Appendix 5 Agriculture

CONTENTS

1   Livestock

The NAEI estimates emissions of methane from farm animals resulting from enteric fermentation and the storage and spreading of animal manures and slurries. The methane emission estimates were supplied by DEFRA (2001a).

1.1   ENTERIC EMISSIONS OF METHANE

Methane is produced in herbivores as a by-product of enteric fermentation, a digestive process by which carbohydrates are broken down by micro-organisms. Emissions are calculated from animal population data collected in the June Agricultural Census and published in DEFRA (2001b) and the appropriate emission factors. Data for earlier years are often revised so information was taken from the DEFRA agricultural statistics database. Table 1 shows the emission factors used. Apart from cattle, lambs and deer, the methane emission factors are IPCC Tier I defaults (IPCC, 1997) and do not change from year to year. The dairy cattle emission factors are estimated following the IPCC Tier 2 procedure (IPCC, 1997) and vary from year to year. For dairy cattle, the calculations are based on the population of the 'dairy breeding herd' rather than 'dairy cattle in milk' because the latter definition includes 'cows in calf but not in milk'. The emission factors for beef and other cattle were also calculated using the IPCC Tier 2 procedure (Table 3), but do not vary from year to year. The enteric emission factors for beef cattle were almost identical to the IPCC Tier I default so the default was used in the estimates. The base data and emission factors for 1990-2000 are given in Tables 2 and 3. The emission factor for lambs is assumed to be 40% of that for adult sheep. In using the animal population data, it is assumed that the reported number of animals are alive for that whole year. The exception is the treatment of sheep where it is normal practice to slaughter lambs and other non-breeding sheep after 6 to 9 months. Hence it is assumed that breeding sheep are alive the whole year but that lambs and other non-breeding sheep are only alive 6 months of a given year. The sheep emission factors in Table 1 are reported on the basis that the animals are alive the whole year.

Table 1 Methane Emission Factors for Livestock Emissions.

	Enteric Methane[a] kg CH_4/head/year	Methane from Manures[a] kg CH_4/head/year
Dairy Breeding Herd	116[b]	13.1[b]
Beef Herd	48	2.74
Others>1, Dairy Heiffers	48	6
Others<1	32.8	2.96
Pigs	1.5	3
Breeding Sheep	8	0.19
Other Sheep	8[e]	0.19[e]
Lambs < 1year	3.2[ce]	0.076[ce]
Goats	5	0.12
Horses	18	1.4
Deer (stags & hinds)	10.4[c]	0.26[c]
Deer (calves)	5.2[c]	0.13[c]
Poultry[d]	0	0.078

a	IPCC(1997)
b	Emission Factor for year 2000
c	Sneath *et al* (1997)
d	Chickens, turkeys, geese, ducks and guinea fowl.
e	Factor quoted assumes animal lives for a year. Emission calculation assumes animal lives for 6 months.

Table 2 Dairy Cattle Methane Emission Factors[1]

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Average Weight of cow (kg)[2]	550	556	561	567	572	578	584	590	596	602	608
Average Rate of Milk Production (liter/d)	14.3	14.2	14.5	14.7	14.7	15.0	15.1	15.9	16.1	16.4	16.6
Average Fat Content (%)	4.01	4.04	4.06	4.07	4.05	4.05	4.08	4.07	4.07	4.03	4.03
Enteric Emission Factor (kg CH_4/head/y)	104	104	106	107	107	109	110	113	114	115	116
Manure Emission Factor (kg CH_4/head/y)	11.7	11.7	12.0	12.1	12.1	12.3	12.4	12.7	12.9	13.0	13.1

1	43% of animals graze on good quality pasture, rest confined
	Gestation period 281 days
	Digestible Energy 65%
	Methane conversion rate 6%
	Ash content of manure 8%
	Methane Producing Capacity of Manure 0.24 m³/kg VS
2	Weight assuming annual growth of 1% from 1990.

Table 3 Beef and Other Cattle Methane Emission Factors[1]

	Beef Cattle	Other Cattle
Average Weight of Animal (kg)	500	180
Time Spent Grazing	50%	46%
GE (MJ/d)	123.3	83.4
Enteric Emission Factor (kg CH_4/head/y)	48.5[2]	32.8
Manure Emission Factor (kg CH_4/head/y)	2.74	2.96

1 Digestible Energy 65%
  Ash content of manure 8%
  Methane producing capacity of manure 0.24 m^3/kg VS
2 IPCC (1997) default (48 kg/head/y) used since calculated factor is very close to default and the difference under the Tier II method will not affect the accuracy of the emission factor at the required level of precision

1.2 METHANE EMISSIONS FROM ANIMAL MANURES.

Methane is produced from the decomposition of manure under anaerobic conditions. When manure is stored or treated as a liquid in a lagoon, pond or tank it tends to decompose anaerobically and produce a significant quantity of methane. When manure is handled as a solid or when it is deposited on pastures, it tends to decompose aerobically and little or no methane is produced. Hence the system of manure management used affects emission rates. Emissions of methane from animal manures are calculated from animal population data (DEFRA, 2001b) in the same way as the enteric emissions. The emission factors are listed in Table 1. Apart from cattle, lambs and deer, these are all IPCC Tier I defaults (IPCC, 1997) and do not change from year to year. The emission factors for lambs are assumed to be 40% of that for adult sheep. Emission factors for dairy cattle were calculated from the IPCC Tier 2 procedure using data shown in Tables 2 and 4 (DEFRA, 2001a). There has been some revision of the allocation of manure to the different management systems based on new data. This is discussed in more detail in Section 1.3. For dairy cattle, the calculations are based on the population of the 'dairy breeding herd' rather than 'dairy cattle in milk' used in earlier inventories as the latter definition includes 'cows in calf but not in milk'. The waste factors used for beef and other cattle are now calculated from the IPCC Tier 2 procedure but do not vary from year to year. Emission factors and base data for beef and other cattle are given in Table 3.

Table 4 Cattle Manure Management Systems in the UK

Manure Handling System	Methane Conversion Factor %[a]	Fraction of manure handled using manure system %	Fraction of manure handled using manure system %
		Dairy	Beef and Other
Pasture Range	1	45.5	50.5
Liquid System	10	30.6	6
Solid Storage	1	9.8	20.7
Daily Spread	0.1	14.1	23

  a **IPCC (1997)**

1.3 EMISSIONS OF NITROUS OXIDE FROM ANIMAL WASTE MANAGEMENT SYSTEMS

Animals are assumed not to give rise to nitrous oxide emissions directly, but emissions from their manures during storage are calculated for a number of animal waste management systems (AWMS) defined by IPCC. Emissions from the following AWMS are reported under the IPCC category, manure management.

- Flushing Anaerobic Lagoons. These are assumed not to be in use in the UK.
- Liquid systems
- Solid storage and dry lot (including farm-yard manure)
- Other systems (including poultry litter, stables)

According to IPCC(1997) guidelines, the following AWMS are reported in the Agricultural Soils category

- All applied animal manures and slurries
- Pasture range and paddock

Emissions from the combustion of poultry litter for electricity generation are reported under power stations.

The IPCC (1997) method for calculating emissions of N_2O from animal waste management systems can be expressed as:

$$N_2O_{(AWMS)} = 44/28 . \sum N_{(T)} . Nex_{(T)} . AWMS_{(T)} . EF_{(AWMS)}$$

where

$N_2O_{(AWMS)}$ = N_2O emissions from animal waste management systems (kg N_2O/yr)

$N_{(T)}$ = Number of animals of type T

$Nex_{(T)}$ = N excretion of animals of type T (kg N/animal/yr)

$AWMS_{(T)}$ = Fraction of Nex that is managed in one of the different waste management systems of type T

$EF_{(AWMS)}$ = N_2O emission factor for an AWMS (kg N_2O-N/kg of Nex in AWMS)

The summation takes place over all animal types and the AWMS of interest. Animal population data are taken from Agricultural Statistics (DEFRA, 2001b). Table 5 shows emission factors for nitrogen excretion per head for domestic livestock in the UK (Nex). These are based on a balance by Smith (1998). The UK methodology assumes that 20% of the total N emitted by livestock volatilises as NO_x and NH_3 and therefore does not contribute to N_2O emissions from AWMS. This is because in the absence of a more detailed split of NH_3 losses at the different stages of the manure handling process it has been assumed that NH_3 loss occurs prior to major N_2O losses. Hence the Nex factors used in the AWMS estimates and those reported in Tables 5 and 6 exclude the fraction of N volatilising. Hence they are 20% less than if they were reported on the same basis as the 'total' Nex factors reported in the IPCC Guidelines. The estimates of

total N excreted reported in the Common Reporting Format are not corrected in this way and report total N excreted from livestock.

Nex factors for dairy cattle take account of the assumed growth in the average cow weight by 1% per annum and are shown in Table 6. The conversion of excreted N into N_2O emissions is determined by the type of manure management system used. The distribution of waste management systems for each animal type ($AWMS_{(T)}$) is given in Table 7. The distributions used have been revised for cattle and poultry in the 2000 Inventory. The change relates to the way that data on 'no significant storage capacity' of farm yard manure (FYM) are allocated. This could have a large effect on emissions because it amounted to around 50% of manure. 'Daily spread' has an emission factor of 0, compared to that of solid storage and dry lot (SSD) of 0.02. However, we are advised (Smith, 2002) that:

In terms of slurry, it seems likely that where a proportion of the estimated slurry production is attributed with "nil" or little storage (<1 month capacity), as above, it can be assumed that such units will rely on a significant amount of daily-weekly spreading activity, according to land availability and trafficability, throughout. With FYM and poultry manure, however, significant storage capacity exists within the house and so, "no storage" generally implies that manure is cleared from the house/straw littered yard and spread direct on land. Storage capacity within the house or yard might comprise between 7 weeks – 12 months (poultry) or several months (cattle) and is unlikely to require "daily" spreading activity.

Therefore, assigning this 'stored in house' manure to 'daily spread' is acceptable only if emissions from the housing phase are thought to be very small. Calculations were performed with the N_2O Inventory of Farmed Livestock to compare housing and storage phases. For pigs and poultry, the emission factor for housing is the same as or greater than that of storage. It would therefore lead to significant underestimation to use the daily spread emission factor. All of the FYM in this case has therefore been re-allocated to SSD.

For dairy and non-dairy cattle, the emission factor for the housing phase is around 10% of the storage phase, so the non-stored FYM has been split between SSD and DS to account for this.

Table 8 gives the N_2O emission factor for each animal waste management system ($EF_{(AWMS)}$). These are expressed as the emission of N_2O-N per mass of excreted N processed by the waste management system.

Emissions from grazing animals (pasture range and paddock) and daily spread are calculated in the same way as the other AWMS. However, emissions from land spreading of manure that has previously been stored in liquid systems, other systems, solid storage and dry lot are treated differently. These are discussed in Section 2.6 on Organic Fertilizer.

Table 5 Nitrogen Excretion Factors for Animals in the UK[1]

Animal Type	Emission Factor kg N/animal/yr[2]
Dairy cows	94.9[3]
Other cattle > 2yr	60
Other cattle 1-2 yr	47
Other cattle >1	11.8
Pigs < 20kg	3
Other Pigs 20-50 kg	7.1
Fattening & Other Pigs > 50 kg	10.7
Breeding pigs > 50 kg	14.3
Breeding Sheep	9.2
Other Sheep <1	9.2[5]
Lambs	3.36[5]
Goats	7.2
Broilers	0.495
Broiler Breeders	0.899
Layers	0.589
Ducks,	0.984
Turkeys	1.052
Growing Pullets	0.106
Horses	32
Deer: Stags[4]	17.5
Deer: Hinds[4]	11.7
Deer: Calves[4]	8.64

1	Smith (1998)
2	Nex factors exclude 20% N volatilising as NO_x and NH_3
3	Estimate for year 1999
4	Sneath *et al,* (1997)
5	Factor quoted assumes animal lives for a year. Emission calculation assumes animal lives for 6 months.

Table 6 Nitrogen Excretion Factors for Dairy Cattle[1]

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Emission Factor kg N/animal/yr	84.8	85.8	86.8	87.7	88.7	89.8	90.8	91.8	92.9	93.8	94.9

1	Nex factors exclude 20% N volatilising as NO_x and NH_3

Table 7 Distribution of Animal Waste Management Systems used for Different Animal types[c]

Animal Type	Liquid System	Daily Spread	Solid Storage and dry lot[a]	Pasture range and paddock	Other[b]	Fuel
Dairy cows	30.6	14.1	9.8	45.5	0	
Other cattle	6	23	20.4	50.5	0	
Fattening & Other Pigs > 20 kg,	29.2	5.8	64	1	0	
Breeding sows	35.5	7.1	28	29.3	0	
Pigs <20kg	38.3	7.7	46	8	0	
Sheep	0	0	2	98	0	
Goats	0	0	0	96	4	
Broilers & Table Fowl (1999)				1	66	330
Breeders (1999)				1	99	
Layers [f]				10	90	0
Pullets [f]				10	90	
Ducks, Geese & Guinea Fowl[f]				50	50	0
Turkeys[f]				8	92	0
Horses				96	4	0
Deer: Stags[d]				100	0	
Deer: Hinds & Calves[d]				75	25	

a   Farmyard Manure
b   Poultry Litter, Stables
c   ADAS (1995a)
d   Sneath *et al* (1997)
f   Tucker (1997)

Table 8 Nitrous Oxide Emission Factors for Animal Waste Handling Systems[a]

Waste Handling System	Emission Factor kg N_2O-N per kg N excreted
Liquid System	0.001
Daily Spread[b]	0
Solid Storage and Dry Lot	0.02
Pasture, Range and Paddock[b]	0.02
Fuel	-
Other	0.005

a   IPCC(1997)
b   Reported under Agricultural Soils

2   Agricultural Soils

Direct emissions of nitrous oxide from agricultural soils are estimated using the IPCC recommended methodology (IPCC, 1997) but incorporating some UK specific parameters. The IPCC method involves estimating contributions from:

(i)   The use of inorganic fertilizer
(ii)   Biological fixation of nitrogen by crops
(iii)   Ploughing in crop residues
(iv)   Cultivation of histosols (organic soils)
(v)   Spreading animal manures on land
(vi)   Manures dropped by animals grazing in the field

In addition to these, the following indirect emission sources are estimated:

(vii)   Emission of N_2O from atmospheric deposition of agricultural NO_x and NH_3.
(viii) Emission of N_2O from leaching of agricultural nitrate and runoff.

Descriptions of the methods used follow.

2.1   INORGANIC FERTILISER

Emissions from the application of inorganic fertilizer are calculated using the IPCC (1997) methodology and IPCC default emission factors. They are given by:

$$N_2O_{(SN)} = 44/28 . N_{(FERT)} . (1-Frac_{(GASF)}) . EF_1$$

where
$N_2O_{(SN)}$ =   Emission of N_2O from synthetic fertiliser application
                            (kg N_2O/yr)
$N_{(FERT)}$ =   Total use of synthetic fertiliser (kg N/yr)
$Frac_{(GASF)}$ =   Fraction of synthetic fertiliser emitted as NO_x + NH_3
                  =   0.1 kg NH_3-N+NO_x-N / kg synthetic N applied
EF_1 =   Emission Factor for direct soil emissions
                  =   0.0125 kg N_2O-N/kg N input

Annual consumption of synthetic fertilizer is estimated based on crop areas (DEFRA, 2001b) and fertilizer application rates (BSFP, 2001).

2.2   BIOLOGICAL FIXATION OF NITROGEN BY CROPS

Emissions of nitrous oxide from the biological fixation of nitrogen by crops are calculated using the IPCC (1997) methodology and IPCC default emission factors. They are given by:

$$N_2O_{(BF)} = 44/28 . 2. Crop_{(BF)} . Frac_{(NCRBF)} . EF_1$$

where

$N_2O_{(BF)}$ = Emission of N_2O from biological fixation (kg N_2O/yr)
$Crop_{(BF)}$ = Production of legumes (kg dry mass/year)
$Frac_{(NCRBF)}$ = Fraction of nitrogen in N fixing crop
                  = 0.03 kg N/ kg dry mass
EF_1 = Emission Factor for direct soil emissions
                  = 0.0125 kg N_2O-N/kg N input

The factor of 2 converts the edible portion of the crop reported in agricultural statistics to the total biomass. The fraction of dry mass for the crops considered is given in Table 9

Table 9 Dry Mass Content and Residue Fraction of UK Crops

Crop Type	Fraction dry Mass[b]	Residue/ Crop
Broad Beans, Green Peas	0.08	1.1
Field Bean[d], Peas(harvest dry)	0.86	1.1
Rye, Mixed corn, triticale	0.855[a]	1.6
Wheat, Oats	0.855[a]	1.3
Barley	0.855[a]	1.2
Oil Seed Rape, Linseed	0.91[a]	1.2
Maize	0.50	1
Hops[c]	0.20	1.2
Potatoes	0.20	0.4
Roots, Onions	0.07	1.2
Brassicas	0.06	1.2
Sugar Beet	0.1	0.2
Other	0.05	1.2
Phaseolus beans	0.08	1.2

a   MAFF(2001b)
b   Burton (1982), Nix (1997) or MAFF estimates
c   Hops dry mass from Brewers Licensed Retail Association(1998)
d   Field beans dry mass from PGRE (1998)

The data for residue/crop are taken from IPCC (1997) defaults in the Agricultural Soils section, or derived from Table 4.17 of the Field Burning of Agricultural Residues section. Crop production data are taken from DEFRA (2000b,2000d). The total nitrous oxide emission reported also includes a contribution from improved grass calculated using a fixation rate of 4 kg N/ha/yr (Lord, 1997).

2.3   CROP RESIDUES

Emissions of nitrous oxide from the ploughing in of crop residues are calculated using the IPCC (1997) methodology and IPCC default emission factors. They are given by:

$$N_2O_{(CR)} = 44/28 \cdot 2 \cdot (Crop_O \cdot Frac_{(NCRO)} + Crop_{(BF)} \cdot Frac_{(NCRBF)})(1-Frac_R) \cdot (1-Frac_B) \cdot EF_1$$

where

$N_2O_{(CR)}$ = Emission of N_2O from crop residues (kg N_2O/yr)

$Crop_O$ = Production of non-N fixing crops (kg dm/yr)

$Frac_{(NCRO)}$ = Fraction of nitrogen in non-N fixing crops

= 0.015 kg N/ kg dm

$Frac_R$ = Fraction of crop that is remove from field as crop

$Frac_B$ = Fraction of crop residue that is burnt rather than left on field

EF_1 = Emission Factor for direct soil emissions

$$= 0.0125 \text{ kg } N_2\text{O-N/kg N input}$$

$\text{Crop}_{(BF)}$ = Production of legumes (kg dry mass/year)
$\text{Frac}_{(NCRBF)}$ = Fraction of nitrogen in N fixing crop
$= 0.03 \text{ kg N/ kg dry mass}$

Production data of crops are taken from DEFRA(2001b, 2001d). The dry mass fraction of crops and fraction of crop removed from the field are given in Table 9. Field burning has largely ceased in the UK since 1993. For years prior to 1993, field burning data were taken from the annual MAFF Straw Disposal Survey. (MAFF, 1995)

2.4 HISTOSOLS

Emissions from histosols were estimated using the IPCC(1997) default factor of 5 kg N_2O-N/ha/yr. The area of cultivated histosols is assumed to be equal to that of eutric organic soils in the UK and is based on a FAO soil map figure supplied by SSLRC.

2.5 GRAZING ANIMALS

Emissions from manure deposited by grazing animals are classified under agricultural soils by IPCC. The method of estimation is the same as that for AWMS in Section 1.3 but applying factors for pasture range and paddock.

2.6 ORGANIC FERTILIZERS

Emissions from animal manures and slurries used as organic fertilizers are classified under agricultural soils by IPCC. The procedure involves estimating the amount of nitrogen applied to the land and applying IPCC emission factors. For daily spreading of manure, the emission is given by:

$$N_2O_{(DS)} = 44/28 . \sum N_T . \text{Nex}_{(T)} . \text{AWMS}_{(T)} . EF_1$$

where

$N_2O_{(DS)}$ = N_2O emissions from daily spreading of wastes (kg N_2O/yr)
N_T = Number of animals of type T
$\text{Nex}_{(T)}$ = N excretion of animals of type T (kg N/animal/yr)
$\text{AWMS}_{(T)}$ = Fraction of Nex that is daily spread
EF_1 = Emission Factor for direct soil emissions
$= 0.0125 \text{ kg } N_2\text{O-N/kg N input}$

For the application of previously stored manures to land, a correction is applied to account for previous N_2O losses during storage.

$$N_2O_{(FAW)} = 44/28 . \sum (N_T . \text{Nex}_{(T)} . \text{AWMS}_{(T)} - N_{(AWMS)}) . EF_1$$

where

$N_2O_{(FAW)}$ = N_2O emission from organic fertiliser application

$N_{(AWMS)}$ = N_2O emissions from animal waste management systems as
nitrogen (kg N_2O-N/yr)

N_T =   Number of animals of type T

$Nex_{(T)}$ =   N excretion of animals of type T (kg N/animal/yr)

$AWMS_{(T)}$ =   Fraction of Nex that is managed in one of the different
waste management systems of type T

The summation is for all animal types and for liquid system, solid storage and other systems
where wastes are stored.

2.7 ATMOSPHERIC DEPOSITION OF NO_x AND NH_3

Indirect emissions of N_2O from the atmospheric deposition of ammonia and NO_x are estimated
according to the IPCC (1997) methodology but with corrections to avoid double counting N.
The sources of ammonia and NO_x considered, are synthetic fertiliser application and animal
manures applied as fertiliser.

The contribution from synthetic fertilisers is given by:

$$N_2O_{(DSN)} = 44/28 \cdot (N_{(FERT)} - N_{(SN)}) \cdot Frac_{(GASF)} \cdot EF_4$$

where

$N_2O_{(DSN)}$ =   Atmospheric deposition emission of N_2O arising from synthetic
fertiliser application (kg N_2O)

$N_{(FERT)}$ =   Total mass of nitrogen applied as synthetic fertiliser (kg N)

$N_{(SN)}$ =   Direct emission of $N_2O_{(SN)}$ as nitrogen (kg N_2O-N)

$Frac_{(GASF)}$ =   Fraction of total synthetic fertiliser nitrogen that is emitted
as NO_x + NH_3

     =   0.1 kg N/ kg N

EF_4 =   N deposition emission factor

     =   0.01 kg N_2O-N/kg NH_3-N and NO_x-N emitted

The estimate includes a correction to avoid double counting N_2O emitted from synthetic
fertiliser use.

The indirect contribution from waste management systems is given by

$$N_2O_{(DWS)} = 44/28 \cdot (N_{(EX)}/(1-Frac_{(GASM)}) - N_{(F)}) \cdot Frac_{(GASM)} \cdot EF_4$$

where

$N_2O_{(DWS)}$ =   Atmospheric deposition emission of N_2O arising from animal
wastes(kg N_2O)

$N_{(EX)}$ =   Total N excreted by animals

$Frac_{(GASM)}$ =   Fraction of livestock nitrogen excretion that volatilises as
NH_3 and NO_x

     =   0.2 kg N/kg N

$N_{(F)}$ =   Total N content of wastes used as fuel (kg N)

The equation corrects for the N content of manures used as fuel but no longer for the N lost in the direct emission of N_2O from animal manures as previously. The nitrogen excretion data in Table 5 already exclude volatilisation losses and hence a correction is included for this.

2.8 LEACHING AND RUNOFF

Indirect emissions of N_2O from leaching and runoff are estimated according the IPCC methodology but with corrections to avoid double counting N. The sources of nitrogen considered, are synthetic fertiliser application and animal manures applied as fertiliser.

The contribution from synthetic fertilisers is given by:

$$N_2O_{(LSN)} = 44/28 \cdot (N_{(FERT)} \cdot (1\text{-}Frac_{(GASF)}) - N_{(SN)}) \cdot Frac_{(LEACH)} \cdot EF_5$$

where

$N_2O_{(LSN)} =$ Leaching and runoff emission of N_2O arising from synthetic fertiliser

               application (kg N_2O)

$N_{(FERT)} =$ Total mass of nitrogen applied as synthetic fertiliser (kg N)

$N_{(SN)} =$ Direct emission of $N_2O_{(SN)}$ as nitrogen (kg N_2O-N)

$Frac_{(GASF)} =$ fraction of total synthetic fertiliser nitrogen that is emitted as $NO_x + NH_3$

         =   0.1 kg N/ kg N

$Frac_{(LEACH)}$ =   Fraction of nitrogen input to soils that is lost through leaching and runoff

         =   0.3 kg N/ kg fertiliser or manure N

EF_5 =   Nitrogen leaching/runoff factor

         =   0.025 kg N_2O-N /kg N leaching/runoff

The estimate includes a correction to avoid double counting N_2O emitted from synthetic fertiliser use.

The indirect contribution from waste management systems is given by

$$N_2O_{(LWS)} = 44/28 \cdot (N_{(EX)} - N_{(F)} - N_{(WS)}) \cdot Frac_{(LEACH)} \cdot EF_5$$

where

$N_2O_{(LWS)} =$ Leaching and runoff emission of N_2O from animal wastes (kg N_2O)

$N_{(EX)} =$ Total N excreted by animals (kg N)

$N_{(F)} =$ Total N content of wastes used as fuel (kg N)

$N_{(AWMS)} =$ Total N content of N_2O emissions from waste management systems including daily spread and pasture range and paddock (kg N_2O-N)

The equation corrects both for the N lost in the direct emission of N_2O from animal wastes and the N content of wastes used as fuel.

3   Field Burning.

The NAEI estimates emissions from field burning under the category agricultural incineration. The estimates are derived from emission factors calculated according to IPCC (1997) and from USEPA (1997) shown in Table 10

Table 10 Emission Factors for Field Burning (kg/t)

	CH_4	CO	NO_x	N_2O	NMVOC
Barley	3.05[a]	63.9[a]	2.18[a]	0.060[a]	7.5[b]
Other	3.24[a]	67.9[a]	2.32[a]	0.064[a]	9[b]

a   IPCC(1997)
b   USEPA (1997)

The estimates of the masses of residue burnt of barley, oats, wheat and linseed are based on crop production data (DEFRA, 2001d) and data on the fraction of crop residues burnt (MAFF, 1997; ADAS (1995b)). Field burning ceased in 1993 in England and Wales. Burning in Scotland and Northern Ireland is considered negligible, as is grouse moor burning, so no estimates are reported from 1993 onwards. The carbon dioxide emissions are not estimated because these are part of the annual carbon cycle.

4   Quality Assurance

The livestock activity data used for constructing the inventory are supplied annually by DEFRA Economics and Statistics Group, who have specific QA procedures they adhere to from the June census. Activity data on mineral fertiliser are calculated using application rates from DEFRA's Annual British Survey of Fertiliser Practice (see reference list) multiplied by crop areas in DEFRA's Survey of Farming Incomes (June Census). Data from the June Census, in the form of *.PDF files, can be downloaded from the DEFRA website (www.defra.gov.uk) and incorporated into inventory spreadsheets without the need for manual data entry and "double entry". Annual comparisons of the emission factors and co-efficient used are made by contractors compiling the inventory on behalf of DEFRA and by DEFRA personally. Any changes are documented in the spreadsheet and in the accompanying chapter of the National Inventory Report. Hardcopies of the submitted inventories, plus associated Emails, copies of activity data, are filed in Government secure files adhering to Government rules on document management.

DEFRA contractors who work on compiling the agricultural inventory, IGER, operate strict internal quality assurance systems with a management team for each project overseen by an experienced scientist with expertise in the topic area. A Laboratory Notebook scheme provides quality control through all phases of the research and these are archived in secure facilities at the

end of the project. All experiments are approved by a consultant statistician at each of the planning, data analysis and interpretation and synthesis stages. A range of internal checks exist to ensure that projects run to schedule, and internal and external (*viz.* Visiting Group procedures etc.) reviews ensure the quality of the outputs.

5   References

ADAS (1995a) - personal communication to A Croxford (MAFF). Distribution of animal waste management systems for cattle

ADAS (1995b) personal communication to A Croxford MAFF. Linseed burning data

Agricultural Economics Unit Exeter University. (1996). The Structure of Pig Production in England & Wales: The Results of the National Survey of Pig Production Systems. Special Studies in Agricultural Economics Report No 33 ISBN 1 870558 38 3. Distribution of animal waste management systems for pigs.

Brewers Licensed Retail Association (January 1998) - personal communication to R Gerry (MAFF). Estimate of dry matter content of hops.

BSFP, (2001). British Survey of Fertiliser Practice: Fertiliser Use on Farm Crops for Crop Year 2000, MAFF, FMA, SO. ISBN 0 11 495885 8. Published by the Stationery Office (2001) (Data for preceding years comes from earlier versions of the same publication)

Burton, (1982), Post-Harvest Physiology of Crops, Longman, London, ISBN 0-582-46038-7

DEFRA, (2001a), Personal communications from S Ellis, Rural and Marine Environment Division.

DEFRA, (2001b), Agriculture in the UK 1999, The Stationary Office, London.

DEFRA (2001d), Basic Horticultural Statistics for the United Kingdom. Calendar and crop years 1984-2000.

IPCC, (1997), IPCC Revised 1996 Guidelines for National Greenhouse Gas Inventories, Volume 3, Greenhouse Gas Inventory Reference Manual, IPCC WGI Technical Support Unit, Hadley Centre, Meteorological Office, Bracknell, UK.

Lord, E (1997). Factor for biological nitrogen fixation by improved grass pers comm to S Gleave (MAFF)

MAFF, (1995), Straw Disposal Survey. Data for earlier years taken from previous editions of the survey. Field burning data. Contact Government Buildings Epsom Rd Guildford Surrey GU1 2LD for copies.

MAFF, (1997), Farm Incomes in the UK 1995/96,The Stationery Office, London, ISBN 0-11-2543026-0.

Nix, J, (1997), Farm Management Pocket Book 1998, 28th ed., Wye College Press, Ashford

PGRE, (1998), personal communication to R Gerry (MAFF). Estimate of dry matter content of field beans - January 1998

Smith, K, (1998), Personal communication from K Smith, ADAS.

Smith, K, (2002), Personal communication from K Smith, ADAS.

Sneath, RW, Chadwick DR, Phillips VR & Pain BF, (1997). A UK inventory of Methane (/Nitrous Oxide) Emissions from farmed Livestock. Two contract reports to MAFF for projects WA0604/5 from SRI/IGER, ADAS

Tucker, S, Canning, P,(1997), ADAS (30 Oct 1997) personal communication to D Wilkins (MAFF)

USEPA, (1997), United States Environmental Protection Agency, Compilation of Air Pollutant Emission Factors. Vol 1, 5th Edition, AP-42, North Carolina.

Appendix 6
Land Use Change and Forestry

CONTENTS

1   Introduction[1]

The estimates for Land Use Change and Forestry are from work carried out by the Centre for Ecology & Hydrology (Cannell *et al* 1999, Milne and Brown 1999). The data are reported under IPCC categories 5A (Changes in Forests and Other Woody Biomass, 5C (CO_2 Emissions from Soils) and 5E (Other). No data are 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 we present a description of the methods used and compare the format for data presentation used in this National Inventory Report compared to that used for the UNFCCC Common Reporting Format (CRF).

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

The estimates are based on data for the areas of forest plantation published by the UK Forestry Commission and the Northern Ireland Department of Agriculture. 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 part of the net uptake by litter and soils is reported in category 5D in the UNFCCC CRF submission. The values of these removals are provided in Section 4 to allow comparison with data from countries which report only changes in woody biomass and include soils etc. elsewhere and to detail the differences between reporting here and in the UNFCCC CRF.

The carbon accounting model of Dewar and Cannell (1992) calculated the mass of carbon in trees, litter, soil and wood products from harvested material in new even-aged plantations that were clearfelled and then replanted at the time of Maximum Area Increment (MAI). Two types of input data and two parameter sets were required for the model (Cannell and Dewar, 1995). The input data are a) areas of new forest planted in each year in the past and b) the stemwood growth rate and harvesting pattern. Parameter values were required to estimate i) stemwood, foliage, branch and root masses from the stemwood volume and ii) the decomposition rates of litter, soil carbon and wood products.

For the estimates described here we used the combined area of new private and state planting from 1921 to 1996 for England, Scotland, Wales and Northern Ireland sub-divided into conifers and broadleaves (Milne *et al* 1998). 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.

---

[1] The land use change and forestry chapter was provided by R Milne, Centre for Ecology & Hydrology, Bush Estate, Penicuik, EH26 OQB

The carbon flow model uses Forestry Commission Yield Tables (Edwards and Christie, 1981) 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. Milne *et al.* (1998) have shown that mean Yield Class for Sitka spruce varied across Great Britain from 10 to 16 m^3 ha^{-1} a^{-1} but with no obvious geographical pattern and that this variation had a less than 10% effect on estimated carbon uptake. The Inventory data have therefore been estimated by assuming all conifers 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}, Sitka spruce. Milne *et al.* (1998) also showed little effect of different assumptions on broadleaf species. Hence it was assumed here, that broadleaf forests had the characteristics of beech (*Fagus sylvatica* L.) of Yield Class 6 m^3 ha^{-1} a^{-1} .

Increases in stemwood volume were based on standard Yield Tables, as in Dewar and Cannell (1992) and Cannell and Dewar (1995), and the mass of carbon in a forest was calculated from this volume by multiplying by wood density, stem to branch and root mass ratios and the fraction of carbon in wood (0.5 assumed). The values used for these parameters for conifers and broadleaves are given in Table 1.

Table 1: Main parameters for forest carbon flow model for species used to estimates carbon uptake by planting of forests of Sitka spruce (P. sitchensis) and beech (F. sylvatica) in United Kingdom (data from Dewar & Cannell, 1992).

	P. sitchensis	*P. sitchensis*	*F. sylvatica*
	YC12	**YC14**	**YC6**
Rotation (years)	59	57	92
Initial spacing (m)	2	2	1.2
Year of first thinning	25	23	30
Stemwood density (t m^{-3})	0.36	0.35	0.55
Max. carbon in foliage (t ha^{-1})	5.4	6.3	1.8
Max. carbon in fine roots (t ha^{-1})	2.7	2.7	2.7
Fraction of wood in branches	0.09	0.09	0.18
Fraction of wood in woody roots	0.19	0.19	0.16
Max. foliage litterfall (t ha^{-1} a^{-1})	1.1	1.3	2
Max. fine root litter loss (t ha^{-1} a^{-1})	2.7	2.7	2.7
Foliage decay rate (a^{-1})	1	1	3
Wood decay rate (a^{-1})	0.06	0.06	0.04
Fine root decay rate (a^{-1})	1.5	1.5	1.5
Soil organic carbon decay rate (a^{-1})	0.03	0.03	0.03
Fraction of litter lost to soil organic matter	0.5	0.5	0.5

The parameters controlling the transfer of carbon into the litter pools and its subsequent decay are given in Table 1. Litter transfer rate from foliage and fine roots increased to a maximum at canopy closure. A fraction of the litter was assumed to decay each year, half of which added to the soil organic matter pool that then decayed at a slower rate. The decay of litter and soil

matter was assumed to be controlled only by tree species and Yield Class and unaffected by other factors that varied with location. Additional litter was generated at times of thinning and felling.

As in Cannell and Dewar (1995) it was assumed that conifer forests increased the amount of organic carbon in litter but did not increase the net amount of carbon in soil due to gains from the new forest being balanced by loss due to the disturbance at planting. Broadleaved forests were assumed to increase the net amount of carbon in litter and soil. Harvested material from thinning and felling, which is made into wood products, was assumed to decay over a period equal to the rotation of the forest, conifer or broadleaf as appropriate, since products from broadleaves (e.g. furniture) will decay more slowly than those from conifers (e.g. paper, building timber). A detailed description of all the assumptions in the model was given by Dewar and Cannell (1992) and Cannell and Dewar (1995).

Variation from year to year in the reported removals to woody biomass, soils and harvested products reflect the changing pattern of afforestation over the period of available data. For example, there are increases in removals to harvested products about 50 years (the forest rotation cycle) after a period of increased planting of conifers.

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

The basic method for assessing changes in soil carbon due to land use change is to use a matrix of change from surveys of land linked to a dynamic model of gain or loss of carbon. In the latest version of the method matrices from the Monitoring Landscape Change (MLC) data from 1947 & 1980 and the DETR/ITE Countryside Surveys (CS) of 1984 & 1990 are used. Land use in the UK can be placed into 4 broad groups – (Semi) Natural, Farming, Woodland and Urban – and hence the more detailed categories for the two surveys were combined as shown in Table 3a for MLC and 3b for CS. In both cases only unimproved grassland is included in the Natural category. For the CS the different types of grass are shown in Table 4.

A database of soil carbon density for the UK has been constructed (Milne and Brown 1995, 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. These densities include carbon to a depth of 1 m or to bedrock whichever is the shallower, for mineral and peaty/mineral soils. 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 the 1999 Inventory. 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 2 show 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.

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

Table 3a: Grouping of MLC land cover types for soil carbon change modelling.

FARM	NATURAL	WOODLAND	URBAN
Crops	Upland heath	Broadleaved wood	Built up
Market garden	Upland smooth grass	Conifer wood	Urban open
Improved grassland	Upland coarse grass	Mixed wood	Transport
Rough pasture	Blanket bog		Mineral workings
	Bracken		Derelict
	Lowland rough grass		
	Lowland heather		
	Neglected grassland		
	Marsh		

Table 3b: Grouping of CS land cover types for soil carbon change modelling. For Managed grass (I) signifies "Improved", usually by ploughing and seeding, (U) signifies "Unimproved" by such means.

FARM	NATURAL	WOODLAND	URBAN
Tilled land	Rough grass/marsh	Broadleaved/mixed	Communications
Managed grass(I)	Managed grass (U)	Coniferous	Built up
	Dense bracken		Inland bare (Hard areas)
	Moorland grass		
	Dense heath		
	Open heath		

Table 4: Different types of CS land cover included in the "Improved" and "Unimproved" groups for soil carbon modelling.

Managed grass (I)	Managed grass (U)
Recreational	Non-agricultural improved
Recently sown	Calcareous
Pure rye	Upland
Well managed	
Weedy swards	

Table 5: Area and change data sources for different periods in estimation of changes in soil carbon. (1) Stamp (1962), (2) MLC (1986), (3) Barr *et al.* (1993).

Year or Period	Area data	Change matrix or data
1930	Land use Survey (1)	
1930 – 1947	Interpolated	MLC 1947->MLC1980
1947	MLC (2)	
1947-1980	Interpolated	MLC 1947->MLC1980
1980	MLC (2)	
1980-1984	Interpolated	Interpolated
1984	CS1984 (3)	
1984-1990	Interpolated	CS1984->CS1990
1990	CS1990 (3)	
1990-2010	Extrapolated from 84->90	CS1984->CS1990

Area data exist for the period 1930 to 1990 and those from 1984 to 1990 are used to extrapolate forward for the years 1991 to 1998. Land use change matrices for the periods 1947 to 1980 and 1984 to 1990 are used. See Table 5 for the sources of information for land use and matrices of change.

The core equation describing changes in soil carbon with time for any land use transition is

$$C_t = C_f - (C_f - C_0)e^{-kt}$$

C_t is carbon density at time t
C_0 is carbon density initially
C_f carbon density after change to new land use
k is time constant of change

If the inventory year is 1990 and A_T is area in a particular land use transition in year T considered from 1930 onwards then total carbon lost or gained from 1930 to 1990 (X_{1990}) and from 1930 to 1989 (X_{1989}) is given by

$$X_{1990} = \sum_{T=1930}^{t=1990} A_T (C_0 - C_f)(1 - e^{-k(1990-T)})$$

$$X_{1989} = \sum_{T=1930}^{T=1989} A_T (C_0 - C_f)(1 - e^{-k(1989-T)})$$

Hence flux of carbon in 1990 is given by difference:

$$F_{1990} = X_{1990} - X_{1989}$$

The land use transitions considered are each of those between the (Semi) Natural, Farm, Woodland and Urban categories. Scotland, England and Wales are treated separately. Northern Ireland does not yet have a matrix of land use change and changes in soil carbon are calculated by a method based on that recommended by the IPCC (1997b, c). The area data for Great Britain are shown in Table 6. The data from the CS have had a small adjustment applied to account for one of the detailed land types (Non-cropped arable) actually bridging the main Natural and Farm categories.

Table 6a: Area of land in England for each use category from field and area surveys (1) Stamp (1962), (2) MLC (1986), (3) Barr *et al.* (1993).

Source	Year	Area(ha)			
		Farm	**Natural**	**Urban**	**Woodland**
lus (1)	*1930*	9,542,340	1,543,000	1,034,858	843,800
mlc (2)	*1947*	9,242,777	1,639,511	823,665	865,370
mlc (2)	*1980*	9,013,401	1,307,178	1,301,965	948,779
cis (3)	*1984*	8,670,815	1,908,436	1,249,383	1,303,455
cis (3)	*1990*	8,336,428	2,120,609	1,323,084	1,353,399

Table 6b: Area of land in Wales for each use category from field and area surveys (1) Stamp (1962), (2) MLC (1986), (3) Barr *et al.* (1993).

Source	Year	Area(ha)			
		Farm	**Natural**	**Urban**	**Woodland**
lus (1)	*1930*	1,094,187	771,520	77,298	120,439
mlc (2)	*1947*	1,061,571	701,347	71,422	160,077
mlc (2)	*1980*	1,148,150	521,131	121,459	203,677
cis (3)	*1984*	1,155,174	585,248	176,112	221,521
cis (3)	*1990*	1,132,768	593,918	188,628	222,953

Table 6c: Area of land in Scotland for each use category from field and area surveys (1) Stamp (1962), (2) MLC (1986), (3) Barr *et al.* (1993).

		Area(ha)			
Source	Year	**Farm**	**Natural**	**Urban**	**Woodland**
lus (1)	*1930*	1,861,215	5,265,673	146,906	443,187
mlc (2)	*1947*	2,037,860	5,209,630	260,313	447,753
mlc (2)	*1980*	2,100,125	4,667,711	297,076	890,644
cis (3)	*1984*	2,109,333	4,940,892	287,471	1,019,931
cis (3)	*1990*	2,059,553	4,935,184	294,291	1,068,543

In the model, the change is required in equilibrium carbon density from the initial to the final land use during a transition. Here, these are calculated for each land use category as averages for Scotland, England and Wales. In order to account for variation in carbon density and Land Use Change in different soil types these averages are weighted by the area of soil groups used by IPCC (1997c). They define five groups, which are represented in Great Britain, on the basis of their carbon content and activity namely; aquic, high activity clay, low activity clay, sandy and organic. In Great Britain few clay soils truly fall into the 'high activity' class so the *total clay content* is used to divide these soils into 'high' and 'low' groups. For Great Britain all soil types not falling into these five types an 'undefined' groups is used. Mean soil carbon density change are calculated as:

$$\overline{C}_{ijc} = \frac{\sum_{s=1}^{6}(C_{sijc}L_{sijc})}{\sum_{s=1}^{6}L_{sijc}}$$

which is the weighted mean, for each country, of change in equilibrium soil carbon when land use changes and
i = initial land use (Natural, Farm, Woods, Urban)
j = new land use   (Natural, Farm, Woods, Urban)
c = country   (Scotland, England & Wales)
s = soil group (High clay, low clay, aquic, organic, sandy, undefined)
C_{sijc} is change in equilibrium soil carbon for a specific land use transition
within a soil group region in a specific country
L_{sijc} is area change (1984 to 1990) for a specific land use transition within a soil group region in a specific country.
The rate of loss or gain of carbon is dependent on the type of land use transition (Table 8). 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 as had been observed at Rothamsted (Howard *et al.* 1994). However, it was observed 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 which took the equivalent of 800 years to reach 99% of the new values was used. Since the 1999 Inventory, a different approach to taking account of the uncertainty in such rates of transition has been 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 7.

Table 7: 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

Table 8: 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*	

The model of change was then 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 7. The mean carbon flux for each region resulting from this imposed random variation was then reported as the estimate for the Inventory. An adjustment was made to these calculations for each country to remove increases in soil carbon due to afforestation, as 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.

Variation from year to year in the reported net emissions reflect the trend in land use change as described by the matrix of change between 1984 and 1990. New survey data covering changes between 1990 and 1998 have recently become available and this will be used to improve estimation of the trend of emissions and removals in future Inventories

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. This is the case because although the schemes were introduced in 1988 there was a slow rate of acceptance by farmers and it was not until after 1990 that significant areas are recorded in the Annual Farm Census. In this post-1990 period the matrix method uses an extrapolation of the CS field data from 1984 to 1990 therefore a separate estimate of the effect of Set Aside on soil

carbon for these later years has been made. Data reported in inventories prior to 1997 were based on the observation from the Annual Farm Census that Set Aside was continuing to increase in total area. However from more recent Census data it would seem that the total area has now passed its maximum and is beginning to fall. This reflects the fact that the Schemes will be phased out, to be replaced with others with different objectives. The data reported here therefore take into account not only the effect of soil carbon increasing in areas where land is not used for arable purposes but 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 and England & 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 & 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. The new areas of land in Set Aside are calculated from the increases in area up to the maximum total recorded area (in 1995 throughout GB). The emission of carbon from these areas are calculated for years up until 1999 when it is assumed that all land will have returned to arable. To compensate for the reducing area, two assumptions were made: a) the area lost in each year from 1995 onwards was assumed to have been in Set Aside for 3 years and b) the carbon gained in these 3 years would be lost at a rate which would cause 99% of the change to occur in 20 years. The 3 year assumption is made as there is no clear indication of how long any area does remain in Set Aside. This value is not unreasonable but may be low given that some Set Aside could have existed from 1988. Prior to the 1998 Inventory it was assumed that all Set Aside was simply abandoned but between 30 and 50% is actually managed by cutting etc. Such areas will not be very different from other rotational pasture situations that we have already shown to have similar soil carbon to arable areas. Hence such areas have been excluded from estimates of the effect of Set Aside reported here.

Thus for the estimates reported here the assumptions are: Set Aside area rises to a maximum in 1995 then falls away to zero by 1999, uptake occurs slowly in Scotland and 50% of areas in the Agricultural Census are in rotational form of management are excluded. 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. Data on the use of limestone, chalk and dolomite for agricultural purposes are 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.

4   Other Sources and Sinks (5E)

These are:
A sink
- Changes in crop biomass

and 3 sources
- Drainage of upland deep peat
- Drainage of lowland wetlands
- Peat extraction

The activity data and carbon fluxes are based on data from Adger and Subak (1996) for the sink and from Bradley (1997), Cannell *et al.* (1993), Cruickshank *et al.* (1997), Hargreaves and Fowler (1997) for the sources.

4.1   CHANGES IN CROP BIOMASS

Adger and Subak (1996) estimated recent changes in carbon storage in biomass on non-forest lands in the U.K., including land used for agriculture, horticulture and urbanization. The land area converted to forest was specifically excluded to avoid overlap with estimates for Table 5A. They used agricultural census statistics for the period 1988-1992 published by the Ministry of Agriculture, Fisheries and Food. These statistics are strongly correlated with agricultural land cover data in 1984 and 1990 U.K. Countryside Surveys, which were used to calculate changes in soil carbon on non-forest lands, so the two estimates are considered to be compatible.

Two carbon sinks were quantified. First, 0.23 MtC a^{-1} was estimated to be accumulating in biomass as a result, mainly, of (i) the transfer of land from arable crops with 2.2 tC ha^{-1} biomass to set-aside land with 5.0 tC ha^{-1} biomass, (ii) the establishment of woodlands on farms in response to financial incentives (Farm Woodland Scheme and Farm Woodland Premium), assuming that these woodlands increased in biomass by 2.8 tC ha^{-1} a^{-1}, (iii) the transfer of agricultural land to urban uses, assuming that urban land has an average carbon density of 3 tC ha^{-1} and (iv) the transfer of rough grass to permanent grass.

Second, 0.14 MtC a^{-1} was estimated to be accumulating on agricultural land, without a change in crop type, on the assumption that the annual average standing biomass has increased linearly with yield. Most of this component was due to increases in cereal yields.

Thus, the total increase in biomass on agricultural land was estimated to be 0.37 MtC a^{-1}. However, this is an upper bound, because some of the farm woodlands were also counted in Forestry Commission statistics which were used to calculate the forest biomass carbon for Table 5A, and because increases in `harvest index' mean that crop biomass generally increases proportionately less than yield. Thus, the lower estimate for this component of 0.3 MtC a^{-1} ±30% has been adopted. From the 1998 Inventory onwards more recent data from the Agricultural Census were considered but did not support any change to the existing estimate. This rate is therefore reported for all years from 1990 to 2000.

4.2   PEAT EXTRACTION

Trends in peat extraction in Scotland and England over period 1990 to 2000 are included. In Northern Ireland no new data on use of peat for horticultural use were 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 is therefore incorporated as constant from 1990 to 2000. Peat extraction is negligible in Wales.

4.3   LOWLAND (FEN) PEAT DRAINAGE

The trend in emissions due to changing areas of drainage is based on the work of Bradley (1997).

4.4   UPLAND (FORESTRY) PEAT DRAINAGE

The area of forestry on peat is unlikely to have changed due to present policy. 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 sources are summarised in Tables 9 and 10.

Table 9 Summary of Emission Factor Data for Upland Drainage and Lowland Wetland Drainage

	Emission Factor $g\ C/m^2/y$
Upland Drainage	200
Lowland Wetland Drainage	297

Table 10 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

5 Data Presentation Formats

Emissions and removals of CO_2 for the Land Use Change and Forestry Sector are presented here in a different format that that used for the Common Reporting Format (CRF) submission to the UNFCCC. This has arisen since clarification was given in the guidance for use of the CRF on how emissions and removals for soils should be treated. However, to maintain historical consistency, the format for reporting in the LUCF Sector used in this National Inventory Report has not been changed from that used previously. Table 11 shows the processes affected. Tables 12, 13a and 13b give more detail on the effect of the different formats on the reported emissions and removals. The reported net emission for the LUCF Sector is not affected by the use of the different formats.

Table 11. Categories used for reporting soils emissions and removals in National Inventory Report and UNFCCC Common Reporting Format

Process	National Inventory Report	Common Reporting Format
Removals to forest soils and litter	5A2 (Removal)	5D (Removal)
Removals to agricultural soils due to Set Aside	As part of a net emission in 5D (Emission)	5D (Removal)
Emissions from soils due to upland drainage	5E (Emission)	5D (Emission)
Emissions from soils due to lowland drainage	5E (Emission)	5D (Emission)

Table 12 Emissions and removals of carbon dioxide by processes in Land Use Change and Forestry Sector. The reporting categories used in the National Inventory Report and for the UNFCCC Common Reporting Format are also shown. (IE Included Elsewhere.)

Process	Gg CO$_2$	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	NIR	CRF
Temperate forest	Removal	-5731.00	-5819.00	-6321.33	-6864.00	-7095.00	-7604.67	-7271.00	-7205.00	-6985.00	-6827.33	-7157.33	5A2	5A2
Other (Harvested wood)	Removal	-1573.00	-1576.67	-1349.33	-1118.33	-1096.33	-913.00	-1155.00	-1111.00	-1199.00	-1294.33	-1151.33	5A5	5A5
Forest soils	Removal	-2152.33	-2170.67	-2075.33	-1991.00	-1994.67	-1910.33	-2086.33	-2141.33	-2244.00	-2317.33	-2244.00	5A2	5D
Mineral soils	Emission	14186.61	14144.58	13879.86	13231.45	13438.55	12809.63	12842.92	12315.72	12106.06	12197.79	11743.41	5D	5D
Mineral soils	Removal	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	5D	5D
Organic soils	Emission	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	5D	5D
Organic soils	Removal	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	5D	5D
Liming	Emission	1430.45	1771.95	1809.58	1130.32	1269.82	1529.44	1515.16	1346.38	1026.52	859.32	768.68	5D	5D
Other (Set Aside)	Removal	-177.75	-263.86	-351.14	-465.25	-1897.02	-2006.88	-1542.40	-1006.69	-136.08	-298.09	-1071.21	5D	5D
Other (Set Aside)	Emission	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5D	5D
Other (Lowland Drainage)	Emission	1650.00	1613.33	1576.67	1540.00	1503.33	1466.67	1430.00	1393.33	1356.67	1320.00	1283.33	5E	5D
Other (Upland Drainage)	Emission	1466.67	1466.67	1466.67	1466.67	1466.67	1466.67	1466.67	1466.67	1466.67	1466.67	1466.67	5E	5D
Peat extraction	Emission	791.57	802.60	791.57	780.54	888.79	949.85	868.98	814.85	703.55	821.60	816.08	5E	5E
Changes in crop biomass	Removal	-1100.00	-1100.00	-1100.00	-1100.00	-1100.00	-1100.00	-1100.00	-1100.00	-1100.00	-1100.00	-1100.00	5E	5E

Table 13a Emissions and removals in categories with the Land Use Change and Forestry Sector as reported in the format used for the National Inventory Report. (IE Included Elsewhere.)

NIR	Gg Carbon	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Category	
Temperate forest	Removal	-7883.33	-7989.67	-8396.67	-8855.00	-9089.67	-9515.00	-9357.33	-9346.33	-9229.00	-9144.67	-9401.33	5A2	Sum of removals to forest biomass, forest litter and forest soil
Harvested wood	Removal	-1573.00	-1576.67	-1349.33	-1118.33	-1096.33	-913.00	-1155.00	-1111.00	-1199.00	-1294.33	-1151.33	5A5	Removals to Harvested wood
Soils	Emission	15439.30	15652.66	15338.31	13896.53	12811.34	12332.19	12815.68	12655.41	12996.50	12759.02	11440.89	5D	Sum of emissions from soils and removals to soils due to land use change (not forestry), Set Aside and liming of agricultural land
Soils	Removal	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	5D	
Sub Total	Emission	3908.24	3882.60	3834.90	3787.21	3858.79	3883.19	3765.64	3674.85	3526.88	3608.26	3566.08	5E	Sum of emissions from soils due to upland drainage, lowland drainage and peat extraction
Sub Total	Removal	-1100.00	-1100.00	-1100.00	-1100.00	-1100.00	-1100.00	-1100.00	-1100.00	-1100.00	-1100.00	-1100.00	5E	Increases in crop biomass
Total	Emission	19347.54	19535.26	19173.21	17683.73	16670.13	16215.38	16581.32	16330.26	16523.38	16367.28	15006.97	5	Gross LUCF Emissions
Total	Removal	-10556.33	-10666.33	-10846.00	-11073.33	-11286.00	-11528.00	-11612.33	-11557.33	-11528.00	-11539.00	-11652.67	5	Gross LUCF Removals
Total	Net	8791.21	8868.93	8327.21	6610.40	5384.13	4687.38	4968.99	4772.93	4995.38	4828.28	3354.30	5	Net LUCF Emissions

Table 13b Emissions and removals in categories with the Land Use Change and Forestry Sector as reported in the format used for the UNFCCC Common Reporting Format. (IE Included Elsewhere)

CRF	Gg Carbon	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Category	
Temperate forest	Removal	-5731.00	-5819.00	-6321.33	-6864.00	-7095.00	-7604.67	-7271.00	-7205.00	-6985.00	-6827.33	-7157.33	5A2	Removals to forest biomass.
Harvested wood	Removal	-1573.00	-1576.67	-1349.33	-1118.33	-1096.33	-913.00	-1155.00	-1111.00	-1199.00	-1294.33	-1151.33	5A5	Removals to Harvested wood
Soils	Emission	18733.72	18996.53	18732.78	17368.44	17678.37	17272.40	17254.75	16522.10	15955.92	15843.77	15262.09	5D	Sum of emissions from soils due to land use change on agricultural soils (net emissions), upland drainage, lowland drainage and liming of agricultural land
Soils	Removal	-2330.08	-2434.53	-2426.47	-2456.25	-3891.69	-3917.21	-3628.74	-3148.03	-2380.08	-2615.42	-3315.21	5D	Sum of removals to forest soils and litter and to agricultural soils due to Set Aside.
Other	Emission	791.57	802.60	791.57	780.54	888.79	949.85	868.98	814.85	703.55	821.60	816.08	5E	Emissions from soils due to peat extraction
Other	Removal	-1100.00	-1100.00	-1100.00	-1100.00	-1100.00	-1100.00	-1100.00	-1100.00	-1100.00	-1100.00	-1100.00	5E	Removals due to increases in crop biomass
Total	Emission	19525.29	19799.13	19524.35	18148.98	18567.15	18222.25	18123.73	17336.95	16659.46	16665.37	16078.18	5	Gross LUCF Emissions
Total	Removal	-10734.08	-10930.20	-11197.14	-11538.58	-13183.02	-13534.88	-13154.74	-12564.03	-11664.08	-11837.09	-12723.87	5	Gross LUCF Removals
Total	Net	8791.21	8868.93	8327.21	6610.40	5384.13	4687.38	4968.99	4772.93	4995.38	4828.28	3354.30	5	Net LUCF Emissions

6 Quality Assurance Methods and Standards

CEH has put in place high quality assurance standards, and selects subcontractors from professional organisations who meet those standards. The general standards are:

- The use of professionally qualified staff.
- The application of rigorous quality control procedures.
- The use of modern equipment.
- The use of validated methods.
- The quality control and curation of databases.
- The establishment of management procedures to ensure compliance.

The particular quality control measures relevant to this report are as follows.

Databases
The databases used to calculate carbon sources and sinks are all quality controlled at source by the responsible organisation, e.g. CEH for land use, SSLRC and MLURI for soils and FC for forestry statistics.

Models
All modelling is done by trained staff, who now have many years' experience of simulating changes in soil and biomass carbon. The output of models is checked against quality assured data. Predictions of future sources and sinks are bench marked against predictions made by other researchers in Europe through a COST E21, other research meetings and the scientific literature.

Output
The integrity of results, the quality of the reports, the relationship to contracted deliverables and the punctuality of reporting, are all subject to management vetting and tracking within CEH, through the Heads of Sections, Directors of Sites and the Finance Administration. Additionally, all staff are required to publish as much non-confidential scientific information in the peer reviewed scientific literature, with the prior approval of the customer and customer acknowledgement.

Field measurements of sources and sinks
All fieldwork, sampling and data handling is done by experienced and trained staff to defined protocols agreed to meet the objectives of the work. The procedures for flux measurement are fully documented and instruments are calibrated directly with primary standards.

Chemical analysis
All chemical analyses are done at CEH, Merlewood and are supported by full quality assurance and control procedures under BS 5750. The integrity of results is checked by conducting bi-monthly inter-laboratory comparisons (Aquachecks and the International Soil Exchange Scheme).

7   References

Adger, N. & Subak, S. (1995) Carbon fluxes resulting from Land Use Change: Land Use Data and Policy. In: Carbon Sequestration in Vegetation and Soils (Ed. by MGR Cannell), DOE/ITE Contract EPG 1/1/3. Interim Report March 1995. Department of Environment, London.

Barr, CJ, Bunce, RGH, Clarke, RT, Fuller, RM., Furse, MT, Gillespie, MK., Groom, GB, Hallam, C.J, Hornung, M, Howard, DC, Ness, MJ, (1993) Countryside Survey 1990, Main Report. London, Department of the Environment.

BGS (2001), United Kingdom Minerals Yearbook 1, British Geological Survey, Natural Environment Research Council

Bradley, I, (1997) Carbon loss from drained lowland fens. In: Carbon Sequestration in Vegetation and Soils (Ed. by MGR Cannell), DOE/ITE Contract EPG 1/1/3. Final Report March 1997. Department of Environment, London.

Cannell, MGR, Dewar, RC, (1995), The carbon sink provided by plantation forests and their products in Britain, Forestry, Vol. 68, No. 1, pp 35-48.

Cannell, MGR, Milne, R, Hargreaves, KJ, Brown, TAW, Cruickshank, MM, Bradley, RI, Spencer, T, Hope, D, Billett, MF, Adger, WN & Subak, S (1999) National inventories of terrestrial carbon sources and sinks: the UK experience. Climatic Change 42, 505-530

Cruickshank, MM, Tomlinson, RW, Devine, PM, Milne, R (1997) Effects of agricultural, management on carbon storage in Northern Ireland. In: *Carbon Sequestration in Vegetation and Soils* (Ed. by MGR Cannell), DOE Contract EPG 1/1/3. Final Report March 1997. Department of Environment, London.

Cruickshank, MM, Tomlinson, RW (1997) Carbon loss from UK peatlands for fuel and horticulture. In: Carbon Sequestration in Vegetation and Soils (Ed. by MGR Cannell), DOE, Contract EPG 1/1/3. Final Report March 1997. Department of Environment, London.

Cruickshank, MM, Tomlinson, RW, Devine, PM and Milne, R (1998) Carbon in the vegetation and soils of Northern Ireland. Proceedings of the Royal Irish Academy, 98B, 9 - 21.

Dewar, RC, Cannell, MGR, (1992) Carbon sequestration in the trees, products and soils of forest plantations: an analysis using UK examples. Tree Physiology Vol. 11, pp49 - 72.

DOE, (1997), Climate Change: The UK Programme; United Kingdom's Second Report under the Framework Convention on Climate Change, The Stationary Office, London.

Hargreaves, K and Fowler, D (1997) Short-term CO_2 fluxes over peatland. In: Carbon Sequestration in Vegetation and Soils (Ed. by MGR Cannell), DOE Contract EPG 1/1/3. Final Report March 1997. Department of Environment, London

Howard, PJA and Howard, DM (1994) Modelling the effects of land use change and climate change on soil organic carbon stores. In: Carbon sequestration by soils in the UK, Report to the Department of the Environment, Contract No. PECD 7/12/80, March 1994.

IPCC, (1997a), IPCC Revised 1996 Guidelines for National Greenhouse Gas Inventories, Volume 1, Greenhouse Gas Inventory Reporting Instructions, IPCC WGI Technical Support Unit, Hadley Centre, Meteorological Office, Bracknell, UK.

IPCC, (1997b), IPCC Revised 1996 Guidelines for National Greenhouse Gas Inventories, Volume 2, Greenhouse Gas Inventory Workbook, IPCC WGI Technical Support Unit, Hadley Centre, Meteorological Office, Bracknell, UK.

IPCC, (1997c), IPCC Revised 1996 Guidelines for National Greenhouse Gas Inventories, Volume 3, Greenhouse Gas Inventory Reference Manual, IPCC WGI Technical Support Unit, Hadley Centre, Meteorological Office, Bracknell, UK.

Milne, R and Brown, TA (1997) Carbon in the vegetation and soils of Great Britain. Journal of Environmental Management, 49, 413 - 433.

Milne, R, and Brown, TA (1999) Methods and data for Land Use Change and Forestry Sector in the 1997 IPCC Greenhouse Gas Inventory. In.: *Carbon Sequestration in Vegetation and Soils* (Ed. by R. Milne), DETR Contract EPG 1/1/39. Interim Report April 1999.

Milne, R, Brown, TAW and Murray, TD (1998) The effect of geographical variation in planting rate on the uptake of carbon by new forests of Great Britain. Forestry, 71, 298 – 309.

MLC (1986) *Monitoring Landscape Change* Vols. 1, 1A & 10. Report prepared by Hunting Surveys & Consultants Ltd for Department of the Environment and the Countryside Commission.

Stamp, LD (1962) *The Land of Britain: Its Use and Misuse.* London, Longman