

Section 5

Development of a MATLAB/Simulink Version of the UK LULUCF GHG Inventory for Quality Control and Other Purposes

Table of Contents

5. Development of a MATLAB/Simulink version of the UK LULUCF GHG Inventory for quality control and other purposes.....	5-1
5.1. Introduction	5-1
5.2. LULUCF Inventory data.....	5-1
5.3. Model Details	5-7
5.3.1. <i>Input Data Module</i>	5-7
5.3.1.(a) Land Types UK submodule.....	5-7
5.3.1.(b) Liming.....	5-10
5.3.1.(c) Upland Drainage.....	5-13
5.3.1.(d) Lowland Drainage.....	5-14
5.3.1.(e) Peat Extraction	5-15
5.3.1.(f) Crop Biomass.....	5-16
5.3.1.(g) Set Aside	5-17
5.3.1.(h) Soils.....	5-18
5.3.1.(i) Deforestation.....	5-18
5.3.2. <i>Country Data, Summary Data & Output Modules</i>	5-18
5.4. References	5-18

5. Development of a MATLAB/Simulink version of the UK LULUCF GHG Inventory for quality control and other purposes

D.C. Mobbs and R. Milne

CEH Edinburgh, Bush Estate, Penicuik, Midlothian, EH26 0QB

May 2004

5.1. Introduction

A review of the LULUCF Inventory procedure is being carried out as part of a quality assurance and quality control exercise. The current hierarchy of linked spreadsheets has evolved over several years with a view to completing the existing Common Reporting Format (CRF) sheets; this format is due to change making it an appropriate time to reassess the LULUCF Inventory compilation system and implement quality assurance and control procedures.

5.2. LULUCF Inventory data

The current system for preparing the LULUCF inventory data consists of multiple spreadsheets. The basic data is assembled from various sources and organised into separate worksheets by category; for example data relating to set-aside, peat or liming are in individual worksheets while the output from forest models is copied into another worksheet. The data is processed appropriately into the four country divisions and the required summary data calculated in other higher-level spreadsheets. Finally the data are entered into the common reporting format files (Figure 5-1).

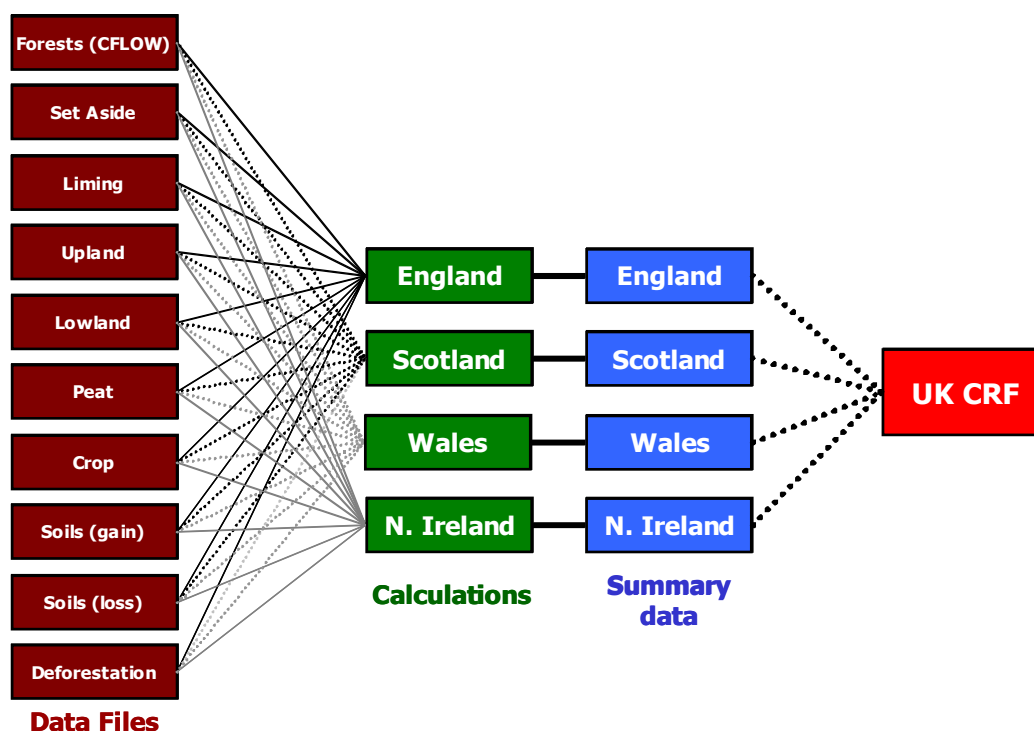


Figure 5-1: The LULUCF Inventory data is organised in a hierarchy of spreadsheets. Each block represents an Excel Workbook which may have one or more sheets.

New or revised output from models or other sources must be entered in the relevant sheet of a workbook, and subsequent calculations updated in all the linked spreadsheets. Each year, all the spreadsheets are duplicated and updated for the annual submissions.

A review of the LULUCF Inventory procedure has been carried out as part of a QA/QC exercise. Although the multiple spreadsheet format is accessible and flexible, care must be taken to maintain correct links between spreadsheets, especially if more than one person is updating the information. Documentation is often in separate files so there is duplication of effort copying tables etc. Some information, *e.g.* land use data, is included in more than one spreadsheet so has to be updated several times. The current spreadsheets have evolved over several years with a view to completing the existing Common Reporting Format (CRF); this format is due to change making it an appropriate time to reassess the LULUCF Inventory procedures.

Some alternative approaches have been considered.

- Oracle - transferring and maintaining the inventory data in an efficient and effective *Oracle* relational database would require experience with the software package and, even with the necessary skills, would be a time-consuming exercise. Oracle may be used in future.
- Matlab/Simulink – Matlab is a high-performance language for technical computing. It integrates computation, visualization and programming in an easy-to-use environment. Simulink is an associated software package that enables you to model, simulate, and analyse systems whose outputs change over time. Matlab/Simulink together allow models, data and documentation to be assembled and analysed in one place, has high quality graphical output and, importantly for this exercise, is available for use immediately.

A system is being developed in which the LULUCF Inventory is represented as a Simulink Model. The current layout is similar to the spreadsheet format in that the data input submodel feeds key output to the calculation submodels, the processed data is then compiled in the appropriate format for submission (see Figure 5-2). Work to date has concentrated on the data input methods as the output format is to be changed so the end presentation is not finalised.

The Simulink model system is useful in allowing documentation and references to be kept together with the data. This enables a detailed record to be kept about the origin and history of each data item and any calculations carried out. References to papers can be noted and easily followed up at a later date by anyone working on the inventory.

Figure 5-3 shows the “Emissions of CO₂ from soil due to liming” submodel as an example, exactly as it would be viewed on screen. The text in the top corner described the data, the key assumptions involved in its derivation, and the main references. The four blocks displaying graphs illustrate the basic data which are read in from a text file in this example (see 5.3); the text file includes other comments where necessary. The top right section of the figure shows input directly passed from another submodel (ensuring consistency across all submodels using the same data). The input data is passed into a submodel containing the routines to estimate land use across the UK, the output from this is combined with the liming data to generate the final output for emissions of CO₂ from soil due to liming. There are nine categories of data, including liming, which are modelled in a similar way (see Figure 5-1, brown blocks), output from the CFLOW model will also be reviewed. These submodels are described below (sections 5.3.1.(a) to 5.3.1.(i)).

The output from all these data input submodels can then be combined, processed and displayed as required. Any change to the data input models will be automatically passed through to higher levels when the model is executed and each new year’s data can be added without the need to duplicate the files, thereby reducing the opportunity for errors!

The model as a whole can be executed over the desired time scale, using annual steps (the systems can be multi-rate, *i.e.*, have different parts that are sampled or updated at different rates) Output can be examined graphically or numerically at any point in the calculations making it

simple to test and explore different scenarios. It may be possible to extend the model to include future projections.

Quality assurance is a process-oriented procedure – a means to check the LULUCF inventory is put together in the best way. Quality control is a check that the output from the method is as expected. The Matlab/Simulink modelling exercise address both these issues by reviewing the systems used to compile the basic LULUCF information for the UK and as an independent method for calculating the summary data.

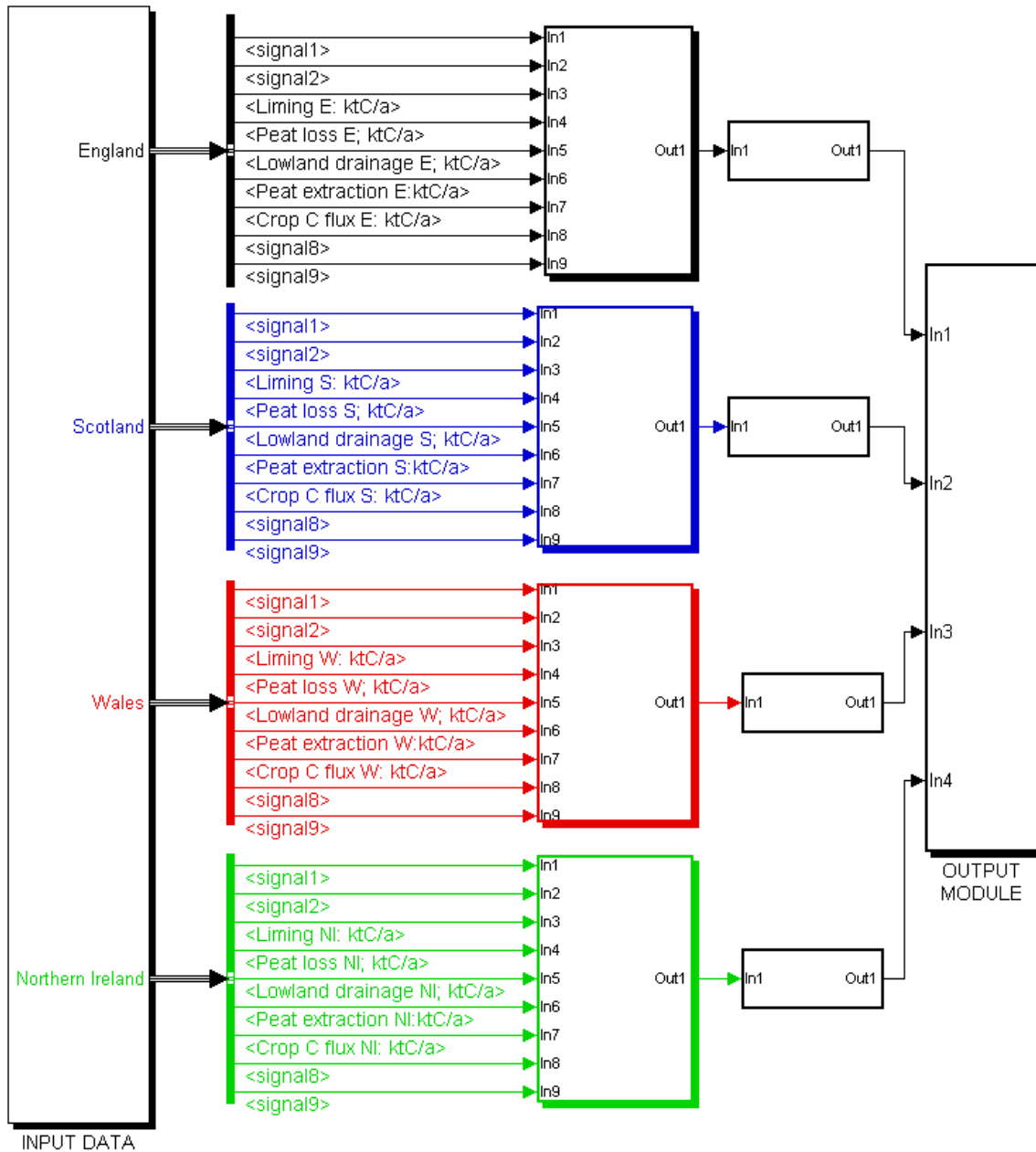


Figure 5-2: The new system has a hierarchy of Simulink submodels. Blocks represent submodels while arrows indicate transfer is data as scalars or arrays. The large block on the left contains further submodels controlling data input while the coloured blocks receive the data for further processing and reformatting in the required output format.

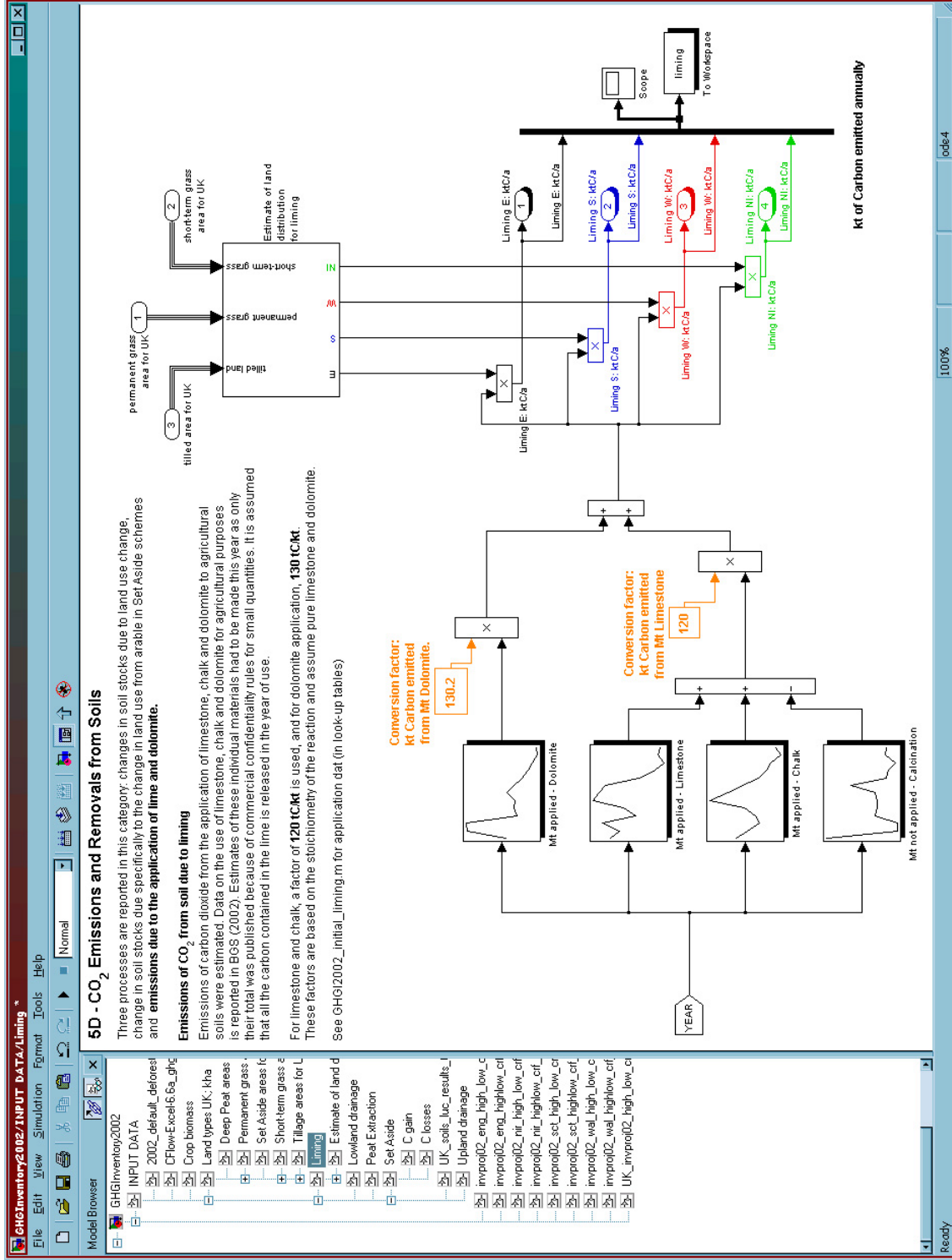


Figure 5-3: The Liming submodel illustrates the Simulink interface; the left panel shows the whole model while the right panel shows the liming data, documentation and links to other submodels.

5.3. Model Details

The model is currently set up to run with annual timesteps, from 1990 to 2003. A number of arrays and tables are populated with raw data either from text input file or by direct entry into model components. When the model is executed, a variable named 'year' with value 1990 to 2003 is created and used to 'look-up' and extract the correct data from the collection of tables and arrays in the model. The necessary calculations are carried out using these data and the output displayed graphically or written to output files.

Section 5.3.1 describes some of the methods used to import the raw data, extract the appropriate values for each time step and process the data to the required country-level values. To date, effort has concentrated on these parts of the model. Work is underway to extend the model and accommodate the new submission formats.

5.3.1. Input Data Module

5.3.1.(a) Land Types UK submodule

Many of the calculations for the UK LULUCF inventory require information about the area covered by each relevant land type. The *'Land Types UK'* submodule contains five further submodules (see Figure 5-4) that are used to hold the land area data from the agricultural census and pass the required information to other parts of the model. In each case the output is a vector containing 4 land area values (for England, Scotland, Wales and Northern Ireland) in kha.

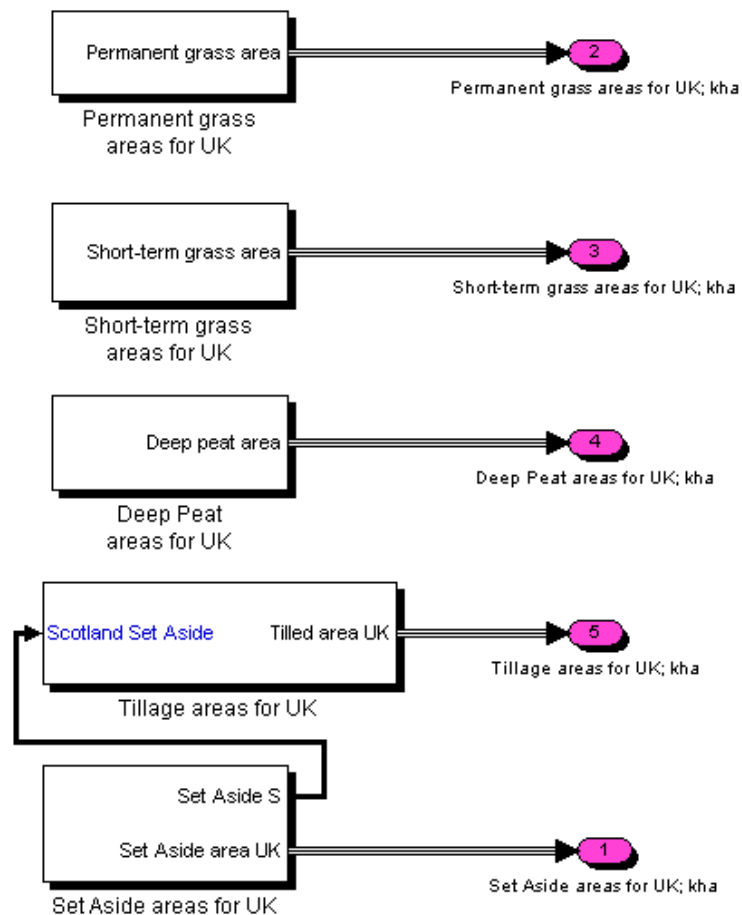


Figure 5-4: Data on land types and the distribution across the UK are passed to the model by the Land Type submodule.

5.3.1.(a) i - Permanent grass, short term grass, deep peat and tillage area

These four submodels are similar so only ‘Permanent Grass’ is described fully here. Data on the amount of land used for permanent grass for each country is obtained from the agricultural census for the years 1990 to 1997 and entered into an array in Simulink. The array is passed out of the submodel for use by other submodels. The average area over this time period is calculated and used to find the average area of permanent grass in each country as a percentage of the total in the UK. These figures are also exported. Figure 5-5 shows the Simulink submodel; the array data on the left of the figure are used to calculate relative coverage across the UK, averaged over the time period 1990 to 1997. Adding additional years’ data to the data block is straightforward and the new averages would be calculated automatically without further modifications to the model.

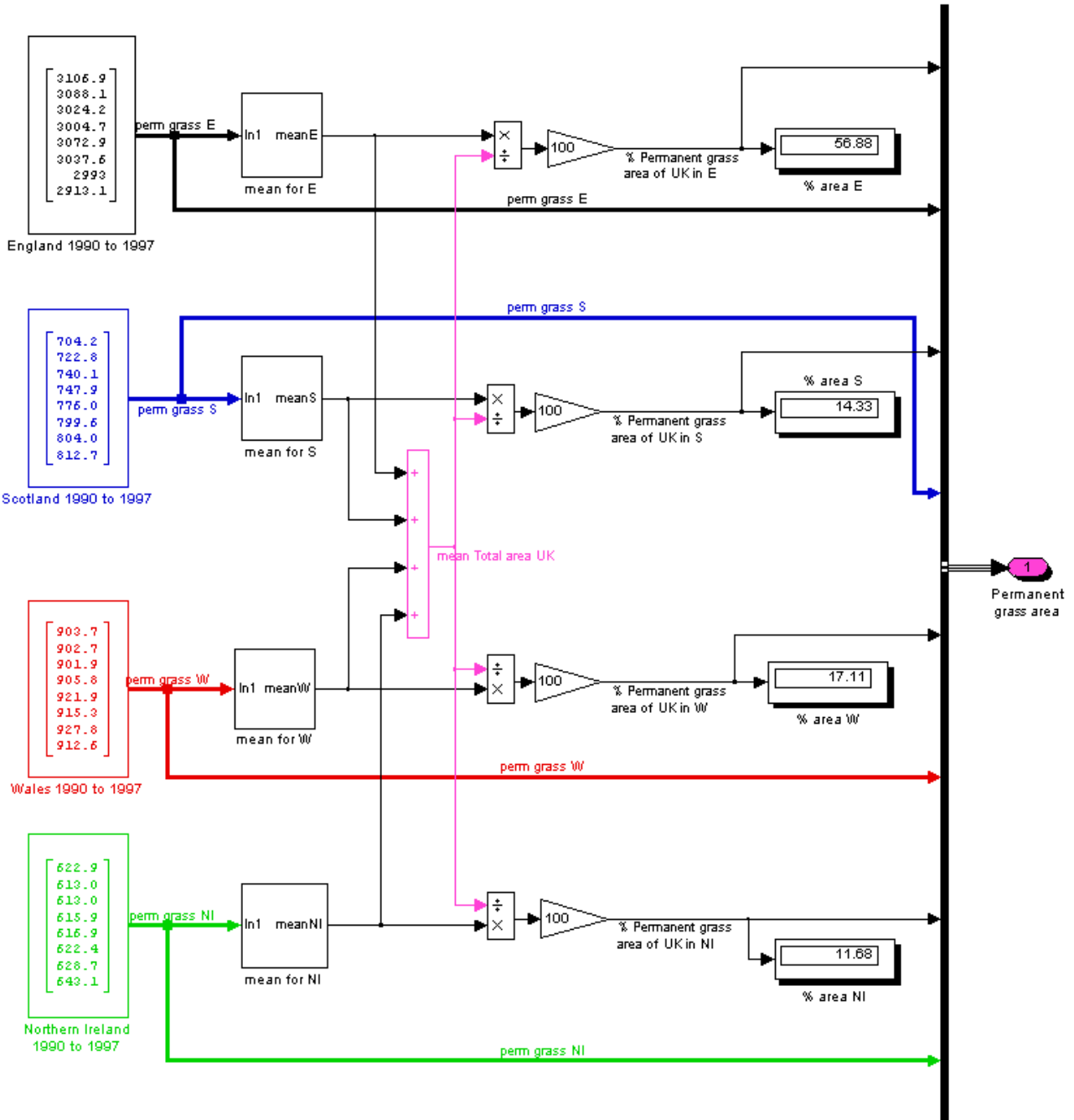


Figure 5-5: The ‘Permanent Grass’ submodel exports area data to other submodels

5.3.1.(a) ii - Set Aside

There are several ways to import data into a Simulink model. For the permanent grass example above, the complete data set is entered directly in an array, visible on the left in Figure 5-5, as all values are used for each time step. For the data relating to set aside land, the original values are brought together from different sources and annual values used as required. In this example, the data are brought together in a commented text file, e.g., for Scotland and array is created with 15 elements with 'NaN' (not a number) values given for unknown values that will be estimated from other sources;

```

%% Scotland - Set aside land area, 1988 to 2002
setaside_sco = [ NaN; NaN;
                NaN; NaN; 27.10; 90.20; 93.20;
                80.50; 69.50; 40.30; 43.40; 70.90;
                77.90; 90.10; 85.50];
%% 88/89/90/91 assumed (R. Milne)
setaside_sco(1:4) = [5.42; 10.84; 16.26; 21.68];
%% need 2003
setaside_sco(16) = [110.12];

```

Here the 1992 to 2002 data are obtained from one source then 1988 to 1991 and 2003 added to the array from another source. the full array, `setaside_sco`, is read into a Simulink look-up table and the appropriate year's data selected when the model executes (Figure 5-6). The variable 'longSA' is a parameter (multiplier) used to estimate the fraction of the current set aside land that is deemed long-term.

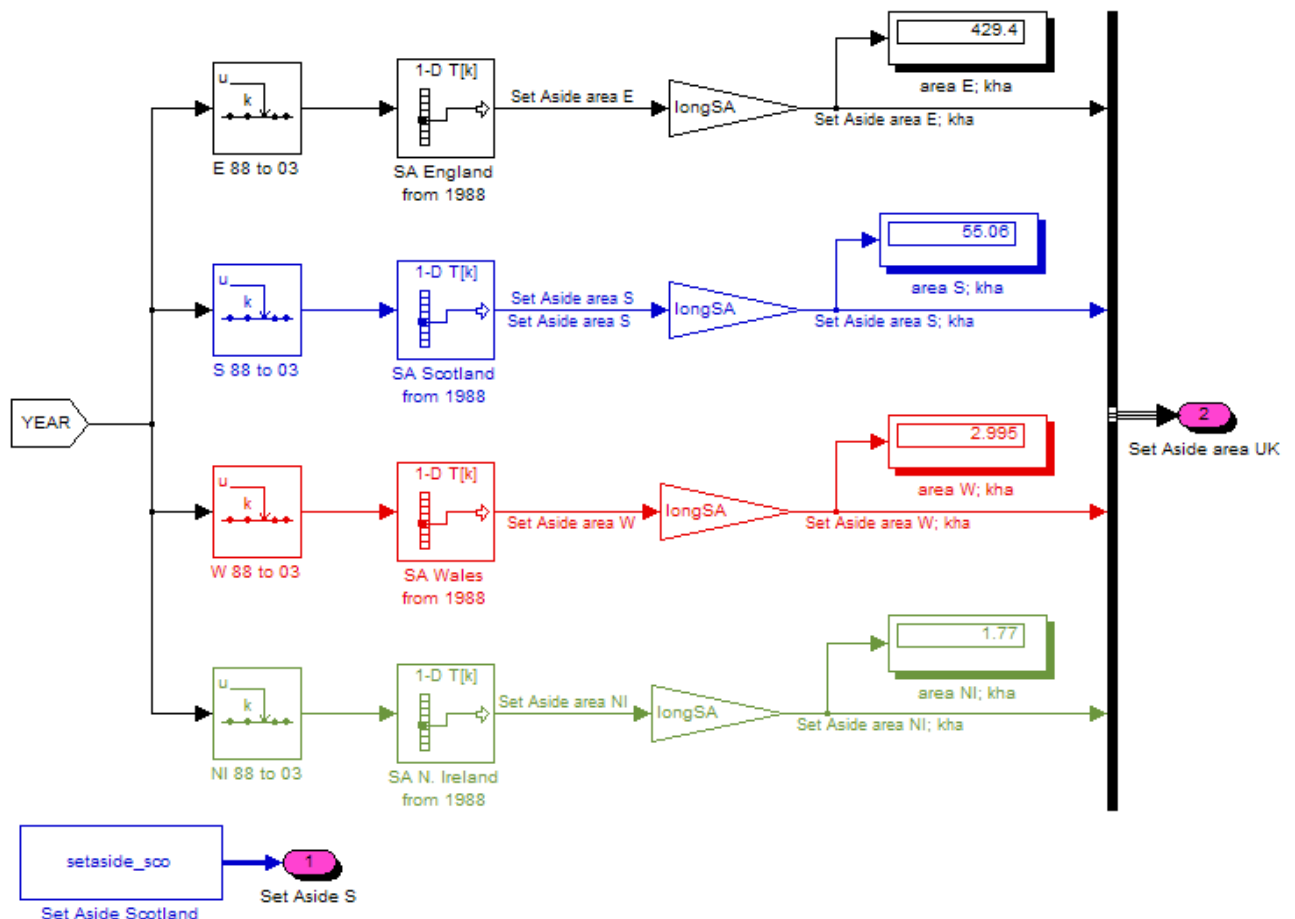


Figure 5-6: In this example the set aside data for 1988 to 2003 are in a 'look-up' table and the appropriate year's value extracted each timestep and passed to other submodels that use these data.

The complete set aside data for Scotland is also read in each timestep and passed directly out of the submodel as it is used to estimate tillage area for Scotland. As more data becomes

available, or existing data modified, it is straightforward to include the new data with minimal alteration to the model code.

5.3.1.(a) iii - Tillage

The example above for set aside land area illustrates how the raw data can be read in from a text file with the array elements populated in groups depending on their origin. The tilled land area provides an alternative method for comparison. For Scotland, the agricultural data available for 1990 to 1999 included 'tillage' separately. From 2000 the data is for tilled land and set aside combined, these data are entered as two arrays as shown in Figure 5-7. Set aside area is estimated elsewhere in the model and passed to this submodel (labeled '1') as a 16 element array (for 1988 to 2003). The 2000, 2001 and 2002 elements are selected, subtracted from the combined 'tillage + set aside' figures and recombined into a single array for use by the model. This method has the advantage that the raw data are visible and the process used to generate combined data from different sources is clearly seen. The same calculations are easily carried out in a spreadsheet but are hidden in cell formulae and may bring together data from linked sheets which need to be kept up to date.

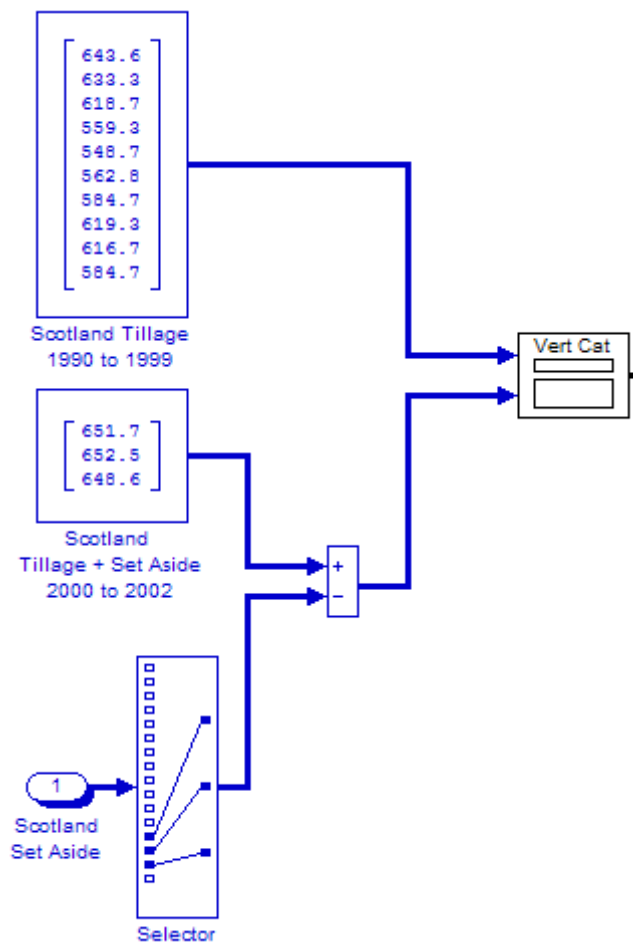


Figure 5-7: Tilled land area for Scotland is calculated by subtracting set aside from the combined data available since the year 2000.

5.3.1.(b) Liming

Emissions due to the application of lime and dolomite are currently reported in category 5D, CO₂ 'Emissions and Removals from Soils'. Emissions of carbon dioxide from the application of limestone, chalk and dolomite to agricultural soils are estimated in this submodel.

The 'Liming' submodel takes input from the 'Land Types UK' submodel and produces four output values for the carbon flux due to liming (ktC/a) for England, Scotland, Wales and Northern Ireland (see Figure 5-8).

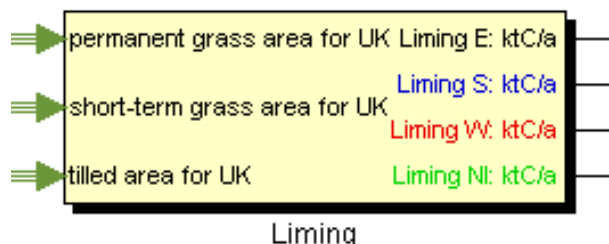


Figure 5-8: The Liming submodel uses land area data as part of the calculations for carbon flux due to liming across the UK.

The model contained in this module is shown in Figure 5-3. Data on the use of limestone, chalk and dolomite for agricultural purposes, reported in BGS (2002), are entered into look-up tables via text input files (the '%' indicates a comment);

```

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%% Inventory 2002 - Simulink model initialisation file for LIMING
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%% ** 2001
%% Mineral Extraction in Great Britain (2001). Business Monitor PA1007.
%% Table A for Limestone, dolomite and chalk
%% Table 5A Dolomite
%% ** 2002
%% Mineral Extraction in Great Britain (2002). Business Monitor PA1007.
%% Table
%% UK -
%% Limestone - agricultural uses
UKlimestone = [1.304; 1.206; 1.384; 1.039; 1.169;
1.476; 1.414; 1.351; 1.009; 0.840;
0.750; 0.810; 0.789]; %%Mt
%% NB 2001: GB = 0.810; Eng = 0.561, Wal = 0.101, Sco = 0.148
%% Conversion by Calcination
UKcalcination = [0.064; 0.000; 0.000; 0.020; 0.018;
0.018; 0.020; 0.042; 0.010; 0.008;
0.002; 0.011; 0.010]; %%Mt
%% Dolomite
UKdolomite = [1.259; 2.096; 2.114; 0.999; 1.070;
1.047; 1.230; 1.070; 0.890; 0.750;
0.670; 0.560; 0.590]; %%Mt
%% 2001: Details sensitive. Agricultural use Eng = 0.426
%% Chalk
UKchalk = [0.645; 0.547; 0.435; 0.466; 0.574;
0.882; 0.715; 0.590; 0.440; 0.370;
0.330; 0.240; 0.290]; %%Mt
%% Calculations for 2001
totalagric = 1.610 ; %% Mt for GB
UKapplied = totalagric - UKcalcination(12) ; %% gives combined application
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

```

The look-up tables display the information graphically to indicate the type of data being used (Figure 5-9). 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 tC/kt is used, and for dolomite application, 130 tC/kt. These factors are based on the stoichiometry of the reaction and assume pure limestone and dolomite. The factors are shown clearly in the model and can easily be changed if required in future runs of the model.

The output from this section of the model is the total carbon emitted for the UK. To subdivide this across the countries needs information on the relative distribution of land types. This data is imported from the Land Use submodel, modified to account for the fraction of land (tilled, permanent grass and short term grass) that is limed and applied to the UK liming figures. The final estimates of carbon emissions due to liming are passed out of the submodel to be used elsewhere.

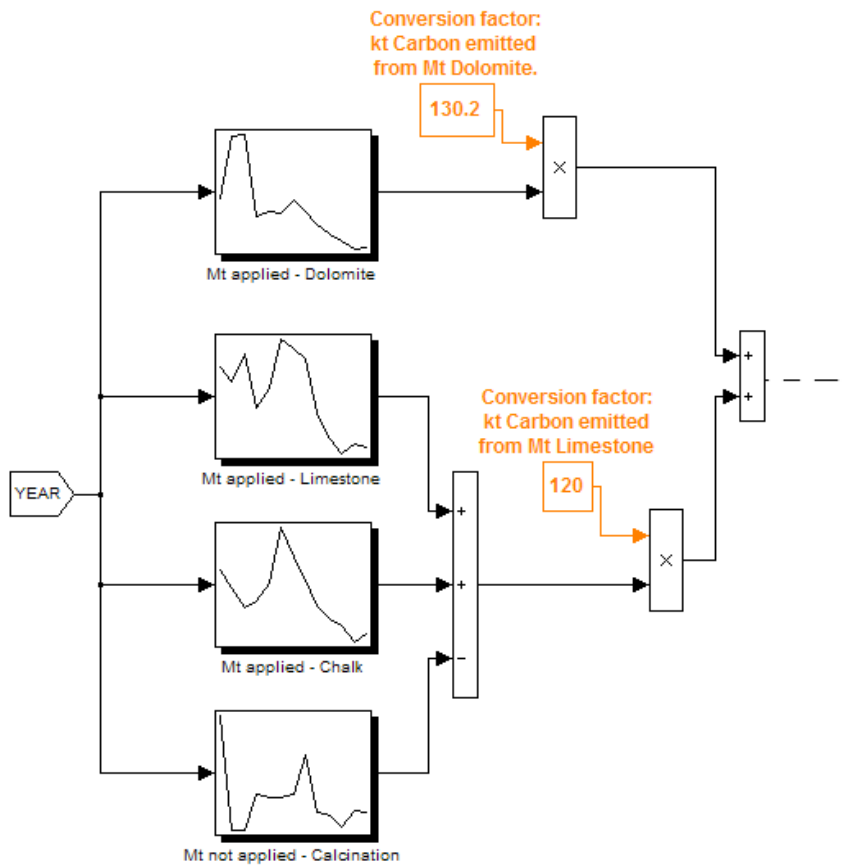


Figure 5-9: The data read in from text file to tables is displayed in the liming submodel.

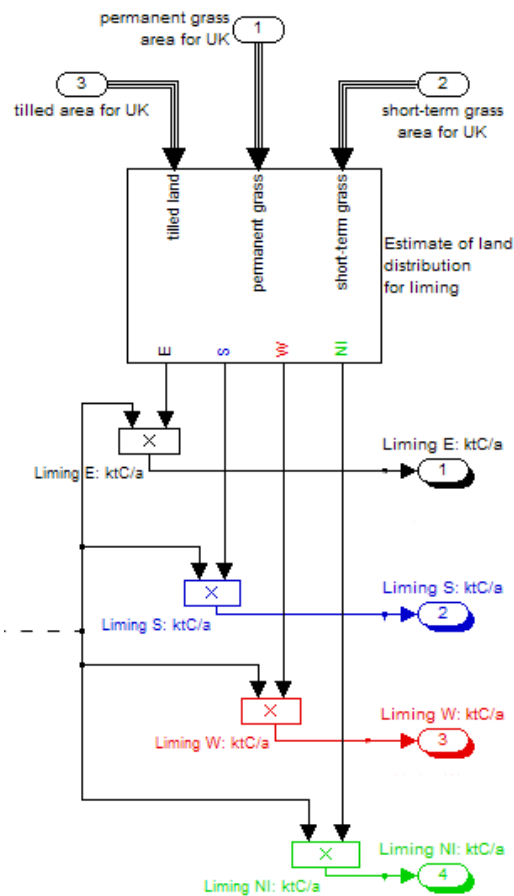


Figure 5-10: Figures for the UK for liming are combined with data on land use to obtain estimates for each country.

5.3.1.(c) Upland Drainage

Drainage of upland deep peat is included in category 5E 'Other sources and sinks'. The Upland Drainage submodel takes the deep peat area for the UK as an input and produces the peat loss values (ktC/a) for each country as output (Figure 5-11).

The data included in this and previous year's CRF submissions and NIR's for emissions from drainage of peat for forestry are based on areas of planted forest in (Cannell et al., 1993) and an emission rate measured by (Hargreaves et al., 1997) and (Hargreaves et al., 2003) measured in the field one year after forest planting. The value for emission is assumed to continue indefinitely at about this early rate. The continuing rate is taken to be $2\text{tC ha}^{-1}\text{a}^{-1}$. (The resulting emission is therefore the same for each year of the Inventory.) The figure of $2\text{tC ha}^{-1}\text{a}^{-1}$ can be seen as a constant input value in Figure 5-12. The figures are rounded and shown in the 'display' blocks. A further rounding of the figures is applied before the output is passed to other submodels; the values in the red boxes in Figure 5-12 can be manually adjusted for the model run. These values are constant for each time step in the model.

This approach is under review following analysis of field data measured for forests with ages up to 26 years after planting.

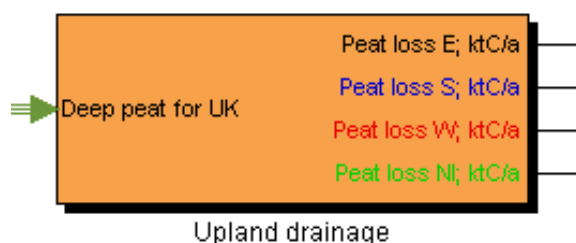


Figure 5-11: The upland drainage submodel has one input from the Land Type submodel and produces four output variables.

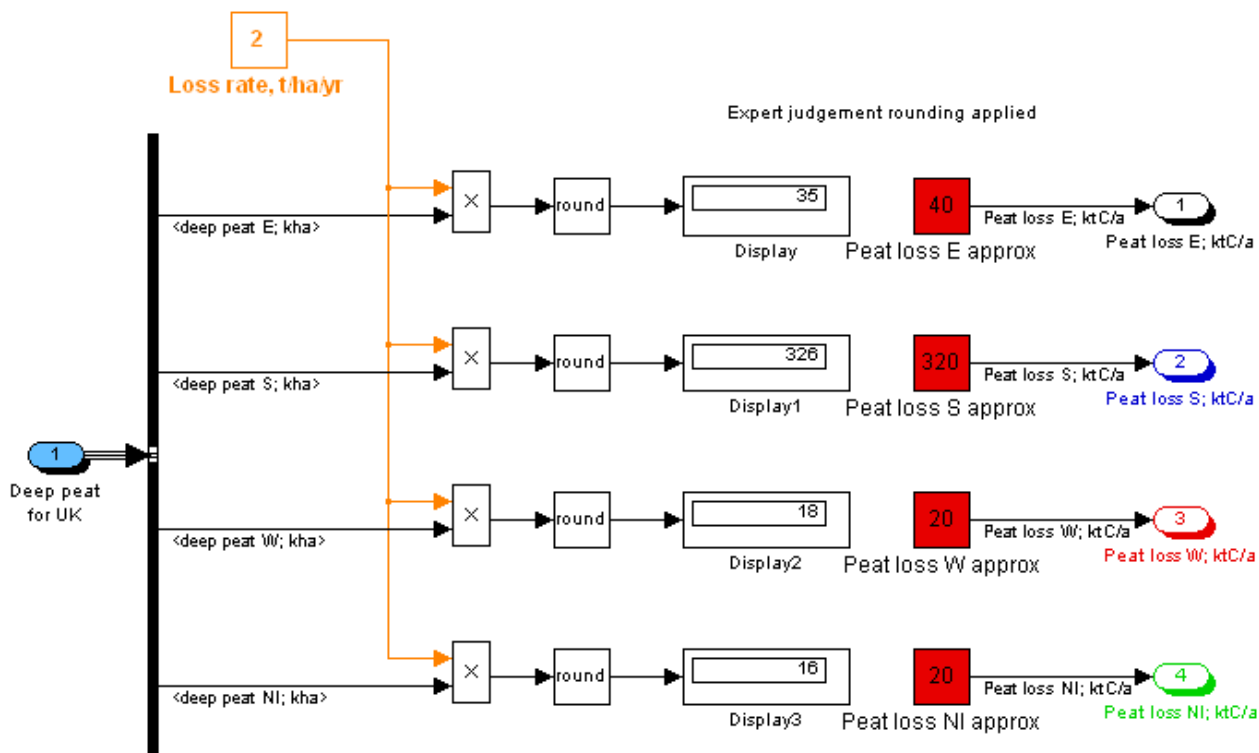


Figure 5-12: The deep peat area values for the UK are provided by the Land Type submodel and the constant loss rate applied.

5.3.1.(d) Lowland Drainage

Drainage of lowland wetlands is included in the category 5E ‘Other sources and sinks’. The Lowland Drainage submodel does not use data from other modules but has four output values; as ktC/a for each country (Figure 5-13).

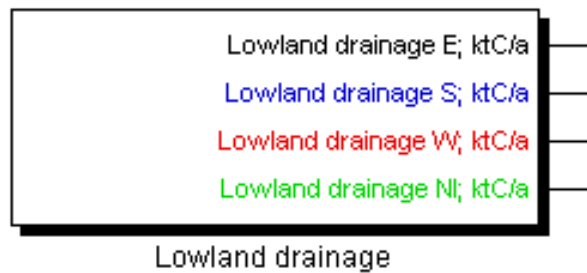


Figure 5-13: The Lowland Drainage submodel has four outputs.

The baseline (1990) for the area of drained lowland wetland for the UK was taken as 150 kha. This represents all of the East Anglian Fen and Skirtland and limited areas in the rest of England. This total consists of 24 kha of land with thick peat (more than 1m deep) and the rest with thinner peats. Different loss rates were assumed for these two thicknesses. The trend in emissions after 1990 was estimated on the assumption that no more area has been drained since then but the existing areas have continued to lose carbon. The annual loss decreases for a specific location in proportion to the amount of carbon remaining. But, in addition to this, as the peat loses carbon it will become more mineral in structure. The Century model of plant and soil carbon was used to average the carbon losses for the areas of component soils as they thinned to lose peat, become humose and possibly even mineral.

The Lowland drainage submodel illustrates another useful feature of the Simulink modelling system. When data is only available for some years, the look-up table can be set up to interpolate or extrapolate to provide estimates for missing years as required (Figure 5-14 and Figure 5-15).

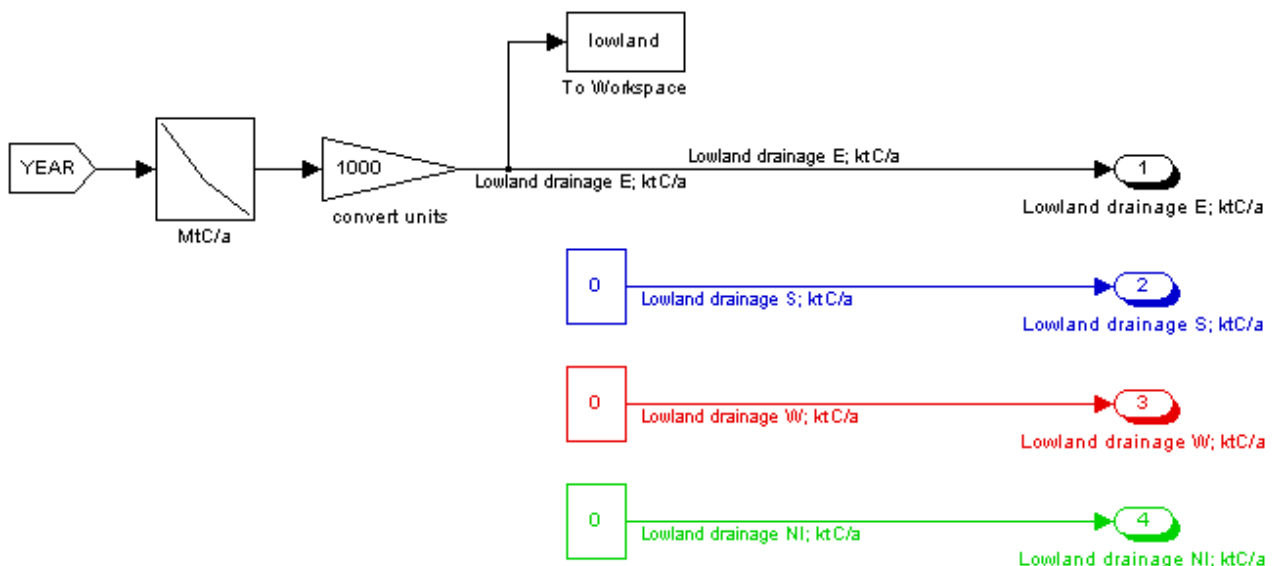


Figure 5-14: Lowland drainage applies only to England; output is zero for the other countries.

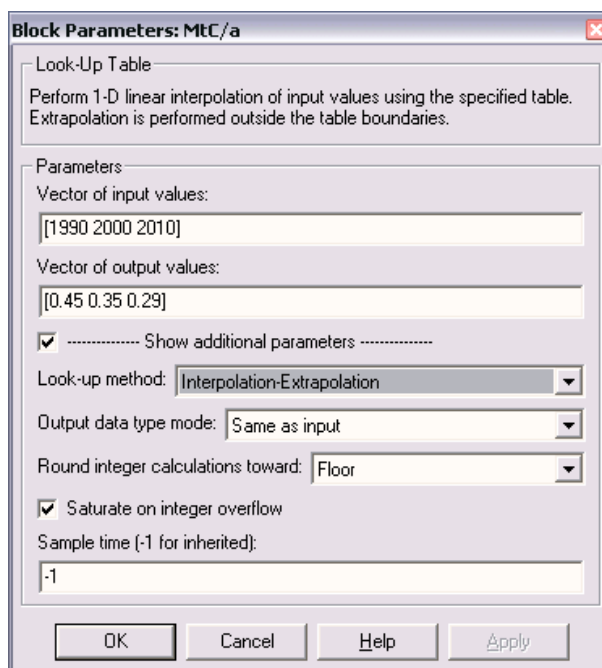


Figure 5-15: A look-up table can be used to estimate values for missing years, assuming a linear change between data points.

5.3.1.(e) Peat Extraction

Carbon emissions due to peat extraction are included in category 5E ‘Other sources and sinks’. The Peat Extraction submodel has no input from other submodels and has four output variables; the carbon flux in ktC/a for each country (see Figure 5-16)

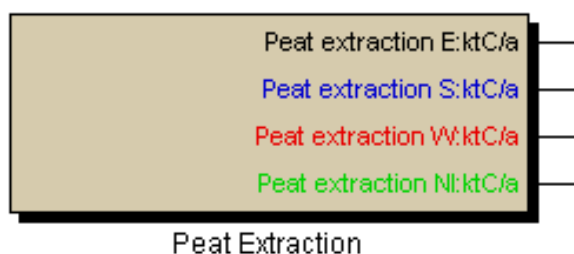


Figure 5-16: The Peat Extraction submodel.

The activity data, for both horticultural activity and fuel activity, are supplied in a text file and displayed in the model as look-up tables (see Figure 5-17). Emissions factors (from Cruickshank et al., 1997) are applied to the annual activity figures and the combined total exported out of the submodel.

The model diagram in Figure 5-17 also illustrates the use of ‘scopes’ in Simulink. These are blocks that are easily added to the model at any point and are used to display the data graphically as the model runs. In this example, the output provides a quick visual check (when opened on screen) that the intermediate data matches the values calculated in the original Excel spreadsheet version of the inventory.

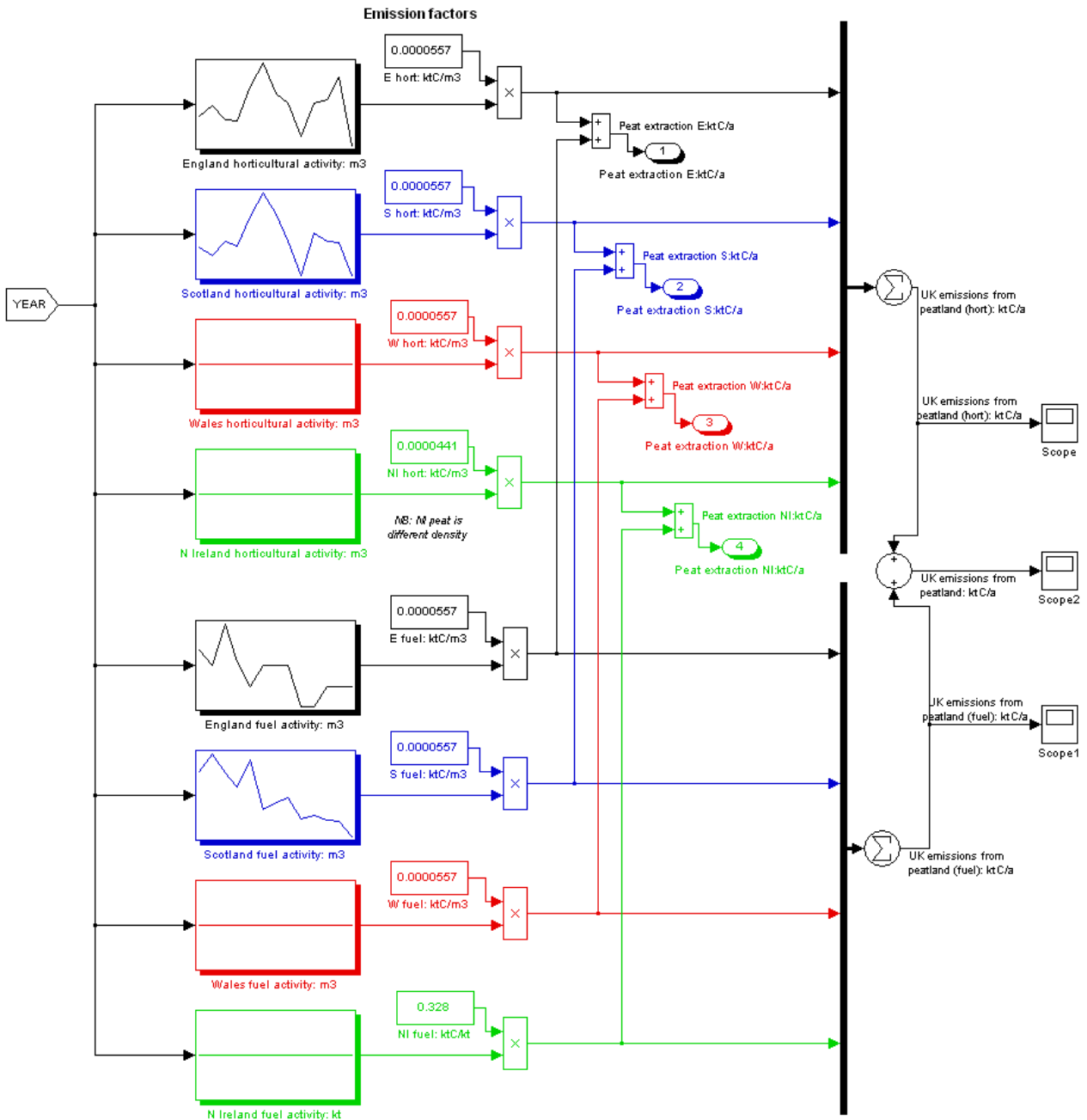


Figure 5-17: The Peat Extraction submodel combines data from two relevant activities.

5.3.1.(f) Crop Biomass

The carbon sink resulting from changes in crop biomass is included in category 5E ‘Other sources and sinks’. The Crop Biomass submodel requires data on the area of tilled land in the UK which is imported from the Land Type submodel (see Figure 5-18).

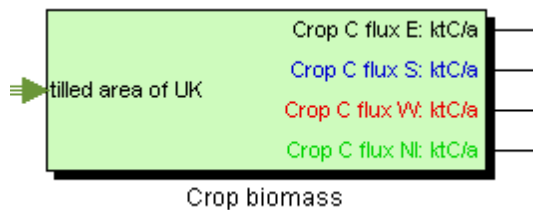


Figure 5-18: The Crop Biomass submodel has input from the Land Type submodel and four output variables.

The area of cropped land in each country is assumed to have a constant flux rate per annum (0.3 MtC a^{-1}), and the output rounded to provide a crop carbon flux estimate (see Figure 5-19).

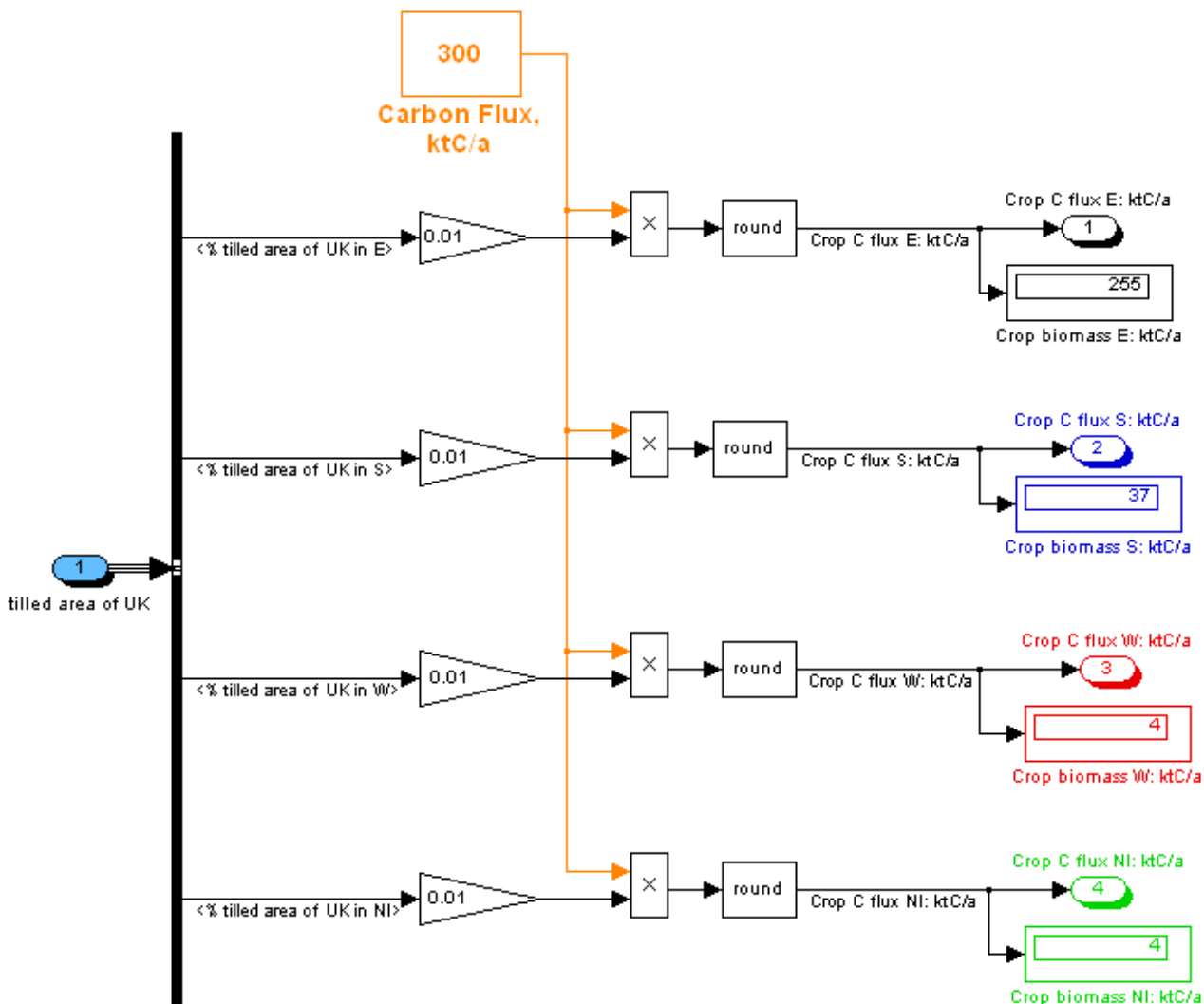


Figure 5-19: The Crop Biomass submodel takes UK land type data and estimates a carbon flux for each country.

5.3.1.(g) Set Aside

The carbon flux associated with set aside land is included in category 5D ‘Emissions and removals from soil’. The Set Aside submodel is currently under construction; the model will require input from the Land Type submodel and the final output will be the carbon flux for each country in ktC/a (Figure 5-20).

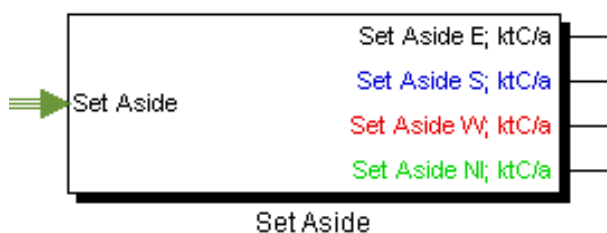


Figure 5-20: The Set Aside submodel is currently under construction.

This submodel is more complex than previous examples; the formulae applied to calculate the carbon fluxes are currently being developed for the Simulink model (e.g. Figure 5-21).

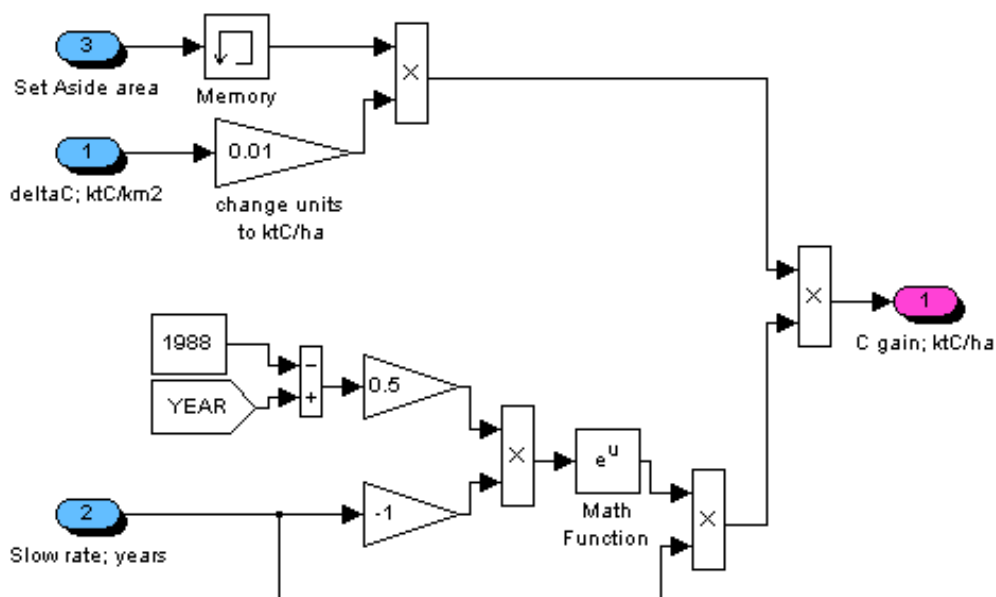


Figure 5-21: Carbon gain is calculated within the set aside submodel.

5.3.1.(h) Soils

Not yet implemented.

5.3.1.(i) Deforestation

Not yet implemented.

5.3.2. Country Data, Summary Data & Output Modules

The Country Data Modules output the LULUCF inventory data organised by country for the UK. These figures can be viewed or exported directly or may be reorganised and displayed in a specified format. The precise output format has not yet been finalised but it is envisaged that the Summary data and/or Output modules will include routines for this.

5.4. References

- Cannell, M.G.R., Dewar, R.C. and Pyatt, D.G., 1993. Conifer Plantations on Drained Peatlands in Britain - a Net Gain or Loss of Carbon. *Forestry*, 66: 353-369.
- Cruickshank, M.M. and Tomlinson, R., 1997. Carbon loss from UK peatlands for fuel and horticulture. In: M.G.R. Cannell (Editor), *Carbon Sequestration in Vegetation and Soils*. DOE, Contract EPG 1/1/3, Final Report March 1997, DOE, Contract EPG 1/1/3, final Report. Department of Environment, London.
- Hargreaves, K.J. and Fowler, D., 1997. Short-term CO₂ fluxes over peatland. In: M.G.R. Cannell (Editor), *Carbon Sequestration in Vegetation and Soils*. DOE Contract EPG 1/1/3 Department of Environment, London.
- Hargreaves, K.J., Milne, R. and Cannell, M.G.R., 2003. Carbon balance of afforested peatland in Scotland. *Forestry*, 76: 299-317.