Land Use Change and Forestry: The 1999 Greenhouse Gas Inventory for England, Scotland, Wales and Northern Ireland

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1. Introduction

Appendix 6 of the UK National GHG Inventory for 1990 to 1999 describes the methods for estimating removals and emissions of carbon dioxide due to Land Use Change and Forestry (LUCF) (Salway et al. 2001).

The estimates for Land Use Change and Forestry are from work carried out by the Centre for Ecology & Hydrology described in the scientific literature (Cannell et al 1999, Milne and Brown 1997, Milne et al. 1998) and in Contract Reports to DETR (Milne et al. 1999, 2000, Cruickshank & Tomlinson 2000). The data is reported under IPCC categories 5A (Changes in Forests and Other Woody Biomass), 5D (CO_2 Emissions from Soils) and 5E (Other). No data is included for Categories 5B (Forest and Grassland Conversion) or 5C (Abandonment of Managed Lands) as these are considered to be negligible, or not occurring, in the UK.

Here further detail is provided on: a) revision of estimates of CO_2 from soil in Scotland, b) methods used for emissions from soils in Northern Ireland and c) disaggregation of UK fluxes in category 5E (Other).

2. Changes in Forests and Other Woody Biomass Stocks (5A)

The UK GHG estimates for carbon uptake relating to changes in forests are based on data for the areas of forest plantation published by the UK Forestry Commission and the Northern Ireland Department of Agriculture (for 1999 data see Forestry Commission 2001, Forest Service 2000). The carbon uptake is calculated by a carbon accounting model (Dewar and Cannell 1992, Cannell and Dewar 1995, Milne et al. 1998) as the net change in pools of carbon in standing trees, litter, soil in broadleaf forests and products. All commercial forest is assumed to be restocked. It should be noted that for consistency with previous reports those parts of the net uptake by litter, soils and products are included in the data reported in category 5A for the National Report (Salway et al. 2001), but are included as a removals under the Soils category (5D) in Common Reporting Format tables. The litter and soils components of these Removals are also provided in footnotes to the National Report tables to allow comparison with data from countries that report only changes in woody biomass and exclude soils etc.

For the estimates described here we used the combined area of new private and state planting from 1921 to 1999 for England, Scotland, Wales and Northern Ireland sub-divided into conifers and broadleaves. Restocking was dealt with in the model through the second and subsequent rotations for the 'new' areas and hence areas restocked each year did not need to be considered separately.

The carbon flow model uses Forestry Commission Yield Tables to describe forest growth. It was assumed that all new conifer plantations have the same growth characteristics as Sitka spruce (*Picea sitchensis* (Bong.) Carr.) under an intermediate thinning management and in Great Britain followed the growth pattern of Yield Class 12 $m^3\ ha^{-1}\ a^{-1}$, but in Northern Ireland Yield Class 14 $m^3\ ha^{-1}\ a^{-1}$. It was assumed that all broadleaf forests had the characteristics of beech (*Fagus sylvatica* L.) of Yield Class 6 $m^3\ ha^{-1}\ a^{-1}$.

3 CO_2 Emissions and Removals from Soils (5D)

Three processes are reported in this category: changes in soil stocks due to land use change, change in soil stocks due specifically to the change in land use from arable in Set Aside schemes and emissions due to the application of lime and dolomite.

3.1 Land Use Change

3.1.1 Land Use Change in Great Britain

The basic method for assessing changes in soil carbon due to land use change in Great Britain is to use a matrix of change from surveys of land linked to a dynamic model of gain or loss of carbon. A database of soil carbon density for the UK has been constructed (Milne and Brown 1997, Cruickshank *et al.* 1998) from information provided by the Soil Survey and Land Research Centre, the Macaulay Land Use Research Institute and Queen's University Belfast on soil type, land cover and carbon content of soil cores. Deep peats in the North of Scotland are identified separately and depths to 5 m are included but these play a minor role in relation to land use change. MLURI reviewed and revised downwards the values of soil carbon density for some peaty soils types in Scotland for this 1999 Inventory.

The basis for estimating soil carbon densities in Scotland is the National Soil Map Of Scotland at 1:250, 000 scale. For each 1:250, 000 map unit the area of different soil types is recorded in a database e.g.:

Map unit 153: Peaty podzols; humus iron podzols; some peat and peaty gleys
Map unit 310: peaty gleys; humic gleys; some shallow peat.

For each 1 km x 1 km square in Scotland the area of each component soil series within the map unit was calculated. The dominant soil series for each square was then assigned. If 2 soils were of occurred equally then that with the greater carbon content (generally more peaty) was assigned dominance. In the latest revision all carbon in layers between the junction of the B & C horizons was neglected to match the method adopted by SSLRC for the soils of England and Wales. A lower detection level (0.2 rather than 0.5 g cm^{-3}) was assumed for carbon content under the present review. The bulk densities of peats were also reassessed. Values previously used by MLURI of 0.35 g cm^{-3} (still used for peats in England and Wales) were probably too large. Peat topsoils are more likely to be about 0.2 g cm^{-3}, and even lower for basin and blanket peats. Bulk density for basin and blanket peat have already been modified in this way by Milne & Brown (1997) and incorporated into the database for flux calculations, but the other changes notes above were included for the 1999 GHG Inventory. In Scotland, there is no soil carbon data for urban areas. Previously a value of zero had been assumed for these areas, but here a representative value of 18.6 t ha^{-1} was calculated from data for England and Wales and applied to urban squares in Scotland. (Note that all improvements introduced for a new Inventory are applied retrospectively for estimates for all years from 1990 to the latest year in the new Inventory). Table 1 summarises the improved soil carbon density data for Scotland.

Table 2 shows average values of soils carbon density for different land covers in the four devolved areas of the UK. The data of Table 2a shows no strong evidence of a major difference in the soil carbon density of tilled cropland or actively managed grass hence the inclusion of both uses within the Farm category in the flux calculations described below.

Table 1. Soil carbon in Scotland showing effect of revisions noted in text. ** Revised values determined by relative occurrence of urban squares marked as 'No Data' or 'Not soils' in soil survey database, but assigned carbon value of 18.6 t ha^{-1} here. ** Total soil carbon in Scotland, if depth restricted to 1 m for peats.*

Soil type	Area km^2	Original carbon kt	Revised carbon kt	Carbon above 1m kt
Alluvial soil (undiff)	1,161	27,438	20,382	
Alpine podzol	601	24,786	18,245	
Brown calcareous soil	435	2,309	7,382	
Brown forest soil	10,851	251,248	238,037	
Brown forest soil with gleying	3,628	72,570	57,652	
Brown magnesian soil	19	731	512	
Calcareous gley (GW)	77	505	1,167	
Complex	294	2,019	3,992	
Humus-iron podzol	9,315	359,547	214,156	
Immature raised beach soil	253	3,711	3,917	
Iron podzol	127	3,500	2,198	
Magnesian gley (SW)	91	2,051	1,905	
Noncalcareous gley	1,437	36,352	30,993	
Noncalcareous gley (GW)	10	199	137	
Noncalcareous gley (GW)?	32	516	413	
Noncalcareous gley (SW)	7,456	179,896	151,570	
Noncalcareous regosol	5	41	58	
Peat, basin	612	81,090	81,090	20,575
Peat, blanket	25,641	4,442,038	4,442,038	1,254,699
Peaty gley	4,620	363,846	157,746	
Peaty gley (GW)	13	270	307	
Peaty gley (SW)	2,998	229,961	107,938	
Peaty podzol	8,850	704,306	354,274	
Peaty ranker	656	46,617	18,218	
Podzolic ranker	78	4,560	1,706	
Saline alluvial soil	43	424	629	
Saline gley	90	317	1,665	
Subalpine podzol	2,900	101,584	84,422	
No data *	1,100	-	15,059	
Not soil *	1,408	-	5,032	
Miscellaneous	127	5,800	5,800	
TOTAL	**84,928**	**6,948,232**	**6,028,642**	**** 2,780,788**

Table 2. Average soil carbon density (t C ha^{-1}) for different land cover in the UK

Region / Cover	England	Scotland	Wales	N. Ireland
Natural	487	1048	305	551
Woodland	217	580	228	563
Arable	153	156	93	151
Pasture	170	192	200	178
Other	33	141	43	102

Matrices from the Monitoring Landscape Change (MLC) data from 1947 & 1980 (MLC 1986) and the DETR/ITE Countryside Surveys (CS) of 1984 & 1990 (Barr et al. 1993) describe areas of land changing use. Land use in the UK can be placed into 4 broad groups – (Semi) Natural, Farming, Woodland and Urban. The land use change data from the CS surveys are used initially to weight the mean change in equilibrium soil carbon used for England, Scotland and Wales (Table 3 a-c).

Table 3a. LUC area weighted mean change in equilibrium soil carbon (tC ha^{-1})for England

Initial / Final	Farm	Natural	Urban	Woods
Farm		-79	-8	-39
Natural	78		71	-20
Urban	9	-63		-24
Woods	38	20	31	

Table 3b LUC area weighted mean change in equilibrium soil carbon (tC ha^{-1}) for Scotland

Initial / Final	Farm	Natural	Urban	Woods
Farm		-410	85	-260
Natural	279		324	-30
Urban	-63	-286		-551
Woods	204	30	396	

Table 3c LUC area weighted mean change in equilibrium soil carbon (tC ha^{-1}) for Wales

Initial / Final	Farm	Natural	Urban	Woods
Farm		-30	40	-23
Natural	31		78	-10
Urban	-38	-72		-53
Woods	25	10	89	

The rate of loss or gain of carbon is also dependent on the type of land use transition (Table 4). For transitions where carbon is lost e.g. transition from Natural to Farm land, a ‘fast’ rate is applied whilst a transition which gains carbon occurs much more slowly. This ’slow’ rate had in the 1998, and earlier, GHG Inventories been set such that 99% of the change occurred in 100 years throughout GB. This rate was based on an estimate for Rothamsted soil by Howard *et al.* (1994). However, it was noted that due to the high carbon densities in Scottish soils that the uptake rates of carbon in that country were unreasonably large when land moved to the Natural class from the Farm class. For the 1998 Inventory the rate of uptake was therefore reduced until the uptake

of soil carbon in such transitions was less than the order of net primary productivity for cold temperate grasslands (about 300 g m^{-2} a^{-1}). Thus, a rate of soil carbon accumulation in Scotland equivalent to taking 800 years to reach 99% of a new value was used. Here, for the 1999 Inventory, a different approach to taking account of the uncertainty in such rates of transition was adopted. A literature search for information on measured rates of changes of soil carbon due to land use was carried out and, in combination with expert judgement, ranges of possible times for completion of different transitions were selected. These are shown in Table 5.

Table 4: Rates of change of soil carbon for land use change transitions. ("Fast" & "Slow" refer to 99% of change occurring in times shown in Table 7.

		1984			
		Farm	**Natural**	**Urban**	**Woods**
1990	**Farm**		*fast*	*slow*	*fast*
	Natural	*slow*		*slow*	*fast*
	Urban	*fast*	*fast*		*fast*
	Woods	*slow*	*slow*	*slow*	

Table 5: Range of times for soil carbon to reach 99% of a new value after a change in land use in England (E), Scotland (S) and Wales (W).

	Low (years)	**High (years)**
Carbon loss ("fast") E, S, W.	50	150
Carbon gain ("slow") E, W.	100	300
Carbon gain("slow") S.	300	750

The rates of change of soil carbon between the equilibrium values were then combined with time series of land use change in a model to produce the net change in stored soil carbon for England, Scotland and Wales for each year from 1990 to 1999. Each of these changes is an estimate of emission or removal of CO_2 relating to soils in a each region (Salway et al. 2001). The model of change in soil carbon was run 500 times with the time constant for change in soil carbon being selected separately, using a Monte Carlo approach, for England, Scotland and Wales from within the ranges of Table 5. The mean carbon flux for each region resulting from this imposed random variation was then used as the estimate for the Inventory. An adjustment was made after these calculations for each country to remove increases in soil carbon due to afforestation, because the value for this was considered to be better estimated by the C-Flow model used for the Changes in Forests and Other Woody Biomass Stocks (5A) category.

The range in the estimated changes in soil carbon is shown in Table 6. The large uncertainty in the estimates for each country due to uncertainty in the turnover rate of soil carbon and the importance of Scottish soils is clearly seen.

Table 6. Range of estimates of Emissions (+ve) /Removals (-ve) of CO_2 due to effect of land use change on soils from a Monte Carlo analysis.

ktC a^{-1}		**Minimum**	**Mean**	**Maximum**
Scotland	**1990**	1539	**2616**	3730
	1999	1385	**2732**	3879
England	**1990**	-1687	**186**	1845
	1999	-3226	**-438**	1580
Wales	**1990**	39	**159**	272
	1999	0	**151**	270

3.1.2 Land use change in Northern Ireland

For this region the default method of the IPCC Guidelines (IPCC 1997 a, b, c) continues to be used. A description of how the results are obtained is given by Cruickshank & Tomlinson (2000). A summary of the changes in land uses and the resulting changes in stored soil carbon for the 1999 Inventory are shown in Table 7.

For the 1999 Inventory the following points are relevant and illustrate some general difficulties with estimates of carbon emissions that depend on land use data:

- Through the mid to late 1990s the 'total area farmed' in the Agricultural Census for N. Ireland remained constant, but in 1999 this showed an increase of 4,500 ha on 1998. This figure is entirely reliant on the farmers' census returns so that an area of land may be included one year but not in another, which may only be due to failure to let/rent land.
- The Forest Service Annual Reports have become less informative recently and there is now no breakdown of the Forest Estate to enable semi-natural, peatland etc. to be estimated. In the absence of this information, it has been assumed that the trends of earlier years have continued.
- Urban area is estimated as the residual after all other land uses have been accounted and the value in 1999 was initially found to less than for 1998. This is not sensible. This was corrected by ignoring the increase in the 'farmed area', which then gives a residual urban area not too different from 1997 and 1998.

No uncertainty analyses have been carried out for the changes on soil carbon for Northern Ireland.

Table 7: Summary of changes in areas of land use and resulting changes in soil carbon in Northern Ireland using the IPCC "default" method.

kha	Arable	Grass	Semi-natural (not peat)	Semi-natural (peat/bog)	Urban	Carbon loss kt/yr
1970	96.9	740.3	249.9	149.0	40.4	
1971	94.4	745.2	248.0	148.4	40.6	
1972	84.2	759.5	233.5	147.8	47.7	
1973	77.6	754.5	227.8	147.1	65.2	
1974	74.8	761.1	239.1	146.5	49.6	
1975	73.4	758.5	226.5	145.9	65.7	
1976	79.2	773.9	226.1	145.3	44.6	
1977	82.9	772.5	214.8	144.7	53.3	
1978	79.9	776.1	210.1	144.1	57.4	
1979	76.8	777.1	219.0	143.5	50.4	
1990	61.5	797.9	212.6	136.9	67.7	-353
1991	62.8	806.1	210.9	135.5	61.2	-361
1992	64.0	800.3	202.6	134.9	70.9	-351
1993	63.0	817.2	199.9	134.9	57.2	-245
1994	57.6	814.8	197.2	134.9	66.6	-366
1995	56.4	819.1	191.0	134.9	68.7	-278
1996	56.5	821.0	188.9	134.9	67.8	-310
1997	58.1	826.7	184.2	134.9	64.4	-222
1998	57.4	832.3	177.7	134.9	65.3	-290
1999	54.8	835.2	177.3	134.9	64.7	-262

3.1.3 Changes in soil carbon in the UK

UK time series of changes in soil carbon reported in the UK Inventory (Salway et al. 2001) were calculated by adding the mean, maximum and minimum data from Scotland, England, Wales and Northern Ireland together to provide aggregate, mean, maximum and minimum. Mean, maximum and minimum values for Northern Ireland were all assumed to be given by the data from the default method.

3.2 Set Aside

The estimation of changes in soil carbon calculated by the matrix method for all transitions does not fully include the effects of the policy of Set Aside from production of arable areas. The data reported here therefore make a separate estimation not only of the effect of soil carbon increasing in areas where set aside land is not used for arable purposes but also the subsequent loss of the extra accumulated carbon from the soil when land is returned to arable use. Set Aside areas are taken from the Annual Farm Census for Scotland, England and Wales separately. Scottish soils coming out of arable use are assumed to be able to take up 300 t/ha but that this happens at a rate that would only allow 99% of that change to occur in 500 years. For English and Welsh soils it is assumed that the change in equilibrium soil carbon density would be 60 t/ha and that 99% of this change would occur in 200 years. These times fall in the middle of the ranges used in the main calculation for the effect of land use change causing an increase in soil carbon. See Salway et al. (2001) for

further information on these estimates. Northern Ireland has negligible change in soil carbon due to Set Aside

3.3 Emissions of CO_2 from soil due to liming

Emissions of carbon dioxide from the application of limestone, chalk and dolomite to agricultural soils were estimated for the UK using the IPCC (1997a, b, c) default method. Data on the use of limestone, chalk and dolomite for agricultural purposes is reported in BGS (2001). It is assumed that all the carbon contained in the lime is released in the year of use. For limestone and chalk, a factor of 120 t C/kt is used, and for dolomite application, 130 t C/kt. These factors are based on the stoichiometry of the reaction and assume pure limestone and dolomite. The UK data was disaggregated to the four devolved regions on the assumption that application is in the proportions 73 : 12 : 8 : 6 to England, Scotland, Wales and Northern Ireland. These proportions are based on the areas of tilled and grass in each region and data from the British Survey of Fertilisers Practice for the fractions of each area that are limed in each region.

4 Other sources and sinks (Table 5E)

These are:

Sources

- Drainage of afforested deep peat
- Drainage of lowland wetlands
- Peat extraction

and a sink

- Changes in crop biomass

The activity data and carbon fluxes for the devolved regions have been developed from estimates made for the UK.

4.1 Changes in Crop Biomass

This value was originally derived for the UK by Adger & Subak (1995) using Agricultural Census and other data up to 1992. From the 1998 Inventory onwards more recent data from the Agricultural Census were considered but did not support any change to the existing UK estimate. The rates for the devolved regions were estimated to be in the proportions 85 : 12 : 1 : 1 for England, Scotland, Wales and Northern Ireland, based on the areas of cropland in each region.

4.2 Peat Extraction

Trends in peat extraction in Scotland and England over period 1990 to 1999 are included. In Northern Ireland no new data on use of peat for horticultural use was available and a recent survey of extraction for fuel use suggested that there is no significant trend for this purpose. The contribution of emissions due to peat extraction in Northern Ireland is therefore included as constant from 1990 to 1999. Peat extraction is negligible in Wales. Activity data are from BGS (2001) and the emission factors are shown in Table 9. Further information is given by Cruickshank and Tomlinson (1997).

4.3 Lowland (fen) peat drainage

The trend in emissions due to changing areas of drainage is based on the work of Bradley (1997). All of the UK emission is assumed to be relate to England. The emission factor is shown in Table 8.

4.4 Upland (forestry) peat drainage

The area of forestry on peat is unlikely to change significantly under present afforestation policies. Emissions from planted areas tend to exist for considerable periods due to the large stock of carbon that is available for decomposition and hence the emissions included under this heading are reported as constant from 1990 to 1999. The UK total emission is allocated to each devolved region in proportion to an estimate of the area of afforested deep peat in each region. The emission factor is shown in Table 8. For further information see Cannell et al. (1993) and Hargreaves and Fowler (1997).

Table 8 Summary of emission factor data for Deep Peat Drainage and Lowland Wetland Drainage

	Emission Factor g $C/m^2/y$
Deep Peat Drainage	200
Lowland Wetland Drainage	297

Table 12 Summary of emission factor data for Peat Extraction (GB Great Britain, NI Northern Ireland)

	Emission Factor	
	kg C m^{-3}	Gg C/Gg
GB Horticultural Peat	55.7	-
GB Fuel Peat	55.7	-
NI Horticultural Peat	44.1	-
NI Fuel Peat	-	0.3

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