591	-110.37	0.012791
1992	12.290	-6.310	-109.04	0.012106
1993	11.976	-6.029	-107.56	0.011421
1994	11.661	-5.748	-135.66	0.010736
1995	11.346	-5.467	-156.25	0.01005
1996	11.031	-5.186	-134.11	0.009365
1997	10.716	-4.905	-119.43	0.00868
1998	10.401	-4.624	-91.08	0.007995
1999	10.086	-4.343	-123.38	0.00731
2000	9.772	-4.062	-122.53	0.006625
2001	9.457	-3.781	-133.48	0.005939
2002	9.142	-3.500	-88.10	0.005254
2003	8.827	-3.219	-144.41	0.004569
2004	8.512	-2.938	-104.18	0.003884
2005	8.197	-2.657	-118.03	0.003199
2006	7.882	-2.376	-123.06	0.002514
2007	7.567	-2.095	-84.74	0.001828
2008	7.472	-2.062	-74.88[a]	0.001783
2009	7.376	-2.028	-74.88[b]	0.001737

[a] *Using the corrected value for England, this emission would be -77.17 Gg C*

[b] *Using the most recent values for England and Scotland, this emission would be -90.23 Gg C*

12 Glossary of Terms Used in this Report

Agricultural UK GHG Platform A Defra-funded consortium project which is aiming to improve the accuracy and resolution of our reporting system by providing new experimental evidence on the factors affecting emissions and statistics relevant to changing farming practices in the UK. For details see http://www.ghgplatform.org.uk/Home.aspx . Consists of three projects

AC0114 – Data synthesis, modelling and management

AC0115- Measurements of methane emissions from livestock and their manures

AC0116 – Measurement of nitrous oxide emissions from soils

Acrotelm Layer The upper layer of a peat bog, in which organic matter decomposes aerobically and much more rapidly than in the underlying, anaerobic catotelm.

Activity Data The land use / land use change data reported within LULUCF, including afforestation, deforestation, biomass burning (controlled and wildfires), crop yield improvement, harvested wood products, liming of agricultural land, lowland drainage, direct N_2O emissions from direct fertilisation of forests, peat extraction etc.

Aerenchyma An air channel in the roots of some plants, which allows exchange of gases between the shoot and the root. The channel of large air-filled cavities provides a low-resistance internal pathway for the exchange of gases such as oxygen and ethylene between the plant above the water and the submerged tissues

BGS British Geological Survey. For details see http://www.bgs.ac.uk/

Blanket Bog An area of wet peat-land that is fed exclusively by rainwater. Peat is a waterlogged soil that is composed of compacted partially decomposed vegetable matter. In the UK, blanket bog vegetation typically includes *Sphagnum* mosses, heather *Calluna vulgaris*, cross-leaved heath *Erica tetralix*, deergrass, *Trichophorum cespitosum*, and cotton grasses *Eriophorum* spp.

Bulk Density A measure of the weight of the soil per unit volume (g/cc), usually given on an oven-dry (110° C) basis. Variation in bulk density is attributable to the relative proportion and specific gravity of solid organic and inorganic particles and to the porosity of the soil.

Carbon Sequestration is the capture of carbon dioxide (CO_2) and may refer specifically to: The process of removing carbon from the atmosphere and depositing it in a reservoir, the process of carbon capture and storage, where carbon dioxide is removed from flue gases, such as on power stations, before being stored in underground reservoirs or natural biogeochemical cycling of carbon between the atmosphere and reservoirs, such as by chemical weathering of rocks.

Carbon Stock The quantity of carbon contained in a "pool", meaning a reservoir or system which has the capacity to accumulate or release carbon. In the context of forests it refers to the amount of carbon stored in the world's forest ecosystem, mainly in living biomass and soil, but to a lesser extent also in dead wood and litter.

Catotelm Layer The bottom layer of peat that is permanently below the water table. Under these anaerobic conditions, microbial activity and peat decomposition is very slow. The catotelm is composed of relatively decomposed compacted peat and water movements are slow.

CH_4 Methane, a relatively potent greenhouse gas. Compared with carbon dioxide, it has a high global warming potential of 72 (calculated over a period of 20 years) or 25 (for a time period of 100 years). It has a net lifetime of about 10 years, and is primarily removed by reaction with hydroxyl radicals in the atmosphere, producing carbon dioxide and water.

CO_2 Carbon Dioxide, a naturally occurring chemical compound composed of two oxygen atoms covalently bonded to a single carbon atom. It is a gas at standard temperature and pressure and exists in Earth's atmosphere in this state, as a trace gas at a concentration of 0.039% by volume.

DA Devolved Administration. Generally meaning the four countries (England, Scotland, Wales and Northern Ireland) that make up the UK

DCLG Department of Communities and Local Government (UK Government)

DECC Department of Energy and Climate Change (UK Government)

Defra Department of Environment, Food and Rural Affairs (UK Government)

Denitrification Microbially facilitated process of nitrate reduction that may ultimately produce molecular nitrogen (N_2) through a series of intermediate gaseous nitrogen oxide products. This respiratory process reduces oxidized forms of nitrogen in response to the oxidation of an electron donor such as organic matter. The preferred nitrogen electron acceptors in order of most to least thermodynamically favourable include nitrate (NO_3^-), nitrite (NO_2^-), nitric oxide (NO), and nitrous oxide (N_2O). In terms of the general nitrogen cycle, denitrification completes the cycle by returning N_2 to the atmosphere.

DOC Dissolved organic carbon

Durham Carbon Model Developed by Fred Worrall at Durham University to calculate the carbon budget of a peatland

ECOSSE Model developed to predict the impacts of changes in land use and climate change on greenhouse gas emissions from organic soils. ECOSSE stands for Estimating Carbon in Organic Soils - Sequestration and Emissions.

Emission Factor The relationship between the amounts of greenhouse gas produced per unit of activity, used to produce the greenhouse gas inventory.

ES0111 Defra-funded project "Development of a Database of Agricultural Drainage". This project aimed to develop a database of agricultural under-drainage which provides a description of the extent, type and maintenance of the drainage systems for England & Wales. http://randd.defra.gov.uk

Gg Giga grammes, unit of mass equivalent to kilotonnes (kT)

GHG Greenhouse Gases, gases which absorb and emit radiation within the thermal infrared range. GHGs covered in this report include CO_2, CH_4 and N_2O.

GIS Geographical Information System, a system designed to capture, store, manipulate, analyze, manage, and present all types of geographically referenced data.

GPG-LULUCF 2003 The 2003 Revision of the Good Practice Guidelines for compiling the LULUCF sector of the Greenhouse Gas Inventory

Grips Man-made drains that cut across the peat, channelling water into the catchment areas further downstream. By blocking grips water run-off is slowed down

Hyaline Cells Type of cells found on the leaf surface of *Sphagnum* which have thickened bands of supporting material, and often haves pores. These cells are dead at maturity, and serve to retain water.

Hypolimnion The dense, bottom layer of water in a thermally-stratified lake. It is the layer that lies below the thermocline. Typically the hypolimnion is the coldest layer of a lake in summer, and the warmest layer during winter. Being at depth, it is isolated from surface wind-mixing during summer, and usually receives insufficient irradiance (light) for photosynthesis to occur.

IPCC Intergovernmental Panel on Climate Change assesses the scientific, technical and socio-economic information relevant for the understanding of the risk of human-induced climate change.

IUCN International Union for Conservation of Nature, an organization which supports scientific research, manages field projects all over the world and brings governments, non-government organizations, United Nations agencies, companies and local communities together to develop and implement policy, laws and best practice.

JNCC Joint Nature Conservation Committee. The public body that advises the UK Government and devolved administrations on UK-wide and international nature conservation.

LULUCF Land Use, Land Use Change and Forestry, one of the sectors reported in the UK Greenhouse Gas Inventory.

LULUCF inventory project DECC-funded project to produce the annual LULUCF emissions and removals reported in the UK Greenhouse Gas Inventory. The next three-year project is 2012-2015. The Centre for Ecology & Hydrology are the main contractors, with input from Forest Research and AEA Technology.

Methanogenesis The formation of methane by microbes known as methanogens. Organisms capable of producing methane have been identified only from the domain Archaea, a group phylogenetically distinct from both eukaryotes and bacteria, although many live in close association with anaerobic bacteria. The production of methane is an important and widespread form of microbial metabolism. In most environments, it is the final step in the decomposition of biomass.

Methanotrophes Bacteria that are able to metabolize methane as their only source of carbon and energy. They can grow aerobically or anaerobically and require single-carbon compounds to survive.

Mineral Soil Any soil consisting primarily of mineral (sand, silt and clay) material, rather than organic matter.

N_2O nitrous oxide, a greenhouse gas with tremendous global warming potential. When compared to carbon dioxide (CO_2), N_2O has 310 times the ability to trap heat in the atmosphere. N_2O is produced naturally in the soil during the microbial processes of nitrification and denitrification.

Non-CO_2 The GHGs excluding CO_2, primarily CH_4 and N_2O

ONS Office of National Statistics (UK Government)

Organic Soil Any soil consisting primarily of organic material, rather than mineral matter (sand, silt and clay).

PIACS Scottish Government funded Pilot Project to determine the suitability of Integrated Administration and Control System (IACS) data to provide Land Use Change data for Annual Greenhouse Gas Emission Estimates. For further details see http://www.scotland.gov.uk/Publications/2011/05/05085633/0

SP0556 Defra- funded project "A compendium of UK Peat Restoration and Management Projects". Reported 2008. http://randd.defra.gov.uk/

SP0567 Defra- funded project "Assembling UK-wide data on soil carbon (and GHG fluxes) in the context of land management". Reported 2010. http://randd.defra.gov.uk/

SP0574 Defra- funded project "A literature review of evidence on emissions of methane in peatlands". Reported 2009. http://randd.defra.gov.uk/

SP1205 Defra-funded project "Greenhouse gas emissions associated with non gaseous losses of carbon- fate of particulate and dissolved carbon". Reporting 2013. http://randd.defra.gov.uk/

SP1210 Defra-funded project "Lowland peatland systems in England and Wales- evaluating greenhouse gas fluxes and carbon balances".

Tier 1 one of three methodological tiers for estimating greenhouse gas emissions and removals. Tier 1 employs the basic method and default emission factors published in the IPCC Good Practice Guidance for LULUCF (2003). Tier 1 methodologies usually use activity data that are spatially coarse, i.e. national or global level estimates.

Tier 2 one of three methodological tiers for estimating greenhouse gas emissions and removals. Tier 2 use the same methodological approaches as Tier 1 but applies region- or country-specific emission factors and higher-resolution activity data.

Tier 3 one of three methodological tiers for estimating greenhouse gas emissions and removals. Tier 3 methods use models and inventory measurement systems tailored to national circumstances, repeated over time, driven by high-resolution activity data and disaggregated to sub-national level.

UK GHG Inventory The UK Greenhouse Gas Inventory. An annual report outlining emissions and removals of greenhouse gases compiled for submission under the Framework Convention on Climate Change

UNFCCC United Nations Framework Convention on Climate Change, an international environmental treaty produced at the United Nations Conference on Environment and Development (UNCED), informally known as the Earth Summit, held in Rio de Janeiro from June 3 to 14, 1992. The objective of the treaty is to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.