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AUSTRALIA'S NATIONAL GREENHOUSE ACCOUNTS

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The Australian National Greenhouse Accounts are available on the Internet at the following address: http://www.climatechange.gov.au/inventory.

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7. Land Use, Land Use Change and Forestry

7.1 Overview

The net emissions from the *land use, land use change and forestry* (LULUCF) sector were 284.7 Mt CO_2-e in 2007 (Table 7.1).

Table 7.1: Land use, land use change and forestry net CO_2-e emissions 2007

Greenhouse Gas Source and Sink Categories	CO_2-e emissions (Gg)			
	CO_2 [(a)]	CH_4	N_2O	Total
5 Land use, land use change and forestry	**278 652**	**4 484**	**1 574**	**284 710**
A. Forest lands	-21 591	2 102	574	-18 916
B. Croplands	22 696	667	202	23 565
C. Grassland	280 519	1 715	469	282 703
D. Wetlands	NE	NE	NE	NE
E. Settlements	NE	NE	NE	NE
F. Other lands	NO, NA	NO, NA	NO, NA	NO, NA
G. Other [(b)]	-2 972		329	-2 643

Note: a) A negative sign denotes a sink;

b) Includes Harvested Wood Products, Agricultural Lime Application and N_2O from Disturbance associated with land-use conversion to Grasslands. N_2O from Disturbance associated with land-use conversion to Cropland is reported under Croplands.

NE = not estimated (voluntary reporting categories). NA = not applicable. NO = not occurring.

Forest lands (5A) comprises emissions and removals from *Harvested Native Forests* and *Plantations* as well as *Other Native Forests*, emissions from *Fuelwood Consumption*, emissions from *Prescribed Burning* and *Wildfire* in forests, and removals from recovery post fire. These categories are estimated to have constituted a net sink of 18.9 Mt CO_2-e in 2007.

Croplands (5B) comprises emissions and removals from *Croplands remaining Cropland* and *Forest land converted to Croplands*. The *Croplands* subsector is estimated to have constituted a net source of 23.6 Mt CO_2-e in 2007.

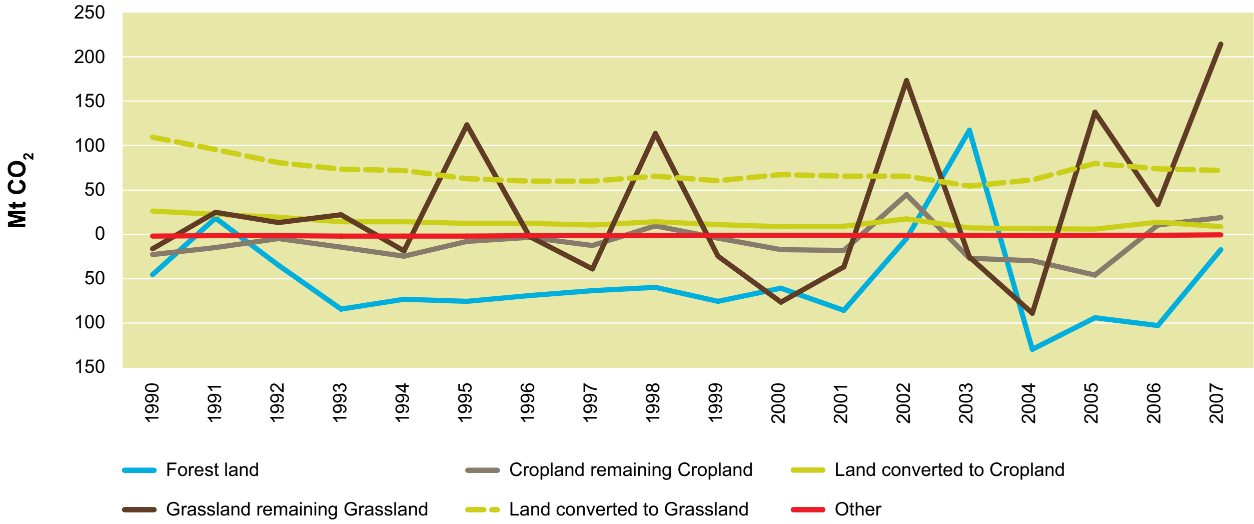
Grasslands (5C) comprises emissions and removals from *Grasslands remaining Grassland* and *Forest land converted to Grassland*. The *Grassland* subsector is estimated to have constituted a net source of 282.7 Mt CO_2-e in 2007.

The preliminary estimate for *Forest land converted to Cropland* and *Grassland* in 2007 is a net source of 76.8 Mt CO_2-e, while the associated emissions of *N_2O from Soil Disturbance* were 0.3 Mt. The 2007 estimates for these sources are the average of the 2004-2006 estimates and as such should be considered as being interim only. These estimates will be revised when areas of forest conversion are confirmed in the next update of the inventory using the National Carbon Accounting System.

Harvested Wood Products are not reported in the *Forest lands* category and carbon stocks are transferred to 5G Other – *Harvested Wood Product*. As the reporting tables do not account for transfers of carbon stocks, this leads to an apparent, but not real, emission from *Forest lands* and a 4.5 Mt ‘sink’ in *Harvested Wood Products*.

Agricultural Lime Application is estimated to have contributed emissions of 1.5 Mt CO_2-e in 2007.

Figure 7.1: Net CO_2-e emissions from Land use, land use change and forestry – by sub-sector 1990–2007



Trends

From year to year the LULUCF sector may change from a net source to a net sink. The trends in the LULUCF sector are primarily driven by inter-annual climate variability and natural disturbance, which tends to mask other, underlying patterns in the sector directly associated with human activities. In 2007, the net *land use, land use change and forestry* emissions increased from 37.6 Mt CO_2-e in 1990 to 284.7 Mt CO_2-e (Figure 7.1).

The trend in net emissions in the early 1990's is primarily driven by the reduction in emissions from forest conversion, however the shift from a net sink to net source in 1995, 1998 and 2002 along with the spike in emission in 2007 reflect natural disturbances such as fires and extensive drought conditions which caused a loss of carbon from all pools.

The preliminary estimate of total emissions from *Forest land converted* to *Cropland* and *Grassland*, was 41.6% (54.8 Mt) lower than in 1990. Since 1990 the annual rates of forest conversion have decreased substantially (Table 7.2) reflecting both the effects of changing market and climatic conditions and of regulatory impacts with consequent reductions in estimated emissions. Emissions from the decay of aboveground biomass and belowground carbon due to extensive past land use change have also been diminishing.

Emissions of *N_2O from Soil Disturbance* associated with conversion of *Forest land* to *Cropland* and *Grassland* has declined by 43.2% (0.3 Mt) between 1990 and 2007.

Within *Forest lands* (5A), *Forest land remaining Forest land* changed from a net sink of -45.3 Mt in 1990 to a net source of 2.2 Mt CO_2-e in 2007, while the removals from *lands converted to Forest land* increased from -2.0 Mt to -21.2 Mt CO_2-e. The combined effect of these changes is a decrease in the *Forest lands* net sink of 60.0% (28.4 Mt) between 1990 and 2007.

Emissions from *Agricultural lime application* have increased from 0.2 Mt in 1990 to 1.5 Mt in 2007.

Table 7.2: Annual area of forest change (ha)

Year	Forest land converted to	
	Croplands	Grassland
1990	116,077	444,776
1991	88,546	339,347
1992	69,153	321,297
1993	65,195	322,830
1994	75,959	292,964
1995	60,939	256,453
1996	65,814	253,458
1997	64,918	249,355
1998	62,954	269,981
1999	61,964	277,790
2000	63,003	295,882
2001	65,504	294,479
2002	64,217	245,107
2003	62,717	232,466
2004	79,390	324,970
2005	75,605	322,207
2006	82,134	296,152

Note: Estimates of forest conversion for 2007 are not yet available

Trends due to climate variability

Several categories of the LULUCF inventory are estimated using the process based, Tier 3 model *FullCAM*. As a result, trends in the emissions reported for these categories reflect all the factors which lead to emissions and removals, including land use change, ongoing management, and climate. The inclusion of climatic effects means that the implied emissions factors can vary considerably between years even though the activity data remains similar. Such trends become much clearer in years of extreme conditions (such as drought) and the effects of these can have flow on effects for several years. This variation does not represent an error or inconsistency in the reporting, but is due to Australia's complex land systems, highly variable climate and the large land areas being modelled. An example of this effect is described below.

An example of climate effects on emissions from Croplands

During 2002/3 emissions from the *Forest land converted to Cropland* and the *Cropland remaining Cropland* categories spiked after several years of relatively stable results (Figure 7.2). This spike led to a sudden increase in the implied emission factors for both categories. The spike is driven by a large reduction in crop yield (Figure 7.3) caused by one of the worst droughts in Australia's history (Figure 7.4).

Figure 7.2: Emissions from Cropland remaining Cropland

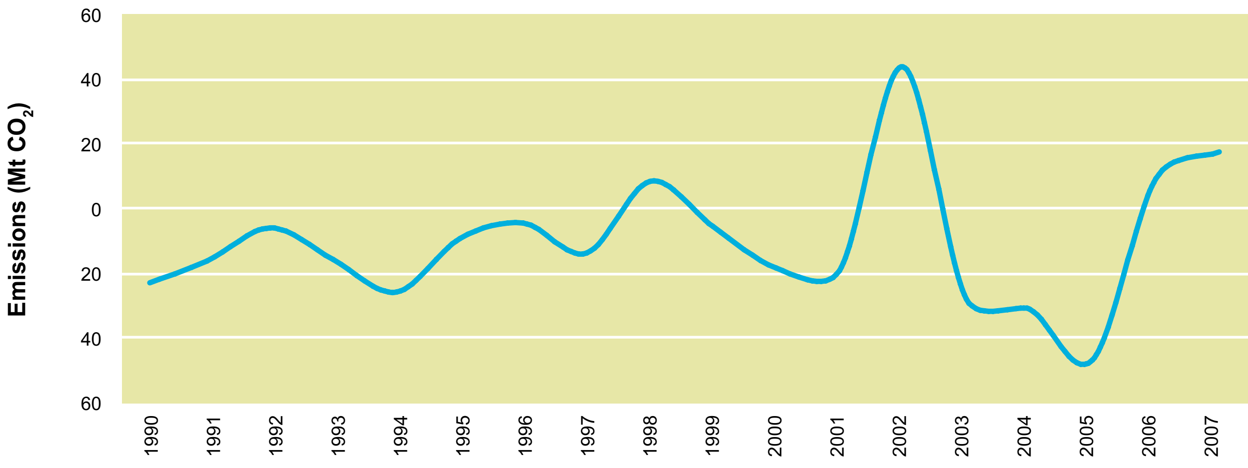


Figure 7.3: Average yield of crops (not area weighted) used in the tier 3 process model since 1990

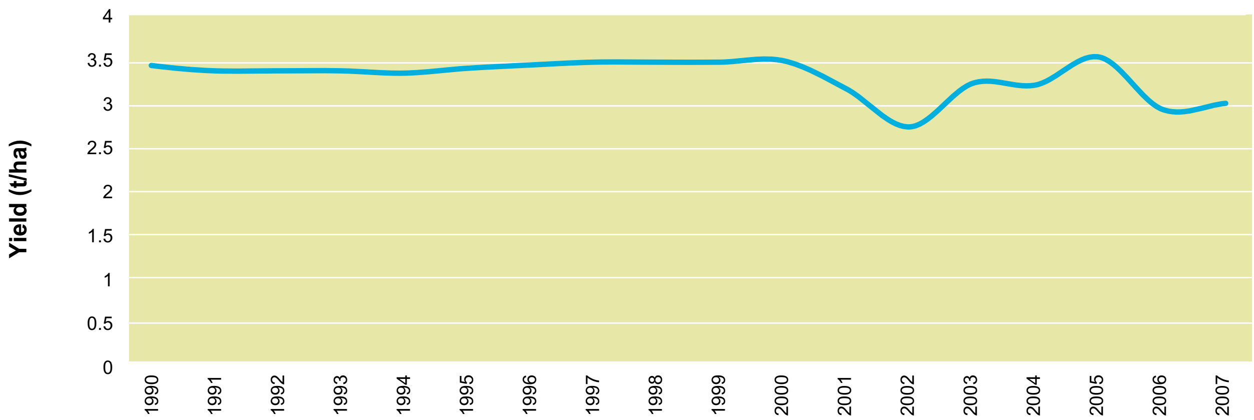
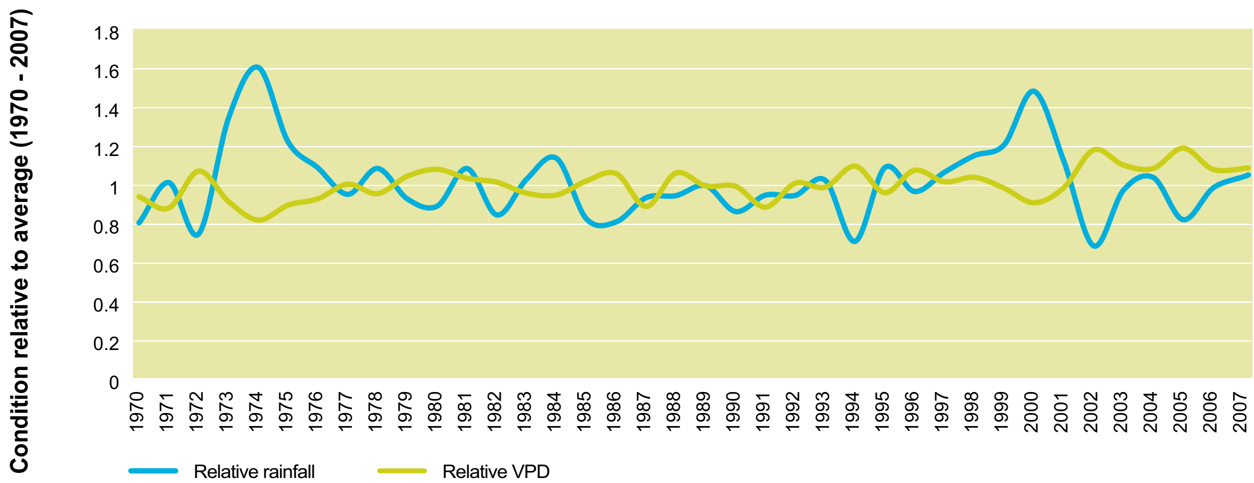
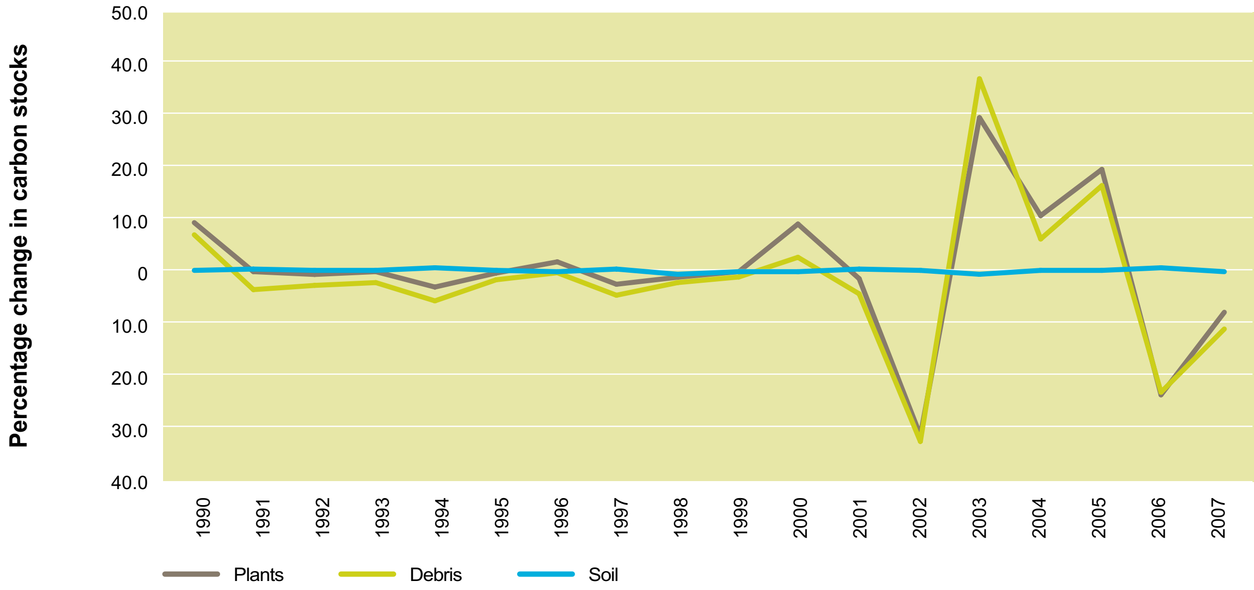


Figure 7.4: Relative rainfall and VPD across Australia



The effect of the drought on emissions in the *Cropland* categories is clearly shown as the percentage change in carbon stocks by pool (Figure 7.5). In Australia, crops are generally still growing at the end of the calendar year, unlike many northern hemisphere countries where crops are not present at this time. This means that any change in crop yield will directly affect the emissions estimates. In 2002 the large decrease in crop yields led to large change in plant and debris stocks due to the drought, which resulted in a large spike in emissions. In 2003, the plant and debris stocks recovered to more average levels as conditions improved and the crops survived. While soil carbon stocks varied only by a small percentage, because soils are a large store of carbon (around 55 t/ha on average), these small changes had a considerable effect on absolute emissions/removals. In 2002, the soil carbon stocks had increased slightly as the dry conditions limited decomposition. During 2003 the soils were deprived of residues from harvest due to the large number of crop failures, while the wetter conditions allowed for more decomposition, leading to a reduction in the soil carbon stocks.

Figure 7.5: Percentage change in carbon stocks in the Cropland remaining Cropland category



7.2 Overview Of Source Category Description and Methodology – Land Use, Land Use Change and Forestry

Land use and management activities influence a variety of ecosystem processes that affect greenhouse gas fluxes. The focus of this sector is the estimation of emissions and removals of carbon dioxide (CO_2) from these activities. CO_2 fluxes between the atmosphere and managed land systems are primarily controlled by uptake from plant photosynthesis and releases from respiration, decomposition and oxidation of organic material. Nitrous oxide (N_2O) may be emitted from the ecosystem as a by-product of nitrification and denitrification and the burning of organic matter. Other gases released during biomass burning include methane (CH_4), carbon monoxide (CO), other oxides of nitrogen (NO_x) and non-methane volatile organic compounds (NMVOC).

The Australian LULUCF methodology contains predominantly country specific methodologies and Tier 3 models (Table 7.3). The methods used in the reporting of the LULUCF categories of the inventory are described in detail in Appendices 7.A to 7.G:

- Appendix 7.A – Overview of the development and implementation of the National Carbon Accounting System;
- Appendix 7.B – *Harvested Native Forests* for *Forest land remaining Forest land;*

- Appendix 7.C – *Forest Plantations* for *Forest land remaining Forest land* and *Grassland converted to Forest land*;
- Appendix 7.D – *Other Native Forests* for *Forest land remaining Forest land;*
- Appendix 7.E – *Forest land converted to Grassland* and *Cropland;*
- Appendix 7.F – *Grassland remaining Grassland;* and,
- Appendix 7.G – *Harvested Wood Products*.

Table 7.3: Summary of methodologies and emission factors – Land use, land use change and forestry sector

Greenhouse Gas Source and Sink Categories	CO_2		CH_4		N_2O		NO_x, CO and NMVOC	
	Method applied	EF	Method applied	EF	Method applied	EF	Method applied	EF
5. Land Use, Land Use Change and Forestry								
A. Forest Lands								
1. Forest Land remaining Forest Land								
Harvested Native Forests	T2	CS						
Other Native Forests	T2	CS						
Plantations	T3	M						
Fuelwood consumed	T1	CS						
5(V) Biomass Burning – 5.1.			CS	CS	CS	CS	CS	CS
2. Land converted to Forest Land	T3	M						
B. Cropland								
1. Cropland remaining Cropland	T3	M						
2. Land converted to Cropland	T3	M						
5(III) *Disturbance associated with land conversion*					T2	CS		
5(V) *Biomass Burning – 5.B.2*			CS	CS	CS	CS	CS	CS
C. Grassland								
1. Grassland remaining Grassland	T3, T2	M, CS						
2. Land converted to Grassland	T3	M						
5 (V) *Biomass Burning – 5.C.2*			CS	CS	CS	CS	CS	CS
D. Wetlands								
1. Wetlands remaining Wetlands	NE	NE						
2. Land converted to Wetlands	IE	IE						
E. Settlements								
1. Settlements remaining Settlements	NE	NE						
2. Land converted to Settlements	IE	IE						
F. Other Lands								
1. Other Lands remaining Other Lands	NA	NA						
2. Land converted to Other Lands	NO	NO						
G. Other								
Harvested Wood Products	T3	M						
5(I) *N fertilisation*					IE	IE		
5(II) *Drainage of soils*					NE	NE		
5(III) *Disturbance associated with land conversion to grassland*					T2	CS		
5(IV) *Agricultural lime application*	T1	CS						

EF = emission factor, CS = country specific, D = IPCC default, M = Model, NA = not applicable, NE= not estimated, NO = not occurring, IE=included elsewhere, T1 = Tier 1, T2 = Tier 2 and T3 = Tier 3,

7.2.1 Australia's National Carbon Accounting System

In 1998 Australia embarked on a development program for a National Carbon Accounting System (NCAS) to provide a complete accounting capability for Australia's land based sectors (AGO 2005). Australia currently invests approximately AUD $4 million per year in the NCAS. The NCAS is being progressively developed to provide a complete greenhouse gas accounting capability for agriculture, forestry and land use change (including all carbon pools, gases, lands and land use activities). The eventual capacity will be a full spatial enumeration with emissions and removals calculated using a process-based, mass balance, carbon and nitrogen cycling ecosystem model.

The full spatial enumeration is achieved through an extensive remote sensing program that uses medium resolution (50m and 25m) Landsat satellite data in a time-series since 1972 (Furby 2002; Caccetta et al., 2003). There are currently sixteen national coverages in the time-series. The medium resolution data is used to determine change in forest extent, and to determine plantation area, age and type.

Monthly climate maps at 1km resolution since 1968 have been derived to model annual variability in emissions and removals due to climatic process drivers (Kesteven et al., 2004). Comprehensive databases on land management practices are also integrated within the system. Coupled together, the information on vegetation cover change, ongoing management, and climate allows the NCAS to comprehensively account for both the principal causes of emissions as well as the sources of annual variability in emissions.

The progressive development of the NCAS is set around priorities according to the scale of emissions from either the land use activity or carbon pool. To date the full Tier 3, Approach 3 (i.e., fully spatially explicit process-based ecosystems modelling) capability of the NCAS has been completed for the conversion of forests to other land uses (e.g., cropping and grazing) and for the *Cropland remaining Cropland* category. Over the inventory time series the conversion of forest to other uses represents the majority of emissions associated with *Land Use, Land Use Change and Forestry* activities.

The other principal reporting elements, *Forest land remaining Forest land*, *Land converted to Forest land* and *Grassland remaining Grassland* are reported using interim Tier 2 and 3 methods that, as yet, have not been fully developed within the NCAS framework. This is also the case for *Harvested Wood Products*. Appendix 7.A gives an outline of the current and planned NCAS capabilities for inventory improvement.

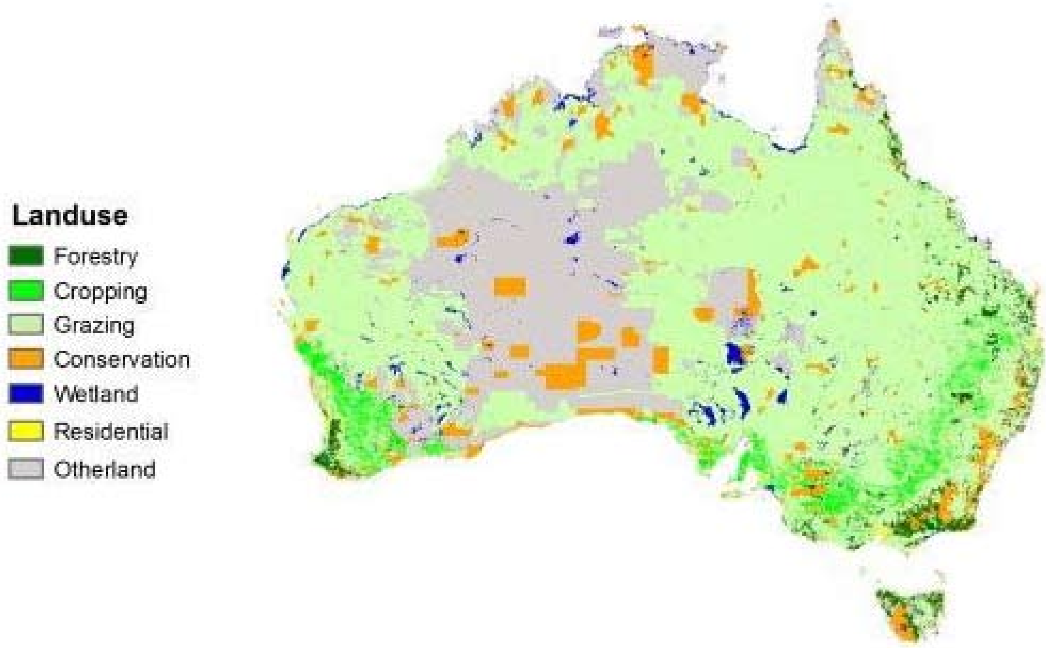
7.3 Land Areas and Land Use Category Definitions

7.3.1 National Circumstances

7.3.1.1 Land Use in Australia

Australia has a land area of 769 million hectares containing unique land, water, vegetation and biodiversity resources. The distribution and land areas of the continent under different land uses are shown in Figure 7.6. The most significant agricultural activities include wool, beef, wheat, cotton and sugar. Australia is also a significant exporter of dairy produce, fruit, rice and flowers. Australia's forest resources consist of native forests (primarily *Eucalyptus* species) which are used for wood production, recreation and conservation, and plantations of native (primarily *Eucalyptus* species) and exotic species (primarily *Pinus* species).

Figure 7.6: Land use in Australia



7.3.1.2 Climate

Australia is a dry continent where rainfall is highly variable and both recurring floods and droughts are a common feature. There are a number of distinct climatic zones with summer dominant rainfall in the tropics and subtropics in the north, Mediterranean climates in the south, the arid and semi-arid regions in the centre, and areas of high rainfall on the coastal fringes and in the ranges of the east (see Figures 7.7 and 7.8).

The tropical north is suited to grazing (predominately cattle) as well as the production of fruit and sugar cane. Land use in the subtropical and Mediterranean climates is cereal cropping and sheep and cattle grazing.

Figure 7.7: Average annual rainfall

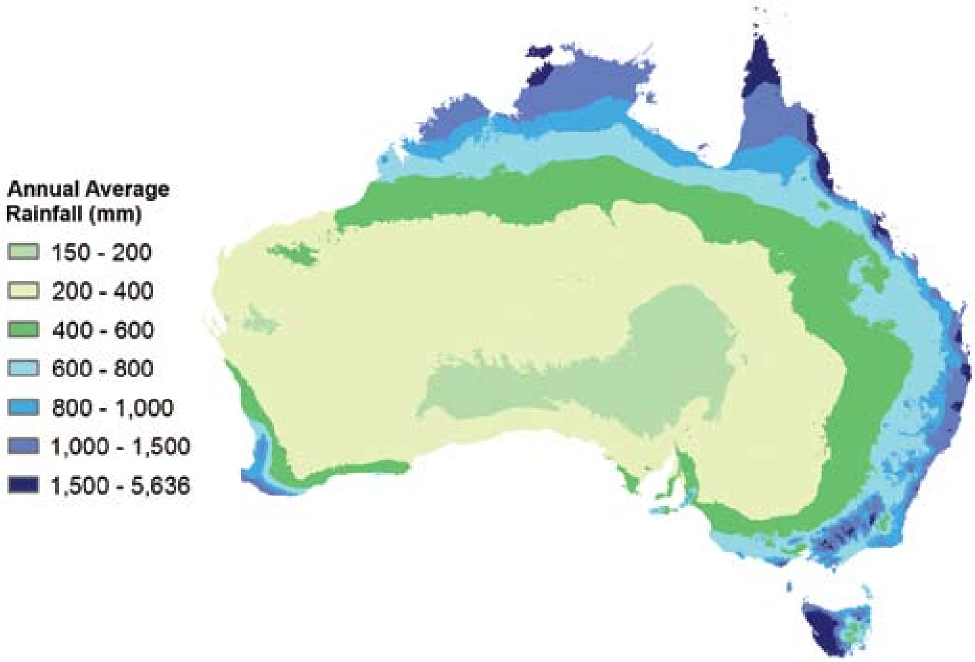
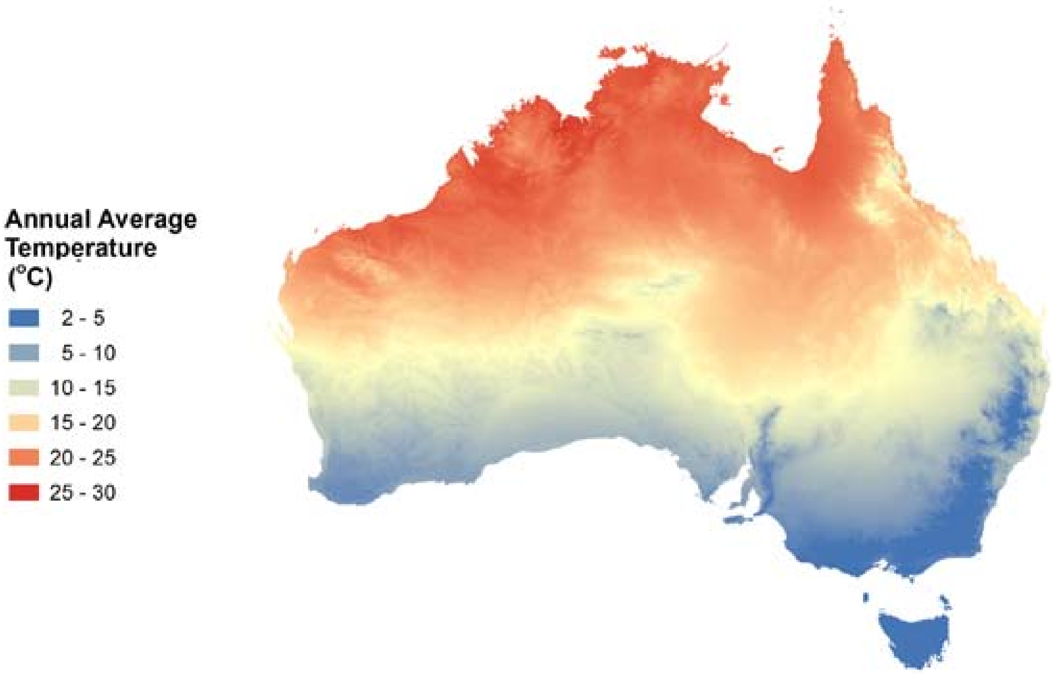


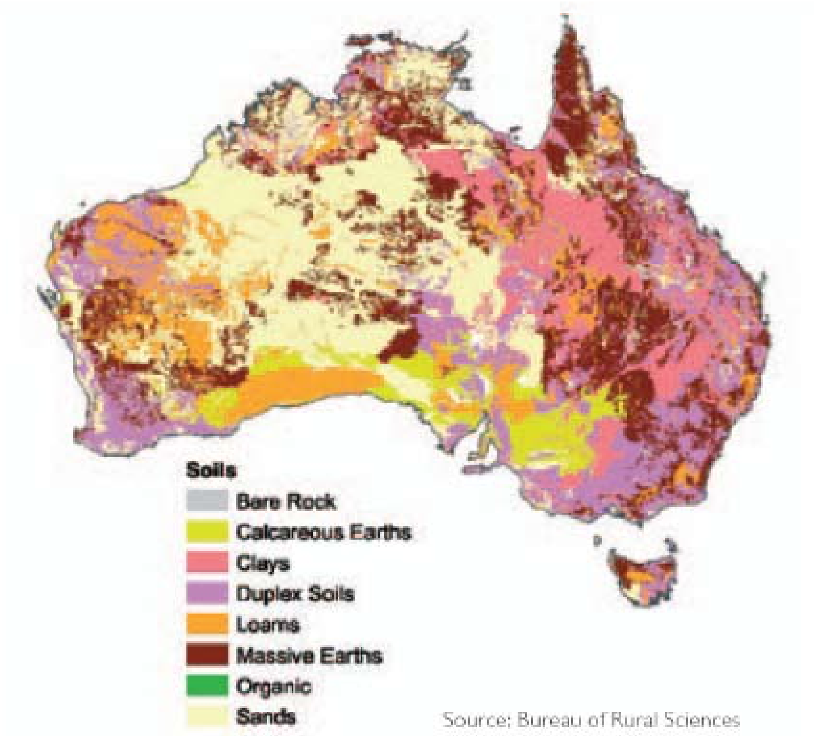
Figure 7.8: Average annual temperature



7.3.1.3 Soils

Australia has a diversity of soil types (Figure 7.9), ranging from old, deeply weathered and infertile, to younger, more fertile soils derived from volcanic rocks and alluvium. Approximately 50 per cent are sandy, 37 per cent are earths and loams, and 13 per cent are clay textured. Many soils have low levels of phosphorus and other nutrients. Soils are managed by maintaining ground cover, avoiding disturbance on steep slopes and use of fertilizer (mainly phosphorus and nitrogen).

Figure 7.9: Soils Map of Australia



7.3.2 Land Category Definitions

7.3.2.1 Forest Land

Forest land includes all lands with a tree height of at least 2 metres and crown canopy cover of 20% or more (Figure 7.10). These thresholds are consistent with the definition used for Australia's National Forest Inventory that has been used for reporting to the FAO and Montreal Process.

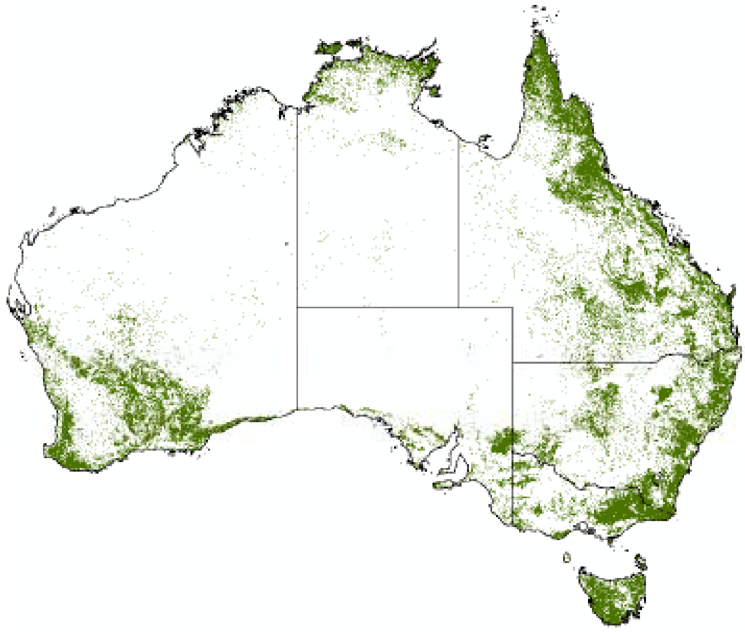
In choosing a forest definition Australia took several factors into account, including:

- the range of values provided for in the Marrakesh Accords LULUCF decision;
- the call in the Marrakesh Accords for consistency of Parties LULUCF reporting with existing international reporting;
- available data sources;
- the nature of deforestation and reforestation, and forest management activity, in Australia; and
- the requirement that the definition would need to remain consistent across all uses in the UNFCCC and Kyoto Protocol inventories and remain in place for time-series consistency.

The Marrakesh Accords provide ranges for forest attributes from within which countries are to derive national definitions. The ranges are a minimum height of 2 to 5 metres, a crown canopy cover of 10 to 30% and a minimum area of 0.05 to 1.0 hectare. Consistent with the definition used since 1992 for Australia's National Forest Inventory, which has been used for reporting to the FAO and Montreal Process, a height of 2 metres and crown canopy cover of 20% were adopted for the forest definition. This definition differs to that used in older reports, such as the Resource Assessment Commission (RAC) of 1992, which used 5m and a crown canopy cover of 30%. This older definition, while suitable for areas of commercial forests of interest to the RAC, excluded large areas of other forest types in drier regions which are of particular interest in the LULUCF inventory.

Australia has adopted a minimum forest area of 0.2 ha. As the National Forest Inventory does not apply a minimum area requirement in its definition an extensive process was undertaken to select an appropriate minimum area value. The selection process considered the structure and distribution of forest cover change in Australian forests, and the capacity of available data and processing systems to identify change at different spatial resolutions. The selection process is described in Appendix 7.A.

Figure 7.10: Forest extent in Australia



7.3.2.2 Cropland

Cropland includes all land that is used for continuous cropping, and those lands managed on crop-pasture (grassland) rotations. Crop-pasture rotations are common in Australia. These systems are considered as *Cropland* because this part of the rotational system has the greatest influence on carbon stocks and greenhouse gas emissions. Because of this, whenever land is cropped it is considered *Cropland* and reported under a *Cropland* category although the emissions are estimated taking into account that management systems may have transferred intermittently between grazing and cropping.

7.3.2.3 Grassland

In Australia, the *Grassland* category represents a diverse range of climate, management and vegetation cover. Grasses range from highly productive, improved introduced pastures, with applications of fertiliser and irrigation, through to unimproved native grasses which extend into the arid regions. The *Grassland* category also includes sub-forest forms of woody vegetation (shrubs) and areas of sparse tree cover that do not meet the cover or area criteria for forests.

7.3.2.4 Settlement

Settlements include areas of residential and industrial infrastructure, including cities and towns, and transport networks.

7.3.2.5 Wetland

Wetlands include areas of lakes, rivers, natural wetlands, and man-made dams.

7.3.2.6 Other land

The *Other lands* category includes all areas that are not included in the *Forest land, Cropland, Grassland, Settlement* or *Wetland* categories. *Other lands* in Australia typically occur in the arid regions.

7.3.2.7 Managed and unmanaged lands

Australia has diverse and extensive forest and agricultural systems with highly varied uses. Forest use is typically evident by physical disturbance, such as in commercial forest harvest, or clearly delineated by land tenure, such as conservation reserves. In extensive systems, such as grazed woodlands, there is a continuum in the intensity and intent of use, but no clear boundary by which to separate managed from unmanaged forest.

In the absence of a definable boundary between managed and unmanaged lands, and given the very broad definition that applies to managed land under the IPCC *Good Practice Guidance for Land Use, Land Use Change and Forestry* (IPCC 2003), Australia has included all forests in its area of managed land. However, while all forests are included in the area of managed land, this does not imply that all emissions and removals on managed lands are anthropogenic.

Other lands are the only land category considered to be unmanaged.

7.4 Representation of Land Areas

The principal method of representing land is through a time-series national remote sensing program. This consistent representation of land is a fully spatial and time-series application of Approach 3 as described in the IPCC *Good Practice Guidance for Land Use, Land Use Change and Forestry* (IPCC 2003). Reconciliations are done on a land unit by land unit basis to ensure that there are no gaps or overlaps which would lead to omission or double counting of areas of land. To support estimation of emissions/removals in the *Forest land* category, Australia uses some non-spatial data drawn from Australia's National Forest Inventory. This is used exclusively within a reporting category consistent with Approach 3. Land areas in the *Croplands remaining Croplands* and *Grassland remaining Grasslands* category are drawn from the Land Use Mapping programme of Australia's Bureau of Rural Sciences. Areas of *Forest land* and *Forest land converted to Grassland and Cropland*, (as determined from the NCAS remote sensing programme) are excluded from this mapping to prevent double counting of land areas. Table 7.4 shows the representation of land according to the IPCC categories. Annual land area matrices are shown in Table 7.5.

Table 7.4: Land representation matrix (1990 to 2007)

	1990	2007	Net Change
	Mha	Mha	Mha
Forest lands total	**112.0**	**106.8**	**-5.2**
Forest land remaining Forest land	111.9	105.6	-6.4
Harvested Native Forests	14.9	14.9	0.0
Plantations	0.8	0.8	0.0
Other Native Forest	96.2	89.9	-6.4
Grassland converted to Forest Land	0.1	1.3	1.2
Grasslands total	**444.4**	**448.4**	**4.0**
Grassland remaining Grassland	436.9	436.0	-0.9
Forest land converted to Grassland	7.6	12.5	4.9
Cropland total	**24.8**	**26.0**	**1.2**
Cropland remaining Cropland	21.7	21.7	0.0
Forest land converted to Cropland	3.1	4.3	1.2
Wetlands total	**13.5**	**13.5**	**0.0**
Settlements total	**1.6**	**1.6**	**0.0**
Other lands	**172.6**	**172.6**	**0.0**
Total Land Area [(a)]	**769.0**	**769.0**	**0.0**

Note: a) Total area does not include external territories

Table 7.5: Annual land area matrices from 1990 to 2007

1990							
	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	111.35	0.68					112.03
Grassland	0.44	443.99					444.44
Cropland	0.12		24.73				24.85
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.60	172.60
Initial Area	111.91	444.67	24.73	13.49	1.60	172.60	769.00
Net change	0.12	-0.24	0.12	0.00	0.00	0.00	0.00

1991							
	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	111.61	0.55					112.16
Grassland	0.34	443.89					444.22
Cropland	0.09		24.85				24.93
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.60	172.60
Initial Area	112.03	444.44	24.85	13.49	1.60	172.60	769.00
Net change	0.12	-0.21	0.09	0.00	0.00	0.00	0.00

1992							
	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	111.77	0.69					112.46
Grassland	0.32	443.53					443.85
Cropland	0.07		24.93				25.00
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.60	172.60
Initial Area	112.16	444.22	24.93	13.49	1.60	172.60	769.00
Net change	0.30	-0.37	0.07	0.00	0.00	0.00	0.00

1993							
	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	112.07	0.42					112.49
Grassland	0.32	443.43					443.76
Cropland	0.07		25.00				25.07
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.60	172.60
Initial Area	112.46	443.85	25.00	13.49	1.60	172.60	769.00
Net change	0.03	-0.10	0.07	0.00	0.00	0.00	0.00

1994							
	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	112.12	0.40					112.52
Grassland	0.29	443.36					443.65
Cropland	0.08		25.07				25.15
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.60	172.60
Initial Area	112.49	443.76	25.07	13.49	1.60	172.60	769.00
Net change	0.03	-0.11	0.08	0.00	0.00	0.00	0.00

1995							
	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	112.20	0.35					112.55
Grassland	0.26	443.30					443.56
Cropland	0.06		25.15				25.21
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.60	172.60
Initial Area	112.52	443.65	25.15	13.49	1.60	172.60	769.00
Net change	0.03	-0.09	0.06	0.00	0.00	0.00	0.00

1996							
	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	112.23	0.27					112.50
Grassland	0.25	443.29					443.54
Cropland	0.07		25.21				25.27
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.60	172.60
Initial Area	112.55	443.56	25.21	13.49	1.60	172.60	769.00
Net change	-0.05	-0.02	0.07	0.00	0.00	0.00	0.00

1997							
	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	112.19	0.26					112.45
Grassland	0.25	443.28					443.53
Cropland	0.06		25.27				25.34
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.60	172.60
Initial Area	112.50	443.54	25.27	13.49	1.60	172.60	769.00
Net change	-0.05	-0.01	0.06	0.00	0.00	0.00	0.00

1998							
	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	112.12	0.28					112.40
Grassland	0.27	443.25					443.52
Cropland	0.06		25.34				25.40
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.60	172.60
Initial Area	112.45	443.53	25.34	13.49	1.60	172.60	769.00
Net change	-0.05	-0.01	0.06	0.00	0.00	0.00	0.00

1999							
	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	112.06	0.55					112.61
Grassland	0.28	442.97					443.24
Cropland	0.06		25.40				25.46
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.60	172.60
Initial Area	112.40	443.52	25.40	13.49	1.60	172.60	769.00
Net change	0.21	-0.27	0.06	0.00	0.00	0.00	0.00

2000							
	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	112.25	0.57					112.82
Grassland	0.30	442.67					442.97
Cropland	0.06		25.46				25.52
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.60	172.60
Initial Area	112.61	443.24	25.46	13.49	1.60	172.60	769.00
Net change	0.21	-0.27	0.06	0.00	0.00	0.00	0.00

2001							
	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	112.05	0.09					112.14
Grassland	0.71	442.88					443.59
Cropland	0.07		25.52				25.59
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.61	172.61
Initial Area	112.82	442.97	25.52	13.49	1.60	172.61	769.01
Net change	-0.68	0.62	0.07	0.00	0.00	0.00	0.00

2002							
	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	111.36	0.09					111.45
Grassland	0.71	443.49					444.20
Cropland	0.06		25.59				25.65
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.61	172.61
Initial Area	112.14	443.58	25.59	13.49	1.60	172.61	769.00
Net change	-0.68	0.62	0.06	0.00	0.00	0.00	0.00

2003							
	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	110.56	0.09					110.65
Grassland	0.83	444.11					444.94
Cropland	0.06		25.65				25.72
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.61	172.61
Initial Area	111.45	444.20	25.65	13.49	1.60	172.61	769.00
Net change	-0.80	0.74	0.06	0.00	0.00	0.00	0.00

2004							
	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	109.77	0.08					109.85
Grassland	0.80	444.86					445.66
Cropland	0.08		25.72				25.80
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.61	172.61
Initial Area	110.65	444.94	25.72	13.49	1.60	172.61	769.00
Net change	-0.80	0.72	0.08	0.00	0.00	0.00	0.00

2005							
	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	108.80	0.06					108.86
Grassland	0.97	445.61					446.57
Cropland	0.08		25.80				25.87
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.61	172.61
Initial Area	109.85	445.66	25.80	13.49	1.60	172.61	769.00
Net change	-0.99	0.91	0.08	0.00	0.00	0.00	0.00
2006							
	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	107.88	0.05					107.93
Grassland	0.89	446.53					447.42
Cropland	0.08		25.87				25.95
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.61	172.61
Initial Area	108.86	446.57	25.87	13.49	1.60	172.61	769.00
Net change	-0.93	0.84	0.08	0.00	0.00	0.00	0.00
2007							
	Forest land	Grassland	Cropland	Wetlands	Settlements	Other land	Final Area
Forest land	106.78	0.05					106.83
Grassland	1.07	447.37					448.44
Cropland	0.08		25.95				26.03
Wetlands				13.49			13.49
Settlements					1.60		1.60
Other land						172.61	172.61
Initial Area	107.93	447.42	25.95	13.49	1.60	172.61	769.00
Net change	-1.10	1.02	0.08	0.00	0.00	0.00	0.00

7.4.1 Land Classification

Australia's reporting meets the IPCC (2003) land representation criteria of being consistent over time and that land is represented in only one category. Movement of land between categories is reported where a land use change occurs, such as a conversion of *Forest land to Cropland and Grassland*, or *Grassland to Forest land*. Areas of forest may also change to *Grassland* and vice versa due to forest regrowth and dieback. This process is largely driven by climate variability. These transitions are included as transfers between *Other Native Forest* and *Grassland remaining Grassland*.

In cases where there is a temporary change, such as a forest harvest, that land is not temporarily transferred in and out of that land category in accordance with good practice guidance. Equally, a temporary regrowth of woody biomass following land use change, as occurs in many grassland systems in Australia, is continuously reported under the *Grassland* category. This ensures that consistency in the treatment of temporary changes in land classification is maintained.

The IPCC (2003) recommends that for Tier 1 and 2 methods, land should be reported in a "conversion subcategory" for 20 years, and then moved to a "remaining subcategory", unless a further change occurs. However, they also note that Tier 3 modelling approaches may utilize different assumptions.

Australia has not, so far, selected a period of time after which reporting land is moved from a land use conversion subcategory to a land use remaining subcategory. This is because under Australia's Tier 3 inventory system, changing the category in the inventory report from the "conversion" to "remaining" subcategories at an arbitrary time period can lead to unintended artefacts in reporting. This problem is recognised in the 2006 IPCC Guidelines. In future submissions Australia plans to institute the method proposed in the 2006 IPCC Guidelines, which is to subdivide the land remaining category to provide a strata of land remaining that accommodates lands that are in later stages of transition following land-use change.

7.5 Monitoring of Forest Conversion

7.5.1 Understanding Patterns of Change

To understand the structure and distribution of forest cover change in Australia, a study was commissioned on the drivers, locations and patterns of forest cover change (AGO 2000a). This work showed significant regional differences in the nature of the drivers of deforestation and reforestation. Broadly, in southern Australia, patterns of deforestation strongly featured small 'patch' clearance for rural residential development, infrastructure such as roads, and the removal of remnant tree patches in agricultural lands. Reforestation also includes many small-scale environmental plantings for revegetation and rehabilitation purposes.

In the north of Australia, where the majority of deforestation occurs, the clearing patterns were for large development fronts involving the removal of remnant forest for expansion of the agricultural estate. Ongoing maintenance of removal of woody regrowth in 8 -15 year cycles was also very common within the existing agricultural estate.

Another factor that became evident from this work was that many ecosystems subject to change, such as woodlands, were characterised by highly variable patterns of tree cover and open spaces. The combination of a large proportion of forest cover change events being small scale, and the variable patterns of tree cover and open space, led to a need for monitoring at the lowest reliably applied spatial scale. This scale is driven by monitoring requirements, international agreements and data availability.

The nature of the deforestation activity also became evident as being largely in mature forests, except in cases where cyclic clearance and regrowth cycles (8-15 years) were being observed. As natural disturbances in Australian forests are rarely stand-replacing (i.e. the old forest is removed), there are few instances of conversion where the initial carbon stocks pre-clearing are below that of mature stands.

In addition to the work described above on forest cover monitoring, parallel studies on post-deforestation land management and emissions profiles were completed. These studies highlighted that the patterns of emissions over time were characterised by the majority of emissions occurring within 1-2 years of the deforestation event.

7.5.2 Data Availability

Australia has available an extensive archive of Landsat satellite data collected since the first Landsat sensor launch delivered data in 1972. Review of the archive in 1998 showed that there was sufficient continental coverage to allow for time-series continental change analysis commencing in 1972.

Once the availability of the Landsat data was established, it was necessary to establish whether the data and processing systems would be able to identify change at the different spatial resolutions at which forest conversion was occurring. Extensive processes were put in place to:

- select an analytic method;
- develop scene acquisition specifications for the geometric registration, radiometric calibration, and analysis and processing of the images to forest monitoring products;
- trial the methods using pilot studies of which the results were used to form detailed operational specifications (Furby and Woodgate, 2002);
- develop methods for continuous improvement and verification of the data; and
- establish the R&D programs that led to enhancement of the processes, such as described by Caccetta et al., (2003) and Wu et al., (2004).

Pilot testing was also used to refine the methods to deal with technical issues including:

- time-series stability given sensor change in the Landsat series;
- consistent application in the diversity of Australian vegetation types; and
- ability to detect change in the variety of spatial configuration and patterns.

7.5.3 Mapping Resolution and Resampling

7.5.3.1 Modelling grid resolution

The pixel resolution of data applied in a Tier 3 grid-based spatial ecosystem model and Approach 3 land representation predicates the use of both time-series consistent and spatially consistent integration of data. To gain time-series consistency in the land representation, 50m resampled Landsat data is always compared to 50m data, and where later best available data is at 25m, comparisons are made at 25m to 25m comparisons. The approaches are described in Appendix 7.A.

The pixel resolution of 50m and 25m are also guided by the need to integrate this spatial data with other spatial data sets. To achieve consistency in this integration a minimum 25m resolution, or select multiples of 25m (e.g., 50m, 100m, 200m, 250m, 1km) are applied so that pixel to pixel registration is achieved.

7.5.3.2 Land cover grid resolution

To deal with the change in pixel size of the various Landsat sensors over time and the need for spatially and temporally consistent integration with other spatial data used in the model, the 'natural' pixel size of the Landsat MSS (57m x79m) was re-sampled to a 50 x 50m pixel. The Landsat TM (~30 x 30m native resolution) and ETM+ data available after 1988 were produced as 25 x 25m pixels (see details in Appendix 7.A).

To apply the pixel-by-pixel analysis over the period where the pixel size changed from 50m to 25m (in 1988), a 50m MSS equivalent (in both spatial and spectral resolution) was derived from the 1989 TM (25m) data, and then forest extent calculated separately from both the 50 and 25m data sets. Differences in the extents of forest between these two outputs are due to "sensor change". An overlap technique, as recommended by the IPCC (2003), is used to ensure time-series consistency such that the assessment of land cover change for 1988-89 was then based on a 50m to 50m comparison, while the 1989-1991 data was a 25m to 25m comparison. This permitted the use of best available data while maintaining time-series consistency.

All Landsat derived data are utilised at a consistent 25m resolution for the full time-series analysis by resampling the 50m pixels (1972-1988) into four 25m pixels. The spatial-temporal model is important at this time, as it reduces the effect of "mixed" isolated and edge pixels. The period of the transition to the true 25m data takes place prior to the period where it would have any significant effect on the first reported year of emissions. The 50m data resolution is effectively only used to run-in the model to establish forest age (if the forest is regrowth from non-forest land or in response to a forest removal since 1972). The ability to determine, from 1990 onwards, the effects of land use change to 0.2ha minimum areas is robust, given that this area is greater than the pixel resolution and the approach used removes mixed and other pixels which are temporally and spatially inconsistent. These methods ensure that the change area within the commitment period (1990 onwards) is consistent at the 0.2ha resolution.

Resampling Landsat TM and ETM data to 25m pixels is common practice. Using a 50m resample to provide consistency over the multiple resolutions of Landsat MSS sensors also provides for uniformity in the time-series. QA and validation processes confirm that accurate results are achieved with this resampled data. Further details on the grid resolution and minimum areas are provided in Appendix 7.A.

7.5.4 Time-series Consistency

From the remote sensing pilot testing, the need for time-series consistency in image data pre-processing, analysis, and subsequent formation of time-series forest presence/absence labels became clear. To this end, the operational standards (Furby 2002) give explicit emphasis through documented rules to each of these areas. For instance, although the processing is performed by different companies, all images are otho-rectified using a standard algorithm (PCI Orthoengine) with standard inputs (a consistent digital elevation model). For time-series classification, these standards also include the use of a joint spatial-temporal model – in this case a conditional probability network (Caccetta, 1997; Caccetta et al., 2003; Kiiveri et al., 2001, 2003) – for determining time-series of forest cover presence/absence labels. This process produces far superior forest extent and change results than a process reliant on pair-wise differencing of image pairs. The use of pair-wise differencing methods can lead to change estimates that are affected by errors due to seasonally changing land management effects (introducing large contiguous areas of false change), or by subtle sampling differences where mixed pixels have varying composition of forest/non forest year to year (producing many isolated false change pixels or edge effects at forest boundaries).

The conditional probability network uses a series of spatial and temporal rules for determining forest presence/absence and change (forest and non-forest conversions). The temporal rules bias against unlikely events such as multiple one year conversions between forest and non forest – for example conversion from non-forest to forest and then back to non-forest is an unlikely event over a short, say three year, period. The rules are particularly effective when the time between observations is less than that of a forest growth and harvest cycle. This is one of the reasons for having a relatively dense time-series sampling.

The spatial rules consider the labelling of a pixel in the context of its spatial surroundings, where labels that are consistent with the neighbouring labels are reinforced as opposed to those that are inconsistent (e.g., isolated pixels). The spatial and temporal rules work together providing spatial and temporal consistency, minimising temporally varying “mixed pixel” effects (due to spatially varying sampling from independent satellite overpass year to year) and subsequent error in pixel and change labelling.

7.6 Source Category 5A Forest Lands

7.6.1 Methodology

7.6.1.1 Forest Land Remaining Forest Land

There are three broad components to *Forest land remaining Forest land – Harvested Native Forests, Other Native Forests* and *Plantations*. These are treated as independent strata and emissions estimates are modelled independently (Table 7.6). The definition of *Forest land* is provided in section 7.3.2.1.

Table 7.6: Sub categories used in the *Forest land remaining Forest land* category

Harvested Native Forests	Fuelwood	Plantations	Other Native Forests			
			Single change in cover	Ephemeral change in cover	Always forest	Fire
This subcategory represents areas of native forest that have been harvested at some time, and may still be available for harvest, or may now be in a reserve or other land tenure unavailable for harvest	Fuelwood is extracted from dead organic matter across all forest categories and not against any individual category or categories	These are the plantations that were established prior to 1990	These forest areas have changed their cover status, but there is no identifiable human intervention and they are likely to change again	These forest areas move above and below the forest determining thresholds, largely from climate influences	These forest areas are always under forest cover, but without commercial forest production	The CO_2 emissions due to wildfire and prescribed burning are reported here.

Harvested Native Forests

Harvested Native Forests are those comprised of endemic species arising from natural regrowth (including very old forests), although various silvicultural techniques may be applied to initiate and promote particular growth characteristics. The areas included in this sub-category are those subject to harvest and those regrowing from prior harvest for which age class (harvest record) data are available. In Australia, many areas that were historically harvested are no longer available for harvest, having been withdrawn from commercial use due to changes in policy, such as new codes of practice and transfer to conservation or recreation reserves. The continued removal of greenhouse gases due to recovery from former harvesting continue to be reported in this category, even if the lands have moved to a reserve status. Areas of deforestation that change to a non-forest land use or to plantation forest (native and exotic) are excluded from this account and are reported elsewhere.

The method used for the estimation of emissions and removals is Tier 2, using country specific data for slash generation, growth and decomposition rates. The reporting of *Harvested Native Forests* includes both above and belowground biomass and harvest slash (including roots) generated from forest harvest. Emissions and removals from soil carbon are not considered to be significant with the losses during forest harvest presumed to be in balance with re-accumulation in areas of regrowth for any inventory period. The detailed methods used are described in Appendix 7.A.

The current methods do not support emissions estimation from other activities in harvested forest lands, but these activities (e.g., grazing, beekeeping etc.) do not have a significant effect on carbon stocks in *Harvested Native Forests*.

Harvested Wood Products are not reported in this category and carbon stocks are transferred to category *5G Other – Harvested Wood Products*. As the structure of the reporting tables does not account for transfers of carbon stocks, this leads to an apparent, but not real, emission from *Harvested Native Forests* and a ‘sink’ in *Harvested Wood Products* in the year of harvest.

Other Native Forests

Other Native Forests include those forests that are (a) comprised of endemic species, (b) not *Harvested Native Forests* (c) not areas of *Deforestation*, and (d) are not *Plantations* (native or exotic) or *Grassland* converted to Forest.

Other Native Forests are divided into several sub-categories for modelling purposes. Each sub-category uses country specific emissions factors or models. These sub-categories include emissions and removals for: permanent changes in forest extent (such as thickening and degradation); ephemeral changes in forest extent due to climate; loss of foliage mass in continuous forest areas due to climate; and controlled burning and wildfire (including removals post-fire). The emissions and removals in the *Other Native Forests* category are overwhelmingly due to natural disturbances and annual climate variability. The detailed methods used are described in Appendix 7.D.

The area of *Other Native Forest* is determined using the remotely sensed areas of forest, excluding areas of *Forest land converted to other land uses, Plantations*, *Grassland converted to Forest land* and *Harvested Native Forests*. The area of *Other Native Forest* changes through time due to ongoing processes such as degradation, regrowth and thickening, and fluctuates due to climate.

Plantations (Native Forests converted to Plantations and Plantations remaining Plantations)

This subcategory contains plantations established prior to 1990 that remain as forest. The *Plantation* forests include those forests that (a) meet the definition of forest, (b) are not harvested native forests, (c) are not areas of deforestation, and (d) for reporting of *Forest land remaining Forest land*, are not other land uses that are converted to *Forest land* (post 1990). Areas included are typically either *Harvested Native Forest* converted to *Plantation*, or long term (second or third rotation) plantation systems. Prior to 1990 it was relatively common practice to convert native forest to forest plantation. After 1990, this practice largely ceased, and now only occurs in limited areas.

The Tier 3 *FullCAM* model is used to estimate emissions and removals from *Plantations* (although not yet in a fully spatially explicit mode) employing growth increment tables and wood flow estimates. The carbon pools considered for *Plantations* include above and belowground biomass and litter. Soil carbon under long term forest use is considered to be in equilibrium. This is consistent with national reviews of forest soil carbon data (Polglase et al., 2004; Paul et al., 2002b; Paul et al., 2003b). The detailed methods used are described in Appendix 7.C.

The areas of *Plantation* have been drawn from Australia's National Forest Inventory. However, the National Forest inventory makes no distinction between native forest conversions to *Plantations* and second rotation plantations (*Forest land remaining Forest land*) and other non-forest land uses converted to forests (*Land converted to Forest land*). To separately identify non-forest land uses that were converted to forest after 1990 the archive of NCAS remotely sensed satellite data was analysed from 1990 onwards. This time-series data was able to separate forests that remained forests from other land uses that were converted to forest, while also keeping these spatially unique from forest regrowth cycles in areas of deforestation that are reported under the *Forest land converted to Other Land Use* categories.

As historic Australian forest inventory data on plantation establishment does not separate new forest establishment from second rotations forests (Jaakko Pöyry Consulting 2000) it is not possible to separate pre-1990 *Plantations* from *Forest lands remaining Forest lands*. Post-1990 this separation is made possible through the plantation mapping using Landsat data as described in Appendix 7.A.

Harvested wood products are not reported in this category and carbon stocks are transferred to the *Harvested Wood Products* reporting (5G *Other*). As the structure of the reporting tables does not account for transfers of carbon stocks, this leads to an apparent, but not real, emission from plantation forests and a 'sink' in *Harvested Wood Products* in the year of harvest.

Fuelwood Consumed

Fuelwood is extracted from dead organic matter across all forest categories and as such the CO_2 emissions associated with the consumption of *Fuelwood* are reported separately rather than against any specific subcategory of *Forest lands*. The amount of *Fuelwood* collected from *Forest lands* is based on the estimates of *Fuelwood* consumption (t dry matter) reported by ABARE. Dry matter is converted to carbon content (0.5) and multiplied by 44/12 to give CO_2 emissions.

7.6.1.2 Land Converted to Forest Land

Grassland converted to Forest land

Grassland converted to Forest land contains forest established on non-forest land since 1990. In Australia, lands converted to forest are almost always formerly grassland. All emissions are therefore reported as *Grassland converted to Forest land*. High land values and high soil nutrient status both limit the access to, and suitability of, former croplands for plantation establishment.

The definition of forest is the same as reported for all other land categories. The areas of *Grassland converted to Forest land* are drawn from remotely sensed data as per the methods described in Appendix 7.A. The multiple national time-series of Landsat satellite data (25m) is analysed to provide the previous vegetation cover, area, time of establishment and type of plantation (Caccetta and Chia 2004).

The modelling method used to estimate emissions is described in Appendix 7.C and is the same as that used for *Plantations* under *Forest land remaining Forest land*. Again, the soil carbon is presumed to be in equilibrium. Polglase et al., (2004), Paul et al., (2002b) and Paul et al., (2003b) have shown that with the establishment of plantations on pasture land an initial loss of soil carbon will be recovered over time. Given the mix of ages of the plantations reported under this category, it is expected that initial losses of soil carbon in young forests would be counterbalanced by the accumulation in older forests. A calibrated and verified soil carbon model will be used to estimate soil carbon emissions in future when the full NCAS spatially explicit modelling (Tier 3, Approach 3) is applied.

7.6.2 Uncertainties and Time Series Consistency

Uncertainties for *Forest lands* were estimated to be ±30% for CO_2. Further details are provided in Annex 7. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to methodology.

7.6.3 Source Specific QA/QC

Specific QA/QC and verification activities undertaken for this source category are described in detail in Appendices 7.B, 7.C and 7.D.

7.6.4 Recalculations Since the 2006 Inventory

In response to the recommendations of the UNFCCC review team, estimates of CO_2 emissions and removals from *Other Native Forests* are now included in the *Forest lands* sub-sector. The effect of these changes was to add a 14.2 Mt sink to the 1990 estimate and a 58.8 Mt sink to the 2006 estimate. In addition the time-series for *Fuelwood consumed* has been revised due to the correction of rounding errors and the update of preliminary estimates. The *Harvested Native Forest* estimates for 2001 to 2006 have been revised following a revision to the ABARE wood removal data.

The net effect of all the changes was to add a net removal of 14.2 Mt to the 1990 estimate and a net removal of 57.7 Mt to the 2006 estimate.

7.6.5 Source Specific Planned Improvements

The method used is yet to reflect the fully spatially explicit (Approach 3), Tier 3 process-based modelling methods of Australia's NCAS. The methods described in Appendices 7.B, 7.C and 7.D. provide interim methods using a combination of Tier 3 and Tier 2 methods. Development of a comprehensive estimation capability for future reporting is ongoing and will be released once the national implementation has been fully calibrated, verified, quality assured and peer reviewed. This is consistent with the approach to inclusion of NCAS results in the national inventory only after all appropriate cross-cutting processes have been completed.

The remote sensing programme is currently further developing methods to identify areas of plantation established prior to 1988 using Landsat MSS data. Work on identifying areas subject to harvest using the remote sensing data is also ongoing.

7.7 Source Category 5B Cropland

7.7.1 Methodology

7.7.1.1 Cropland Remaining Cropland

The distribution of land areas in the *Cropland remaining Cropland* subcategory estimate are mapped by the National Land and Water Resources Audit (http://nlwra.gov.au/) provided by the Bureau of Rural Sciences. *Cropland remaining Cropland* covers an area of over 20 million hectares (Figure 7.11). The lands covered by *Cropland remaining Cropland* also include the rotational crop and pasture systems that on a regular basis swap from one to the other. No lands are converted from *Cropland to Forest Land* or from *Cropland to Grassland*. In this reporting structure, *Cropland remaining Cropland* includes only those lands that were used for cropping prior to 1972, and remain in a crop land use. Table 7.7 shows the various crop types that are in this land use category.

Cropland is generally located along a broad inland fringe across the southern and eastern land mass, with highest yields commonly obtained in the south west and the eastern regions. In the southern regions, *Cropland* is dominated by wheat production, with barley, oats, lupins and canola being the other dominant crops. In the north sugarcane, sorghum and cotton dominate.

The majority of crops grown in Australia are winter dominant given that they are predominantly reliant on winter rainfall and are subject to the climatic conditions in any given year. Crop yields vary according to the annual distribution of rainfall and the types of crops grown within a region. Irrigated crops account for about 5% of the total cropped land.

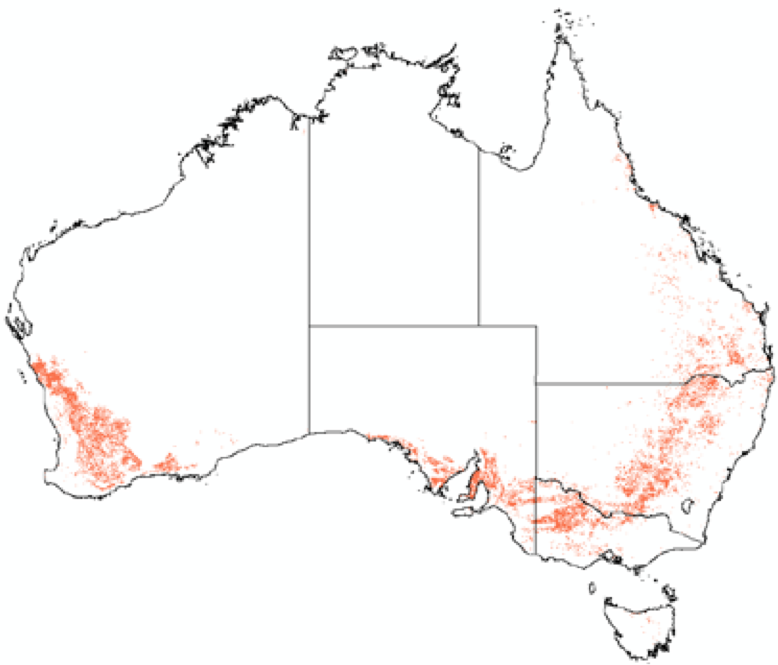
The reporting of *Cropland remaining Cropland* includes all on-site carbon pools (living biomass, dead organic matter and soil). Emissions and removals are estimated using the Tier 3, Approach 3 NCAS mass balance, process-based ecosystem model *FullCAM*, as described in Appendix 7.A. The calibration and verification of this model, along with the associated quality assurance and quality control program are described in Appendix 7.A and the data used in the modelling is provided in Appendix 7.C.

For *Cropland remaining Cropland*, no land use changes (deforestation) took place after 1972, so to initialise the model, it was presumed that land in the *Cropland remaining Cropland* area entered this category following deforestation between 1940 and 1971. The exact date of deforestation of each pixel is randomly allocated between these years. As the lands in the *Cropland remaining Cropland* category have been retained under a similar land use for at least 36 years (i.e., the land has been *Cropland* since 1972), changes in carbon stocks are affected primarily by land management practice and climate. These two factors largely determine the amount of live biomass and therefore the residues in dead organic matter that subsequently become incorporated into the soil carbon (Janik et al., 2002).This is further described in Appendix 7.A.

For the current *Cropland remaining Cropland* estimates, management is not varied as comprehensive management data for all of Australia's *Cropland*s is not yet available (as opposed to the *Forest land converted to Cropland* category where data is available). Hence variation in the live biomass, dead organic matter and soil pools is largely driven by crop production, which varies due to climate and improved breeding. They thus show a pattern of emissions and removals that follow climate affects on crop production. However, while the interannual climate variability affects crop production, there is also an underlying increase in per hectare crop production that contributes to an underlying removal trend as shown in Figure 7.F2.

Non-CO_2 emissions from *Cropland remaining Cropland* are reported in the Agriculture sector.

Figure 7.11: Distribution of Cropland in 2001-02



Note: figure presents areas of both *Cropland remaining Cropland* and *Forest land converted to Cropland*

Table 7.7: The crop types and approximate areas in Cropland in 2001-02

Crop type	Area (M ha)
Cereals	18.57
Legumes	2.27
Oil seeds	1.47
Irrigated cereals	0.61
Irrigated cotton	0.43
Sugar	0.29
Irrigated sugar	0.25
Irrigated vegetables and herbs	0.15
Irrigated vine fruits	0.15
Cropping	0.13
Irrigated tree fruits	0.11
Irrigated cropping	0.04
Cotton	0.04
Perennial horticulture	0.03
Hay and silage	0.03
Tree fruits	0.03
Tree nuts	0.02
Irrigated oil seeds	0.02
Vine fruits	0.02
Irrigated tree nuts	0.02
Irrigated legumes	0.02
Irrigated perennial horticulture	0.01
Vegetables and herbs	0.01
Irrigated hay and silage	0.01

Note: table presents data for both *Cropland remaining Cropland* and *Forest land converted to Cropland*

7.7.1.2 Land Converted to Cropland

Forest land converted to Croplands

The definition for a forest used by Australia (2m height, 20% crown canopy cover and minimum area of 0.2ha) is also used to define areas of forest conversion. That is, the conversion of greater than 0.2ha of forest to another (non-forest) land use is taken as a forest conversion. When the land use subsequent to a forest conversion contains a cropping activity, associated emissions are reported under *Forest Land converted to Cropland.*

The reporting of *Forest Land converted to Cropland* includes all on-site carbon pools. The areas are identified by the NCAS remote sensing program as described in Appendix 7.A. Emissions and removals are estimated using the Tier 3, Approach 3 NCAS mass balance, process-based ecosystem model *FullCAM*, as described in Appendix 7.A.

N_2O emissions from disturbance associated with land-use conversion to *Cropland* are estimated as described in section 7.12.1.4. Non-CO_2 emissions other than N_2O from disturbance due to land-use conversion to Cropland are reported in the Agriculture sector.

7.7.2 Uncertainties and Time Series Consistency

Uncertainties for Cropland conversion at the national scale were estimated to be ±10% for CO_2. Based on a qualitative assessment the uncertainties for *Cropland remaining Cropland* were estimated to be medium. Further details are provided in Annex 7. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to methodology.

7.7.3 Source Specific QA/QC

The calibration and verification of the NCAS *FullCAM* model, along with the associated quality assurance and quality control program are described in Appendix 7.A. and 7.E.

7.7.4 Recalculations Since the 2006 Inventory

The CO_2 emissions and removals from *Cropland remaining Cropland*, are now estimated using the Tier 3 NCAS *FullCam* model which introduces into the estimates both natural and anthropogenic emissions and removals in living biomass, dead organic matter and soil associated with land management practice and annual climate variability. In the 2006 inventory this category was estimated using Tier 1 methods which assumed emissions and removals were in equilibrium. The recalculation added a 24.5 Mt sink to the 1990 estimate and 8.4 Mt of emissions to the 2006 estimate.

The preliminary estimates of the area of forest conversion to Cropland 2005 and 2006 have been revised with the provision of updated data from the NCAS. As the system randomly allocates the date of forest conversion in each run of the *FullCAM* model this leads to small recalculations in the time-series although there have been no methodological changes. These recalculations result in a 0.9 Mt decrease in the 1990 estimate and an 8.0 Mt increase in the 2006 emissions estimate.

7.7.5 Source Specific Planned Improvements

Planned improvements for *Croplands* include the development of a new crop growth model and the implementation of non-CO_2 components into *FullCAM* (see Appendix 7.A).

7.8 Source Category 5C Grassland

7.8.1 Methodology

7.8.1.1 Grassland Remaining Grassland

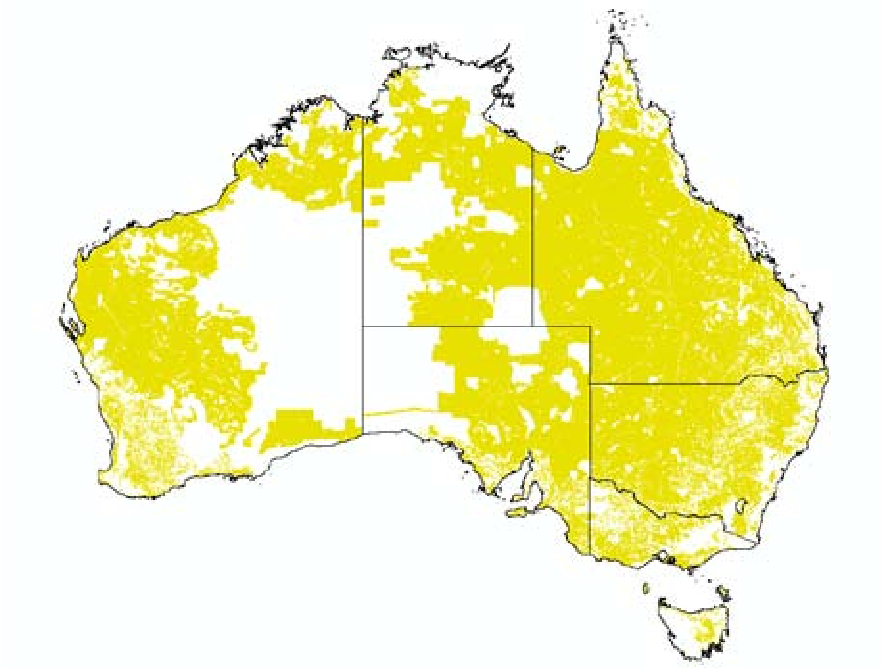
The *Grassland remaining Grassland* category includes all areas of *Grassland* that are not reported under *Forest land converted to Grassland*. Areas that are in rotational use between *Grassland* and *Cropland* are reported under either *Forest land converted to Cropland* or *Cropland remaining Cropland*.

The distribution of land areas in the *Grassland remaining Grassland* subcategory estimate are mapped by the National Land and Water Resources Audit (http://nlwra.gov.au/) provided by the Bureau of Rural Sciences. In 2007 *Grassland remaining Grassland* covered an area of 436 million hectares which is evenly distributed around Australia (Figure 7.12).

There are three broad components to the *Grassland remaining Grassland* estimates – the grassland component, the shrubland component and the CO_2 emissions and post fire removals associated with savanna burning. The grasslands and shrublands components are estimated using interim methods. The Tier 3 *FullCAM* model is used to estimate emissions and removals for the grass only areas of the *Grassland* category, including all pools (living biomass, dead organic matter and soil). A Tier 2 method is used to estimate emissions and removals for the shrubland (sub-forest) areas for living and debris. These methods are described in Appendix 7.F.

Non-CO_2 emissions from *Grassland remaining Grassland* are reported in the Agriculture sector.

Figure 7.12: Distribution of *Grassland remaining Grassland*



7.8.1.2 Land Converted to Grassland

Forest Land Converted to Grassland

The definition for a forest used by Australia (2m height, 20% crown canopy cover and minimum area of 0.2ha) is also used to define areas of forest conversion. That is, the conversion of greater than 0.2ha of forest to another (non-forest) land use is taken as a forest conversion. When the land use subsequent to a forest conversion is grassland only (i.e., no crops), associated emissions are reported under *Forest Land converted to Grassland*.

The reporting of *Forest land converted to Grassland* includes all carbon pools. The areas are identified by the NCAS remote sensing program as described in Appendix 7.A. Cyclic forest regrowth and reclearing of woody regrowth in grasslands is continuously reported under *Forest land converted to Grassland*. Lands which are managed under a crop-pasture rotation are reported under *Forest land converted to Cropland*.

Emissions and removals from this category are estimated using the Tier 3, Approach 3 NCAS mass balance, process-based ecosystem model *FullCAM*, as described in Appendix 7.A.

N_2O emissions from disturbance associated with land-use conversion to *Grasslands* are estimated as described in section 7.12.1.4. As it is not possible to include these emissions under *Lands converted to Grasslands* in the UNFCCC CRF tables they are reported under 5G. Non-CO_2 emissions, other than N_2O from soil disturbance associated with land-use conversion to Grassland, are reported in the Agriculture sector.

7.8.2 Uncertainties and Time Series Consistency

Uncertainties for *Grassland* conversion at the national scale were estimated to be ±10% for CO_2. Based on a qualitative assessment the uncertainties for *Grassland remaining Grassland* were estimated to be medium. Further details are provided in Annex 7. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to methodology.

7.8.3 Source Specific QA/QC

The calibration and verification of the NCAS *FullCAM* model, along with the associated quality assurance and quality control programs are also described in Appendix 7.A.

7.8.4 Recalculations Since the 2006 Inventory

In response to the recommendations of the UNFCCC review team the CO_2 emissions and removals from *Grassland remaining Grassland*, are now estimated using Tier 2 and 3 methods which introduce into the estimates both natural and anthropogenic emissions and removals in living biomass (both grass and woody material), dead organic matter and soil associated with land management practice, natural disturbance and annual climate variability. In the 2006 inventory this category was estimated using Tier 1 methods which assumed emissions and removals were in equilibrium. The recalculation added an 18.3 Mt sink to the 1990 estimate and 31.7 Mt in emissions to the 2006 estimate.

The preliminary estimates of the area of forest conversion to grassland in 2005 and 2006 have been revised with the provision of updated data from the NCAS. As the system randomly allocates the date of forest conversion in each run of the *FullCAM* model this leads to small recalculations in the time-series although there have been no methodological changes. These recalculations result in a 3.9 Mt decrease in the 1990 estimate and a 12.7 Mt increase in the 2006 estimate.

7.8.5 Source Specific Planned Improvements

Planned improvements for *Grasslands* include the time-series mapping of areas of sparse woody (shrub) vegetation, and implementation of non-CO_2 components into *FullCAM* (see Appendix 7.F).

7.9 Source Category 5D Wetland

7.9.1 Methodology

7.9.1.1 Wetland Remaining Wetland

Australia does not estimate emissions and removals from this voluntary reporting category.

7.9.1.2 Land Converted to Wetland

Australia has no peat extraction and any removals of forest biomass for the purposes of water storage infrastructure are reported under *Forest land converted to Grassland*.

7.10 Source Category 5E Settlements

7.10.1 Methodology

7.10.1.1 Settlements Remaining Settlements

Australia does not estimate emissions and removals from this voluntary reporting category.

7.10.1.2 Land Converted to Settlements

The conversion of forest prior to infrastructure development is captured and reported under *Forest land converted to Grassland*. Therefore emissions and removals from this category are included elsewhere.

7.11 Source Category 5F Other Lands

7.11.1 Methodology

7.11.1.1 Other Lands Remaining Other Lands

All *Other lands* are considered unmanaged and as such Australia does not report emissions and removals from this voluntary reporting category.

7.11.1.2 Land Converted to Other Land

It is assumed that no lands are converted to *Other lands*

7.12 Source Category 5G Other

7.12.1 Methodology

7.12.1.1 Harvested Wood Products

Australia reports the carbon stock changes and associated emissions and removals of CO_2 from the *Harvested Wood Products* pool. The carbon pool considered is defined as the wood products in service life within Australia. This includes the national production (including transfers from *Forest land* after harvest that are recorded as a carbon stock reduction in *Forest land remaining Forest land* and *Grassland converted to Forest land*) plus the imported material, minus exported material and losses to landfill and the atmosphere. The methods used are described in detail in Appendix 7.G.

7.12.1.2 N_2O Emissions from N Fertilisation 5(I)

Nitrous oxide emissions associated with nitrogen fertilisers are reported under the Agriculture sector (4D).

7.12.1.3 N_2O Emissions from Drainage of Soils 5(II)

Australia does not estimate emissions and removals from this voluntary reporting category.

7.12.1.4 N_2O Emissions from Disturbance Associated with Land-Conversion to Cropland and Grassland 5(III)

An increase in N_2O emissions can be expected following the conversion of *Forest land* to *Cropland* and *Grassland*. This is a consequence of enhanced mineralisation of soil organic matter that takes place as a result of that conversion. The conversion results not only in net loss of soil organic carbon but the mineralised nitrogen can result in N_2O emissions from the process of nitrification and denitrification.

A method for calculating N_2O emissions from this source is provided in IPCC 2006 Guidelines for National Greenhouse Gas Inventories (chapter 11). This method is used for estimation of this emission source. The amount of nitrogen mineralised is calculated from the C:N ratio of soil. The C:N value used is 18, reflecting the approximate median value extracted from a survey of national estimates (Snowden et al., 2005). The same emissions factor as used for fertiliser additions to pasture (0.004) is then applied, as recommended in the 2006 IPCC Guidelines. Also, following the methods outlined, nitrogen sequestered into carbon stocks is not taken into account, leading to zero emissions for Forest to cropland and grassland conversions where appropriate at the regional level (State).

7.12.1.5 CO_2 Emissions from Agricultural Lime Application 5(IV)

Limestone and dolomite are used in Australia to ameliorate soil acidity and improve plant growth in both *Croplands* and *Grasslands*. Adding carbonates to soils in the form of lime (eg., calcic limestone ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$) leads to CO_2 emissions as the carbonate limes dissolve and release biocarbonate which evolves into CO_2 and water.

For agricultural lime application, the annual emissions of CO_2 are calculated as:

$$E_{ijk} = ((M_{jk} \times FracLime_{jk} \times P_{k=1} \times EF_{k=1}) + (M_{jk} \times (1 - FracLime_{jk}) \times P_{k=2} \times EF_{k=2})) \times C_i / 1000 \quad (5IV\_1)$$

Where: E_{ijk} = annual emission of CO_2 from lime application (Gg)

M_{jk} = mass of limestone and dolomite applied to soils (t)

$FracLime_{jk}$ = fraction limestone

$P_{k=1}$ = fractional purity of limestone = 0.9

$P_{k=2}$ = fractional purity of dolomite = 0.95

$EF_{k=1}$ = 0.12 - IPCC (2006) default emission factor for limestone

$EF_{k=2}$ = 0.13 - IPCC (2006) default emission factor for dolomite

C_i = 44/12 factor to convert elemental mass of CO_2 to molecular mass

7.12.2 Uncertainties and Time Series Consistency

A qualitative assessment of uncertainty was undertaken and uncertainties for *Harvested Wood Products* were estimated to be medium. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to methodology.

National data on limestone and dolomite applications to agricultural soils are only available from the Australian Bureau of Statistics for five years (1993, 1994, 1996, 2001 and 2002) with limestone and dolomite reported separately for only three (1996, 2001, 2002) of those years. Additional data are available for Western Australia (1991, 1995, 1998-2000 and 2004). Interpolation and extrapolation techniques have been used to estimate the mass of limestone and dolomite applied in years for which data are not available. The fraction of the estimated mass applied that is assumed to be limestone was based on the average of years for which data are available.

7.12.3 Source Specific QA/QC

Specific QA/QC and verification activities undertaken for this *Harvested Wood Products* are described in detail in Appendix 7.G.

7.12.4 Recalculations Since the 2006 Revised Inventory

The methods used to determine the disposal of HWP stocks have been revised (see Chapter 8 for more details on the changes made to the model). This recalculation results in a 0.2 Mt increase in the 1990 sink estimate and an 0.7 Mt increase to the 2006 sink estimate.

As the estimates for *Forest land* converted to *Cropland* and *Grasslands* have been recalculated, the estimate of N_2O emissions from disturbance associated with land-use conversion has also been recalculated. These recalculations result in a minor increase in the 1990 estimate and a 0.1 Mt CO_2-e decrease to the 2006 estimate.

7.12.6 Source Specific Planned Improvements

All data and methodologies are kept under review and development. Appendix 7.A specifies the detailed development plans for the National Carbon Accounting System.

7.13 Source Category 5(V) Biomass Burning

7.13.1 Methodology

7.13.1.1 Forest lands (5A.1) – Prescribed Burning and Wildfires

In *Forest lands*, burning occurs in Australia either anthropogenically or as a result of wildfires. The anthropogenic burning occurs for a variety of reasons including fuel reduction for the prevention of uncontrollable wildfires, and traditional Aboriginal burning. These anthropogenic fires often replace wildfires that would occur naturally otherwise, albeit with differing frequency and at other times of the year.

Climatic variability contributes large year-to-year variations in biomass burning in Australia. Consequently, to obtain a representative value, emissions are reported as a 3–year moving average of individual annual estimates as recommend by the IPCC (1997, Volume 1, page 2.3). [1]

For prescribed burning and wildfires, the total mass of fuel burnt is calculated as:

$$M_{jk} = A_{jk} * FL_{jk} * Z_{jk} * 10^{-3} \qquad (5V\_1)$$

Where: A_{jk} = area of category burnt annually (ha),
M_{jk} = mass of fuel burnt annually (Gg),
FL_{jk} = fuel loading (dry weight) (Mg ha^{-1}) (Table 7.8 and 7.9),
Z_{jk} = burning efficiency (Table 7.10),

then for CH_4, CO and NMVOCs the total annual emissions are calculated as:

$$E_{ijk} = M_{jk} * CC_{jk} * EF_{ijk} * C_i \qquad (5V\_2)$$

Where: E_{ijk} = annual emission of gas *i* from biomass burning (Gg),
M_{jk} = mass of fuel burnt annually (Gg yr^{-1}).
CC_{jk} = carbon mass fraction in vegetation (Table 7.11),
EF_{ij} = emission factor for gas *i* from vegetation (Table 7.12),
C_i = factor to convert from elemental mass of gas species *i* to molecular mass (Table 7.13),

and total annual emissions for NO_x and N_2O are:

$$E_{ijk} = M_{jk} * CC_{jk} * NC_{jk} * Ei_{jk} * C_i \qquad (5V\_3)$$

Where: E_{ijk} = annual emission of gas *i* from biomass burning (Gg),
M_{jk} = mass of fuel burnt annually (Gg),
CC_{jk} = carbon mass fraction in vegetation (Table 7.11)
NC_{jk} = nitrogen to carbon ratio in biomass (Table 7.11)
EF_{ijk} = emission factor for gas *i* from vegetation (Table 7.12)
C_i = factor to convert from elemental mass of gas species *i* to molecular mass (Table 7.13)

The CO_2 emissions and removals associated with the burning and subsequent regrowth of forest lands are reported under 5.1. *Other Native Forest* and thus are not reported under 5(V) *biomass burning* so as to ensure no double counting. A description of the method used to estimate these emissions and removals is provided in Appendix 7.D.

[1] While IPCC (2003) provides methods for estimating annual emissions, as an elaboration of the Revised 1996 IPCC Guidelines (IPCC 1997), they do not explicitly remove the option of reporting average emissions.

Table 7.8: Fuel loads for prescribed burning of forest in Australia

State	ACT[a]	NSW[a]	NT[a]	Qld[a]	SA[b]	Tas[b]	Vic[a]	WA[a]
	FL_{jk} (Mg/ha)							
Load	17.6	18.2	4.1	9.7	9.6	20.0	17.9	12.0

Source: a) State agencies; b) Tolhurst (1994)

Table 7.9: Fuel loads for wildfires in Australia

State	ACT[a]	NSW[a]	NT[a]	Qld[a]	SA[b]	Tas[b]	Vic[a]	WA[a]
	FL_{jk} (Mg/ha)							
Load	35.2	36.4	7.2	19.4	19.2	40.0	35.8	33.4

Source: a) State agencies; b) Tolhurst (1994)

Table 7.10: Burning efficiencies for prescribed burning and wildfires in Australia

Category	Burning efficiency Z_{jk}
Prescribed burning	0.42
Wildfires	0.72

Source: Tolhurst (1994)

Table 7.11: Forest biomass composition

System	Carbon mass fraction in dry residue CC_{jk}	Nitrogen to carbon mass fraction NC_{jk} [a]
Forest	0.5	0.011

Source: a) Hurst et al., (1994a,b)

Table 7.12: Mean emission factors for carbon and nitrogen trace gases from forest biomass burning

	Gas species *i*	Emission factor E_{ijk} (Gg element in species/Gg element in fuel burnt)
1.	CH_4	0.0054
2.	N_2O	0.0077
3.	NO_x	0.15
4.	CO	0.091
5.	NMVOC	0.022

Source: Hurst et al., (1996) mean of 4 Australian temperate forest fires.

Table 7.13: Elemental to molecular mass conversion factor (C_i)

CH_4	N_2O	NO_x	CO	NMVOC
1.33	1.57	3.29	2.33	1.17

7.13.1.2 Grasslands remaining Grasslands (5C.1) – Prescribed Burning of Savannas

The CO_2 emissions and removals associated with the burning and subsequent regrowth of savannas and temperate grasslands are reported under 5.C.1. *Grassland remaining Grassland* and thus are not reported under 5(V) *biomass burning* so as to ensure no double counting. The description of the method used to estimate these emissions and removals is provided in Appendix 7.G.

7.13.1.3 Forest lands Converted to Croplands and Grasslands (5B.2 and 5C.2)

Carbon dioxide emissions from on-site burning associated with land conversion is estimated by the National Carbon Accounting System (Appendix C) and as such these emissions are reported under 5.B.2 and 5.C.2. The mass of carbon burnt annually (FC_{jk}) is taken directly from the National Carbon Accounting System and is used to estimate the non-CO_2 gases associated with burning.

There are no direct measurements of trace gas emissions from the burning of cleared vegetation in Australia, however, it is considered that these fires will have similar characteristics to hot prescribed fires and wildfires (Hurst et al., 1996).

The algorithms for total annual emissions of CH_4, CO and NMVOCs are:

$$E_{ijk} = FC_{jk} * EF_{ijk} * C_i \qquad (5V\_6)$$

and for total annual emissions for NO_x and N_2O are:

$$E_{ijk} = FC_{jk} * NC_{jk} * EFi_{jk} * C_i \qquad (5V\_7)$$

Where: FC_{jk} = annual fuel carbon burnt in land conversion (Gg),

EF_{ijk} = emission coefficient for gas *i* from vegetation (Table 7.12),

NC_{jk} = nitrogen to carbon ratio in biomass (Table 11.)

C_i = factor to convert from elemental mass of gas species *i* to molecular mass (Table 7.13).

7.13.2 Uncertainties and Time Series Consistency

Uncertainties for biomass burning CH_4 and N_2O were estimated to be in the order of -45 to +93% for Forest Lands and ±20% for forest conversion categories. The difference in these certainty values is due to the more accurate fuel load estimates developed through the Tier 3 modelling, further details are provided in Annex 7. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to methodology.

7.13.3 Source Specific QA/QC

Specific QA/QC and verification activities undertaken for the NCAS *FullCAM* model are described in Appendx 7. This source category is also covered by the general QA/QC procedures detailed in Section 1.6.

7.13.4 Recalculations Since the 2006 Inventory

As the emission estimates for wildfire and prescribed burning in *Forest lands* is a 3 year average the most recent year is recalculated as the next years data becomes available. In addition data on the areas of prescribed burning wildfires in the Australian Captial Territory for 2003-2006 are now available and preliminary 2006 estimates of the area of wildfire for Queensland and Victoria have been replaced with actual estimates. The above recalculations result in no change to the *Forest lands* biomass burning estimate for 1990 and a minor reduction to the 2006 estimate.

As the estimates for *Forest lands converted to Croplands* and *Grasslands* have been recalculated so to have the emissions from biomass burning. This recalculation has resulted in a 0.2 Mt decrease to the 1990 estimate and a 0.5 Mt increase to the 2006 estimate.

7.13.5 Source Specific Planned Improvements

All data and methodologies are kept under review and development.

Appendix 7.A: Overview of the Development and Implementation of Australia's National Carbon Accounting System

7.A1 Introduction

The National Carbon Accounting System (NCAS) was developed to provide a comprehensive system to report on Australia's land-based greenhouse gas emissions and removals to support both Australia's international reporting obligations and national policy development. The NCAS integrates a wide range of spatially referenced data through a hybrid of process and empirical models that estimate carbon stock change and greenhouse gas emissions at fine spatial and temporal scales. Analysis and reporting includes all carbon pools (biomass, dead organic matter and soil) and all principal greenhouse gases (CO_2, CH_4 and N_2O), and can be applied at a variety of scales, from the project level through to regional and continental levels, covering both forest and agricultural land uses.

NCAS was specifically designed to be relevant to both annual national reporting and supporting location specific management actions. The resulting need to operate at fine temporal and spatial scales, for management relevance, led to a bottom-up approach of aggregating 25 m grid resolution data and modelling into a national account. Even though the land cover change data (the principal driver) and modelling are performed at a 25 m resolution, not all data are available or needed at this fine scale for the bottom-up approach to be effective. A top-down approach to form the national account with a relatively large sample over the entire continent could not provide sufficient samples or resolution to support site specific management decisions or allow project-level estimates.

The terrestrial ecosystem model implemented by the NCAS is the Full Carbon Accounting Model (*FullCAM*) (Richards 2001; Richards and Evans 2004). *FullCAM* is a carbon:nitrogen (C:N) ratio ecosystem model that calculates greenhouse gas emissions and removals in both forest and agricultural lands using a mass balance approach to carbon and nitrogen cycling. As most emissions and removals of greenhouse gases occur on transition between forests and agricultural land-uses, the integration of agricultural and forestry modelling was essential. Model calibration and ongoing refinement programs are undertaken in parallel to the NCAS science and data collection programs and reporting activity. The continental spatial and temporal modelling capabilities of *FullCAM* help prevent errors of omission and commission.

FullCAM also forms the basis of the publicly available National Carbon Accounting Toolbox (NCAT) which allows users to develop project level carbon accounts using the same data as used for deriving national accounts, achieving consistency between national and project level accounting activity.

Although specifically developed to estimate greenhouse gas emissions, the *FullCAM* model and NCAS data have the potential to serve as a valuable framework for a range of land resource inventory and monitoring tasks. The national scale, fine spatial and temporal resolution, and breadth of data (climate, soils, productivity, land cover and management information) provide a comprehensive data and modelling capability not previously available in a single system. The process understanding generated through models allows for the development of management practices and land use policies with reliably estimated outcomes. Having such a capacity is fundamental to a cost:benefit analysis of mitigation actions and for optimising outcomes for multiple goals (e.g., maintaining production while reducing emissions). This Appendix reviews the ongoing development of *FullCAM* and NCAS, and presents some of the verification and validation results to date.

Method selection

Several possible methods were available for the development of the NCAS. These included direct measurement via a range of remote sensing techniques (e.g., optical, radar and lidar sensors), field sampling (e.g., stratified random or plot sampling inventory approaches), process modelling, or an integration of methods (e.g., combination of models, inventory data and remote sensing). The chosen method was an integrated approach combining remote sensing data with empirical and process models. Landsat images are used to determine changes in land cover. An integrated suite of verified empirical and process models are then used to model the cycling of carbon and nitrogen in plant biomass, dead organic matter, soils and offsite products and to estimate the associated emission and removal of greenhouse gases.

A primary concern was the effect of changes in land cover and land use on greenhouse gas emissions. Therefore the modelling framework was designed to accommodate both forest and agricultural land uses, and any transitions between them. The model framework was fully integrated so that mass balance checks could be performed to ensure that all inputs, transfers and emissions were properly reconciled at each time step in the calculation.

A purely measurement approach to developing the NCAS may have provided a robust national account, but at potentially greater cost than the model approach chosen. Given the lack of forest inventory data in Australia, in particular in the forests which are subject to the majority of deforestation, a measurement approach would also have limited Australia's capacity to develop a consistent time series of data on emissions and removals. A measurement approach would not have supported analysis of either project level estimates or management decision making.

7.A2 Land Cover Change

The importance of land cover change to the pattern of greenhouse gas emissions and removals led to the need to develop a national time series of land cover change showing both where and when change occurs. National coverages of Landsat satellite data (MSS, TM, and ETM+) across sixteen time epochs from 1972 to 2007, have been assembled and analysed for change. The historic cover and cover change information is important in two ways. Firstly, the effects on greenhouse gas emissions from land cover change are typically long lasting, and historic activities may still contribute to current estimates. Secondly, the emissions and removals by current activities will be affected by the site history. For example, a current deforestation event will likely generate fewer emissions if the forest cleared is secondary forest (regrowth after a previous deforestation) rather than a primary (mature) forest.

7.A2.1 Data Selection

Areas of land cover change[2] that contribute to emissions in 1990 include those areas with lagged emissions from activities undertaken since the early 1970s. The ability to map land cover change over an extended period is therefore required for the emissions inventory. With Australia's land area of some 769 million hectares, establishing this record of activity presented many challenges, particularly as areas of change of less than one hectare need to be considered. In response to these requirements, a remote sensing approach using archival coverage of Landsat satellite data of Australia since the early 1970s was used.

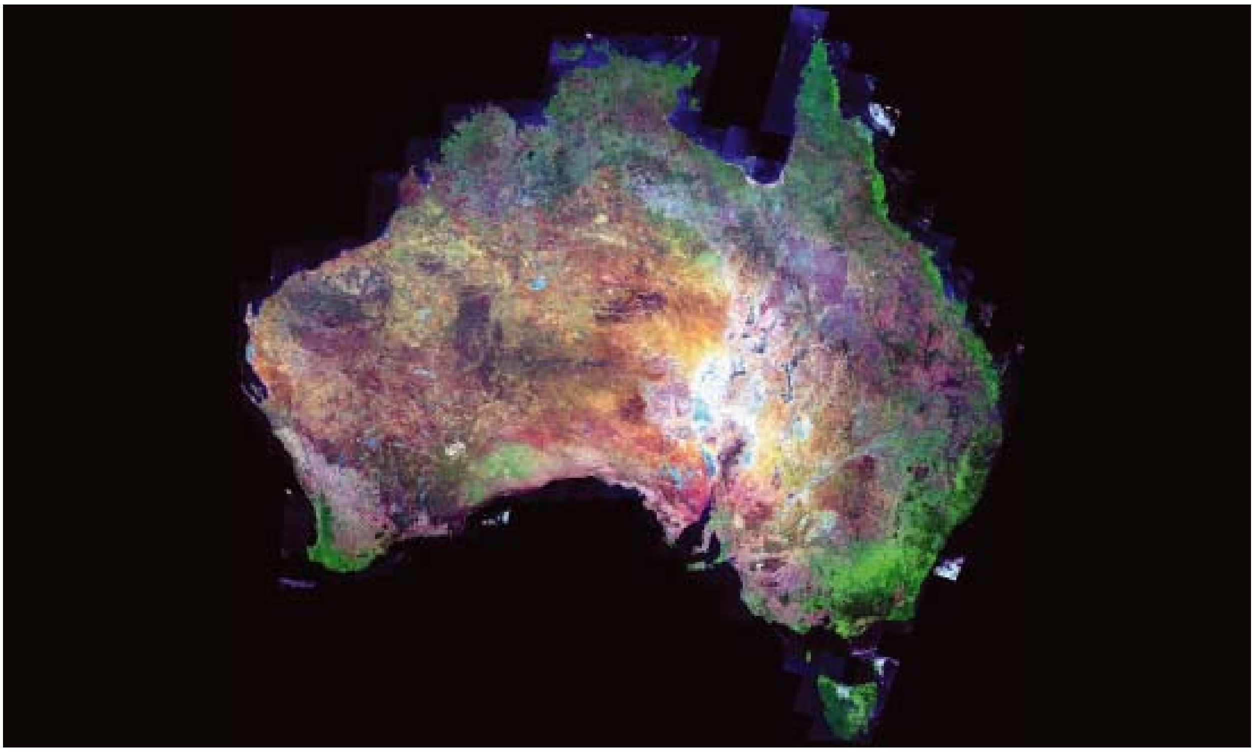
The remote sensing options available for the land cover change program were limited by the retrospective time-series requirement to the use of either air photographs, National Oceanic & Atmospheric Administration (NOAA)/Advanced Very High Resolution Radiometer (AVHRR) data, or Landsat data. No other options met the temporal and spatial requirements outlined above.

- Air photographs: The air photograph archive is not uniformly adequate and available across the nation. Also, the use of air photographs presented an excessively intensive analytic task due to the largely manual interpretation required. However, the archive of available air photographs provides a high-resolution calibration and verification tool to support other techniques when used as an independent sub-sample or as instrument 'training' data for satellite-based methods.

[2] Land Cover Change refers to a change in forested to non-forested (or vice-versa) vegetation cover.

- NOAA/AVHRR: Data is generated at a nominal 1.1 km (approximately 120 ha) resolution. With accounting for Deforestation for the purposes of the Kyoto Protocol requiring monitoring at a sub-hectare scale, remote sensing at such a coarse resolution was not adequate.
- Landsat (MSS, TM and ETM+): Data, with comprehensive national coverage of areas with woody vegetation, are available through archives held in the USA and Australia since 1972. The Landsat MSS data (since 1972) can be effectively resampled to a 50 m pixel resolution (4 pixels per ha) and TM (since 1988) and ETM+ (1999-2002) can be resampled to 25 m pixel resolution (16 pixels per ha).
- The use of Landsat data to analyse land cover change through time at a fine pixel resolution required a consistent geographically registered[3] and spectrally calibrated[4] reference base (Figure 7.A1). Also, standard specifications for processing and interpretation (including attribution[5]) of the sequence of Landsat data are needed to achieve a consistent national assessment of land cover change over the time-series.
- It was important to move from the 50 m resolution MSS data to the 25 m resolution TM and ETM+ data without assessment of false land cover change being introduced due to instrumentation differences. To do this, a MSS equivalent 1989 image coverage was created from the TM images at 50 m resolution using a subset of the TM spectral bands corresponding to the MSS bands. Land cover change assessments bridging the switch from MSS to TM/ETM+ was then based upon MSS to MSS and TM/ETM+ to TM/ETM+, across similar image spectra and pixel size. The use of this overlap technique is consistent with the good practice methods recommended by the IPCC for ensuring time-series consistency where the instruments used to collect activity data change or degrade through time (IPCC 2003 page 5.58).

Figure 7.A1: The year 2000 mosaic registration and calibration base



[3] Registration uses stationary and identifiable ground features (ground control points) as constant reference points for the image sequence.

[4] Calibration uses a reference image to adjust spectral characteristics to remove inconsistencies such as illumination caused by sun angle at time of image capture etc.

[5] Attribution uses a combination of automation and visual inspection of the image sequence to determine the cause of land cover change and determine subsequent/existing land use.

7.A2.2 Data processing

In producing the assessment of an Australia-wide land cover change over the time series (shown schematically in Figure 7.A2) the sequence of processing stages carried out is:

- image identification;
- image registration and calibration;
- mosaicing[6] of registered and calibrated images to the single map tiles for each time sequence (Figure 7.A3);
- sun-angle (terrain illumination) correction;
- thresholding[7] through all time sequences; and,
- attribution of change to direct human-induced change.

Figure 7.A2: Land Cover Change Program conceptual framework

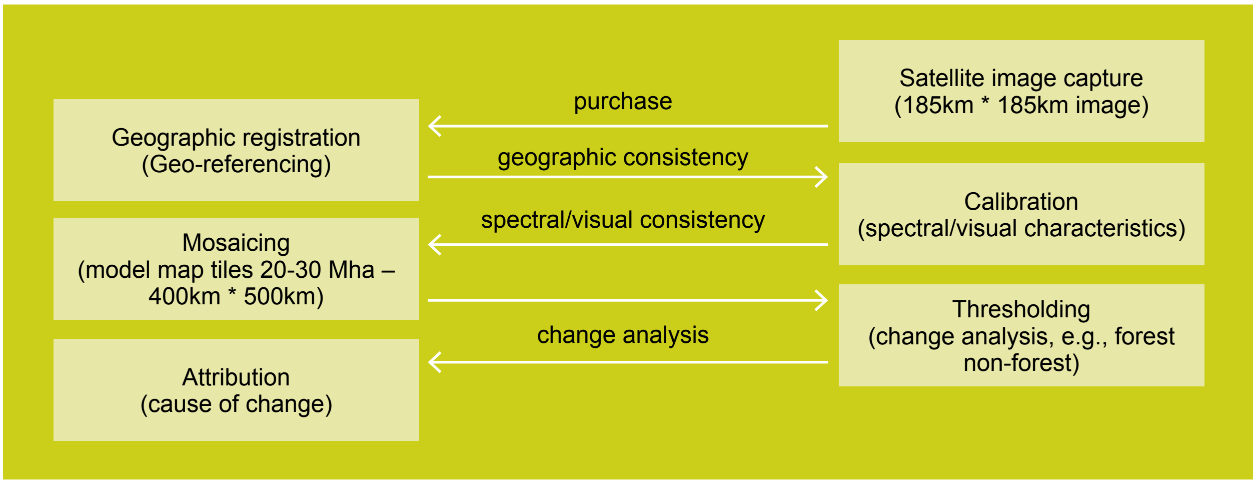
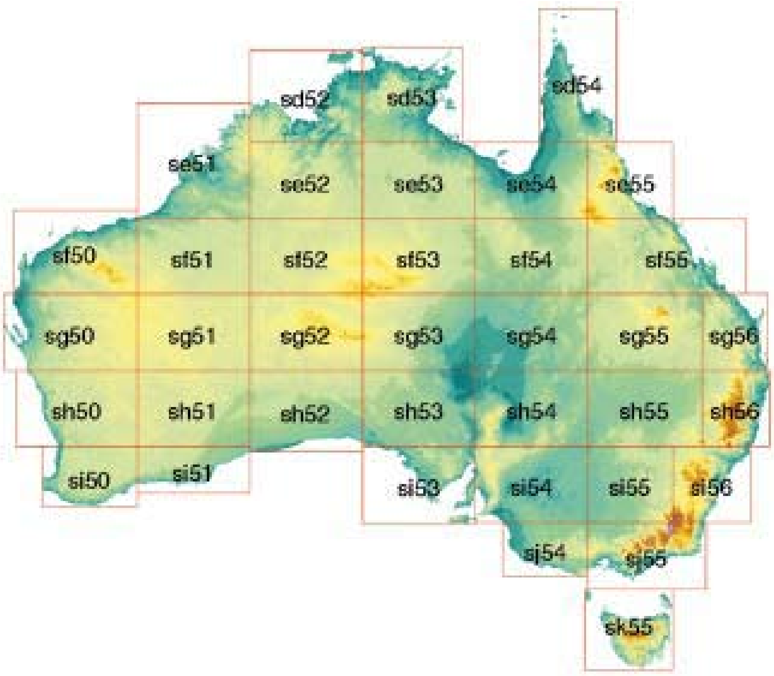


Figure 7.A3: The 37 1:1 million scale map tiles used in the program



6 Mosaicing aggregates images into the map tiles shown in Figure 7.A3, removing overlaps in the original 185 km*185 km images.

7 Thresholding compares each image pixel to a reference set of spectral characteristics formed by specific band mixes (indices) that represent forest and non-forest conditions.

7.A2.3 Program implementation

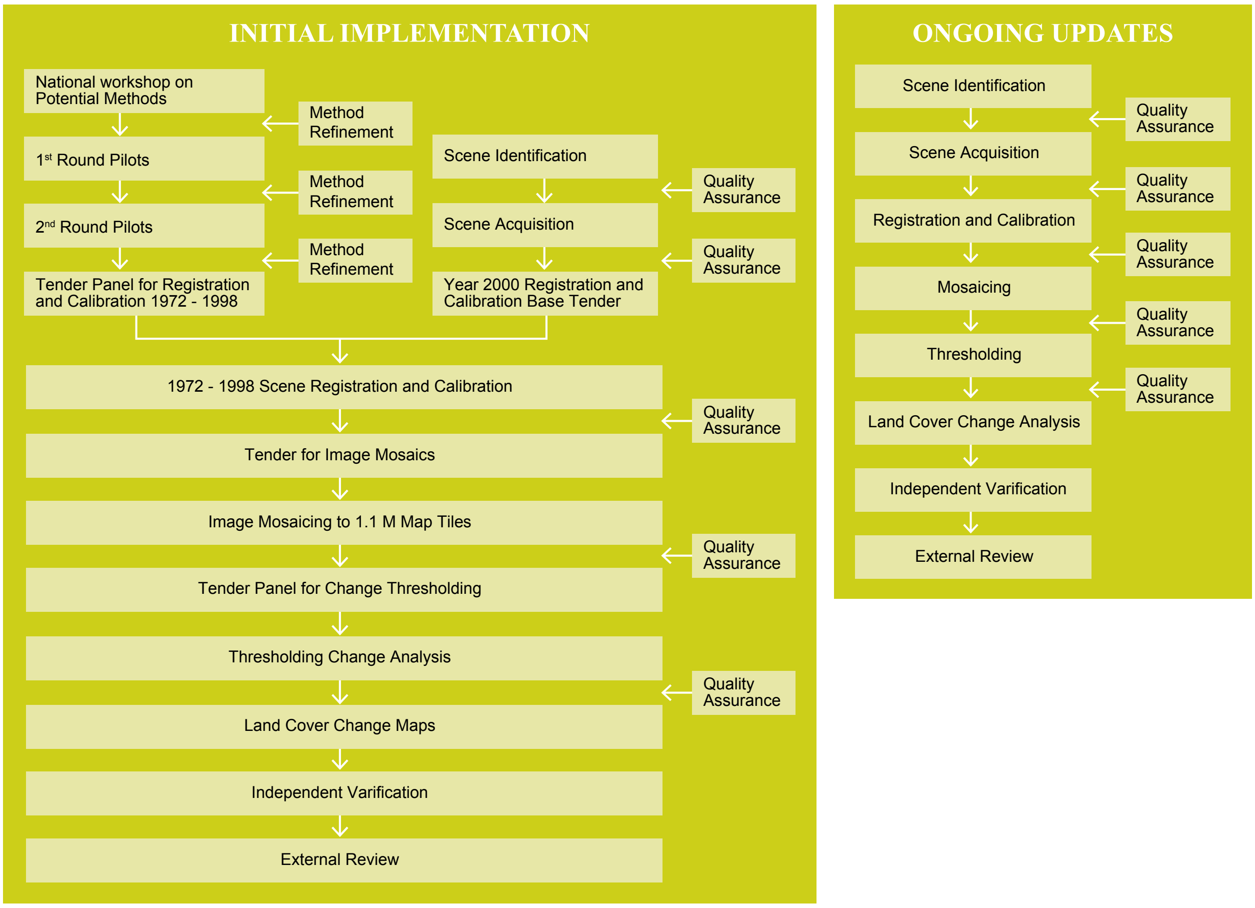
Pilot tests were used to train and develop industry capacity, refine methods and software and to develop logistical systems to maximise both output and opportunity for progressive quality assurance and quality control (QA/QC). The results of the pilot studies are published in Furby and Woodgate (2002).

The approach to program administration provides for centralised progress monitoring and QA/QC at each stage in the processing of the Landsat data. Figure 7.A4 outlines the program stages and their sequence. Each processing stage is a regionally defined package of work based on 37 1:1,000,000 (1:1 M) map tiles of Australia (Figure 7.A3). The finalised program approach maximised quality assurance opportunities, expanded the use of competitive service acquisition and enhanced information flow. Separating the processing into the stages identified in Figure 7.A4 allows for the central and progressive implementation of a QA/QC program.

A set of 16 national coverages of Landsat data have been compiled at intervals between 1972 and 2007. The sequence of images shown in Table 7.A1 was designed to give maximum temporal resolution immediately before and after 1990, so as to achieve the best possible accuracy of emissions in 1990.

Though minimal in quantum, lagged emissions from land cover change events undertaken in the 1970s can persist through to the current inventory. These long-lagged emissions are largely insensitive to timing of land cover change events in early years (e.g., emissions in 1990 are generally insensitive to whether clearing occurred in 1972 or 1976) and therefore a lower, temporal resolution of early 1970s remote sensing images was considered acceptable for greenhouse accounting purposes. As well as identifying lagged emissions, the historic land cover change record also provides for initialisation of regrowth models, so that estimates of forest age are available for situations involving land cover change through removal of regrowth.

Figure 7.A4: Sequence of implementation of the Land Cover Change Program



APPENDICES

The median of the actual capture dates of the approximately 5,000 185 km *185 km Landsat images processed for this project are summarised in Table 7.A1. The image selection criteria (Furby 2002) require the images to be within three months of the nominated target date. The target dates vary between the north (winter or dry season) and south (summer) of the country and aim to provide the best possible forest discrimination. The precise date allocated to each land cover change (clearing and regrowth) pixel was randomly generated by the *FullCAM* model (see section 7.A3), within the sequence of coverage dates for the relevant map tile. This method provided a random (unbiased over a large sample) distribution of initialisation dates (timing of land cover change event) for the carbon model, within the constraint of the two dates in the overall interval of the image sequence.

Table 7.A1: Image sequence

Year	Resolution	Time Since Previous Image (yrs)
1972	50	-
1977	50	5
1980	50	3
1985	50	5
1988 (early)	50	3
1989 (end)	25/50	2
1991 (early)	25	1
1992	25	2
1995	25	3
1998	25	3
2000	25	2
2002	25	2
2004	25	2
2005	25	1
2006	25	1
2007	25	1

Technical Specifications

The technical specifications for the land cover change program (Furby 2002) evolved through two rounds of pilot testing undertaken by CSIRO and RMIT (Furby and Woodgate 2002) and reflect the key technical decisions on method selection and implementation. These included:

- using a Landsat ETM+ national mosaic (year 2000) as the base for registration and calibration;
- using an orbital (earth surface) correction model as implemented through the PCI (PCI Geomatics 2000) software package;
- using a BRDF (Bi-Directional Reflectance Distribution Function) atmospheric correction model;
- applying a sun angle correction (Wu et al., 2004);
- using an 'automated' change thresholding, using derived indices within zones based on specific vegetation and soil characteristics;
- digitising areas of fire scars, later using these as fire masks to differentiate change due to fire from change associated with mechanical land clearing;
- applying a 'Conditional Probability Network' (CPN[8]) so that the probability of forested condition for each pixel at each time in the image sequence is placed in the context of the preceding and subsequent images; and

[8] Conditional Probability Network (CPN) is a rule set which enables the status of a pixel of uncertain land cover status at a point in time to be resolved by reference to the previous and subsequent land cover status.

- using the *FullCAM* model to interrogate the full change sequence of each pixel. The analysis of each pixel by *FullCAM* establishes whether a clearing or regrowth event has occurred between each image sequence for that pixel and allocates a time.

Selection of Indices

Thresholding is the process through which pixels in the land cover image sequence are identified as either forest or non-forest. Pixel identification involves comparing the spectral indices of each pixel in the land cover image sequence with reference indices that identify areas of forest in select strata. Reference indices are established through the use of air photographs, site data and very high resolution satellite data. Air photographs with known forested areas are interpreted and compared with the Landsat data of the same area and around the same time. The Landsat data spectral bands of the forested area are then identified as reference indices for a given forest and soil type. The air photograph interpretation was undertaken centrally by appropriately qualified and experienced air photograph interpreters. The interpreters provided brief descriptions of forest or non-forest areas at a set of known locations. These descriptions were then used in the selection of reference indices from the Landsat data.

The final reference indices allow for variability in both forest and soil type by selecting indices within homogeneous strata. The stratification to deal with this variability was achieved largely through the vegetation and soils mapping. The final reference indices used to identify areas of forest/non-forest are consistent with the definition of a forest, i.e., a minimum of 20 per cent canopy cover and a minimum potential height of 2m.

Conditional Probability Network

The multiple sequences of geographically referenced images are essential for the robust analysis of land cover change. The Conditional Probability Network (CPN) strengthened confidence in the 'forest' or 'non-forest' classification of a pixel by considering the previous and subsequent images in a sequence to resolve any uncertainty in the classification (forest/non-forest) of a particular image. This comparative analysis of the same land unit over time was made possible by the accurate and consistent geographic registration and spectral calibration of the image sequences, providing the ability to 'drill' through time on a pixel-by-pixel basis.

Geographic registration ensures that the same pixel is being looked at through the time sequence. It avoids incorrect change status determination due to substitution of neighbouring pixels having potentially different forest cover status, relative to the correct pixel for that location. Spectral inconsistency can also potentially increase the area attributed to clearing and regrowth events by variable status determination due to image calibration difference. This is addressed by consistent (spectral) calibration, thereby preventing the identification of false clearing or regrowth events and results in a more accurate land cover change map. Consistent registration and calibration are both required to ensure robust multi-temporal change analyses.

The CPN empirically assesses the logic of a forest cover status determination of a pixel at a point in time compared to the previous and subsequent images. The 25 m carbon modelling and accounting is achieved by resampling the early series Landsat remote sensing 50 m MSS data to four 25 m pixels.

There is also potential for sub-pixel shifts to change the forest/non-forest status on the edges of forest systems where a small edge portion of the pixel may have previously been just over the forest area, but a small shift in geographical registration (say 10 m) would be enough to move the pixel out of the forest area. The nearest-neighbour approach to the CPN has been developed and applied to reduce this effect. The nearest neighbour CPN (Caccetta et al., 2003) evaluates the status of adjoining pixels as well as the pixel of interest. This has the effect of reducing flicker in scattered and edge forest pixels.

Forest extent and change analysis

Once the change in forest cover status has been determined for each pixel for a point in time, the spatial relationship of each change pixel to other surrounding or nearby change pixels is assessed to identify isolated pixels with forest cover that do not form part of a forest system. This allows for the identification of pixels that are isolated trees not meeting the minimum canopy criterion defining a forest, as opposed to those pixels that may be part of sparse linear features such as roadsides and riparian zones which do meet the canopy criterion.

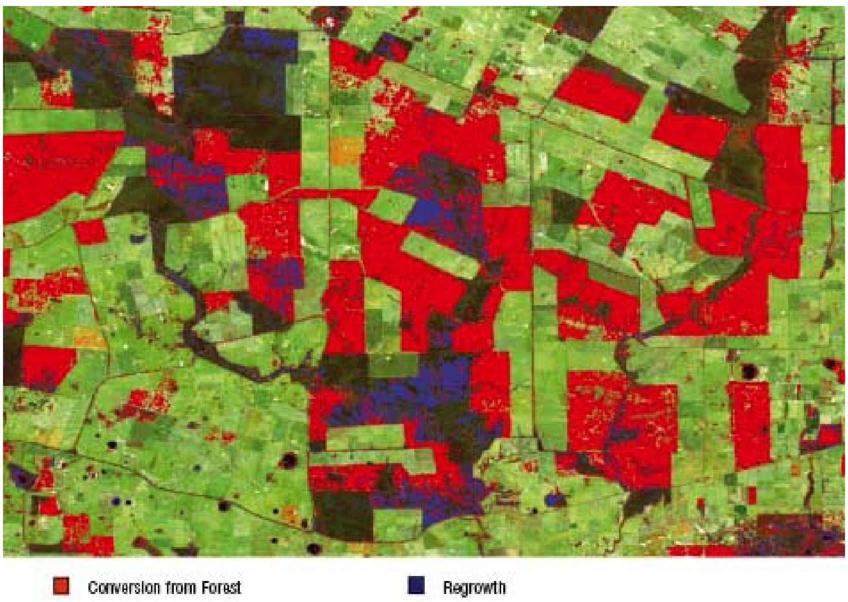
The area of land cover change is determined as the sum of the changed pixels through time. This approach avoids inclusion of pixels that represent gaps in the forest canopy. An independent study which looked at the implication of the inclusion or exclusion of forest canopy gaps in this way found that the resultant area estimate could vary significantly between approaches (ERIC 2001). The approach used in the NCAS considers only the area of forest canopy loss and not 'gaps' in the forest canopy. This approach provides a much lower estimate than specified in clearing permits, which usually define the area bounded by the clearing, including gaps in forest canopy cover. Subsequent carbon stock and emissions estimates are computed consistently with the spatial area calculation method. That is, the carbon stock values should reflect the area under canopy, and are not an average that includes 'gaps' between areas of tree canopy.

Further robustness is introduced by the use of a three class determination of forest cover: non-forest, forest and uncertain forest. Pixels identified as uncertain forest have a lower probability of being forest, and unless confirmed as forest after the CPN application, are determined as non-forest. The same applies to non-forest determination. This will typically yield lower (more certain and conservative) cover change statistics than more common analytic methods using only a two class (forest, non-forest) analytic procedure, particularly in the last step of the time-series. Therefore the last step uncertainties may be confirmed in a time-series update and CPN re-run. The three class approach is most relevant to a multiple (as opposed to single pair) change analysis. It is this approach that leads to small adjustments to the areas cleared over the last 2-3 years of the time series as the CPN becomes more accurate as new images become available.

Use of 3 pixel clusters for forest extent

The approach used provides for an analytic unit (pixel) that is approximately 0.06 ha, but a requirement to be spatially related to other change pixels infers that a minimum area of approximately 0.2 ha of forest area (including gaps between trees) is required for inclusion. To be classed as a forest for the purpose of the land cover change analysis a minimum of three forest pixels must be connected either at their edges or at their corners. Should one or two pixels be removed from a three pixel cluster by a deforestation event, emissions are only estimated for the one or two deforested pixels.

Figure 7.A5: An example land cover change image



7.A2.4 Attribution of Change

The high resolution spatial assessment (by pixel) across the continent identifies land cover change resulting from many causes. For unique identification of conversion to another land use it is necessary to attribute the change event to a cause and subsequent land use. Examples of forest cover loss events that do not meet the definition of forest conversion to another land use include forest harvesting, dieback of forest during drought periods, and bushfires.

Loss of forest cover due to factors other than a change in land use are initially identified through the application of both the fire masks developed during the image processing, and the tenure masks to define areas of public forest management. Subsequently, land cover change due to salinisation, tree dieback, natural dynamics of tree mortality and recruitment, drought and both seasonal and interannual variability (causing green 'flushes' of growth with similar spectral signals to regrowth) are also identified and excluded. These are separated from those changes that can be attributed to a forest conversion.

This attribution is achieved by the development of a second series of 'masks' that are derived via visual interpretation of the sequences of images against change mapping. Masks derived include:

- forest harvest on private land;
- intermittent water features and irrigation areas that may give a false change signal;
- salinisation;
- drought and growth flushes; and
- terrain illumination.

7.A2.5 Plantation typing

To allow for more accurate modelling of emissions and removals from newly established forests (under *Grassland converted to Forest land*), new plantings (reforestation) identified in the remote sensing are mapped into three classes; native forest (environmental type plantings), hardwood plantation and softwood plantation. Plantation forests are those that are identified as being due to deliberate human action and are identified by type (e.g., introduction of non-endemic species), evidence of establishment practices (e.g., rip lines) and planting patterns (e.g., rows, stand geometry). The identification of conversion between forest and non-forest condition follows the same general approach described above. Plantation classes are identified by discrimination against regionally specific collection of ground training data. The method uses an automated spectral discrimination and is described in Caccetta and Chia (2004). Currently, only Landsat TM or ETM+ data is used for plantation classification.

7.A2.6 Quality Assurance and Quality Control

Rigorous and consistent quality standards are crucial to the application of the objective techniques applied in the program. The objective approaches minimise direct (and potentially subjective) operator interpretation and intervention in the processing stream and are generally more repeatable than approaches reliant on operator interpretation. The QA/QC procedures for application of the NCAS land cover change methods are described in full in Furby (2002).

The QA/QC stages applied at each update are:

- independent date and scene quality checking of selected Landsat image scenes;
- image quality checks on the raw data by the Australian Centre for Remote Sensing (ACRES) (the data distributor) under their internal quality assurance program. Additional checking of images (visually) is conducted by contractors prior to scene registration and calibration;
- checking the registered and calibrated images and mosaicing products against published QA/QC standards (Furby 2002);
- checking that the indices selected during thresholding represent ground conditions for vegetation types of interest in homogenous zones (strata) and that these reflecting similar vegetation and soil types;

- checking of change maps against raw imagery and air photographs to remove errors of omission or commission in assessing change in forest cover; and
- visual quality assurance of masks derived to identify direct human-induced change.

Once the processing stages are completed, and the abovementioned QA/QC programs satisfied, a further visual check is carried out by creating ‘animations’ of land cover change over time. This allows for review of both the spatial and temporal patterns of change. The methods chosen and implementation of the program have also been submitted to external (international) review (Lowell et al., 2003). The review by Lowell et al., (2003) provided re-assurance in the robustness of the technical methods, processing and quality assurance programs.

7.A2.7 Continuous Improvement and Verification

The validation of the remotely sensed land cover mapping is contained within an overall continuous improvement and validation program. An independent program of checking the Landsat results is conducted by external parties, both to confirm the veracity of the method (and hence the accuracy of the product) and to identify areas for improvement. This program involves checking the results of the land cover mapping against high resolution satellite and air photograph interpretation using a stratified sampling technique. The initial validation considered the initial time-series of change data from 1972-2000 and was done using air photograph comparisons. When the recommended improvements were implemented, with the update for the 2002 data, the full time-series was reanalysed to reflect the improvements (Lowell et al., 2003; Jones et al., 2004; Lowell et al., 2005). Subsequent analysis has led to further improvements being implemented during the 2004 and 2005 updates. Since 2005 the validation of the change analyses has been done using very high resolution satellite data which has significantly improved the quality of the validation.

The initial independent assessment of the “raw” accuracy of the classification of woody and non-woody points across the continent and over period 1972 – 2000 indicated that 94-98% of forest and 85-96% of non-forest woody vegetation was correctly classified (Jones et al., 2004). Accuracy in the data used for estimated rates of change (afforestation / regrowth or deforestation) however, was higher than the above as a process of manual ‘attribution’ was used to confirm or reject changes in cover in the final dataset. Forms of error removed were those associated with green flushing in imagery, degradation, terrain illumination, irrigation, water bodies and fire scars.

Incremental method development beyond that described in Caccetta et al., (2003), and applied throughout the current time-series, includes the implementation of terrain illumination correction (Wu et al., 2004), and the use of ‘texture’ based analysis to map sparse vegetation extent and change (Caccetta and Furby 2004). Mapping of tree crown cover density and the development and calibration of methods to map plantation types across Australia is ongoing, with both method refinement and field data being collected across Australia (MBAC Consulting *in prep*.).

Plantations

Validation of plantation type mapping accuracy was carried out against specifically collected field data showing plantation species, stocking, condition, age and extent. This validation data was collected during a national program of site visits. The recently completed plantation mapping achieved an accuracy of 91% in terms of both species and spatial referencing for plantations identified as post 1990 plantations (MBAC Consulting, *in prep*.). Incorrect forest typing (e.g., labelling hardwood as softwood and vice versa) contributed 5% of the error, with only 4% being incorrect by both location and type. These results provide considerable confidence in the methodology applied and allow, for the first time, a spatio-temporal analysis of Australia’s plantation estate.

Methods to separate conifer plantations from native forest using the Landsat MSS data from 1972-88 (Landsat MSS data) are being developed and will be used in future inventories.

Harvested Native Forests

Identification of areas of native forest harvest and subsequent regrowth using the general mapping of forest and non-forest condition over time is currently being investigated. Areas of native forest which have been harvested can be identified by considering the temporal pattern of change, the spatial pattern of change, vegetation type, land tenure and context. The development of this mapping is ongoing.

7.A3 FullCAM model framework

7.A3.1 Overview of model framework

A considerable challenge was presented by the requirement for the NCAS to provide an integrated, transparent and verifiable framework for data management and modelling. A fundamental requirement was that the framework needed to be capable of implementing an integrated suite of models within a geographic information system (GIS). As there was no integrated framework capable of carrying out this task, and producing the results in a manner required for national inventory reporting, a purpose-built model framework was developed for the NCAS.

The model framework and its development are described in Richards (2001) and Richards and Evans (2004). In addition to the major development of providing the complex modelling in a spatial (GIS) framework, the model also provided for mixes and transitions between forest and agricultural systems and to change plant species and management over both space and time. *FullCAM* (Full Carbon Accounting Model) has been developed as an integrated compendium model that provides the linkage between various sub-models. *FullCAM* has components that deal with both the biological and management processes which affect carbon pools and the transfers between pools in forest, agricultural, transitional (afforestation, reforestation and deforestation) and mixed (e.g., agroforestry) systems. The exchanges of carbon, loss and uptake, between the terrestrial biological system and the atmosphere are accounted for in the full/closed cycle model which includes all biomass, litter and soil pools (Figure 7.A6). The five sub-models integrated to form *FullCAM* are:

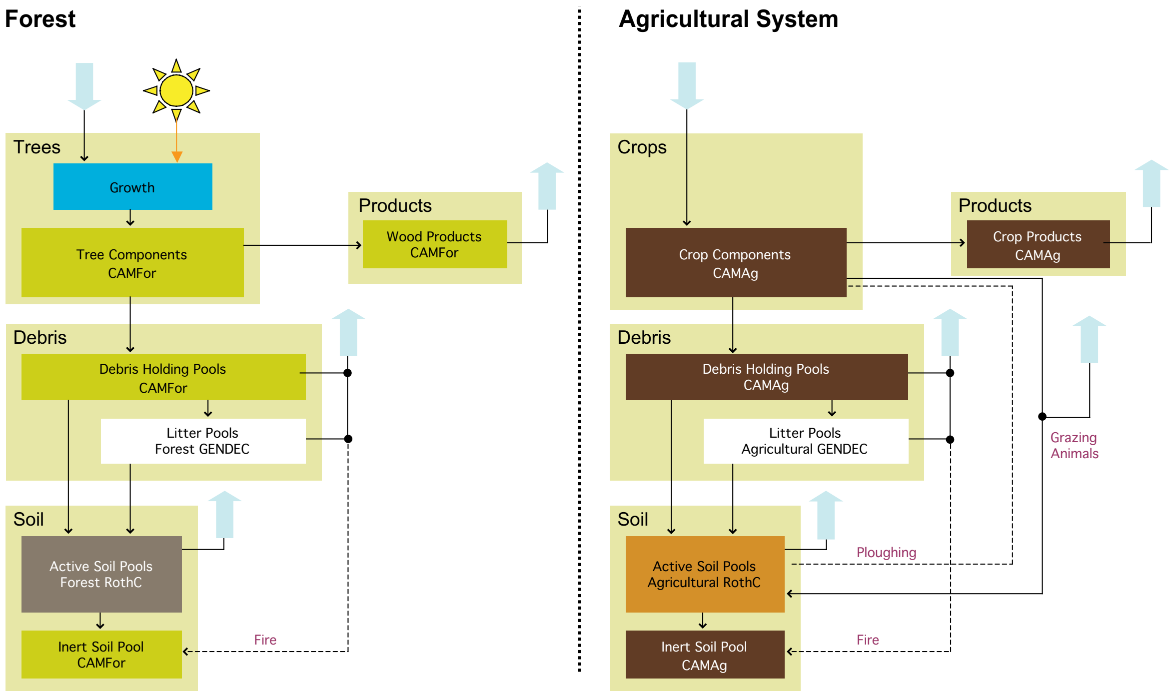
- a variant of the physiological growth model for forests, *3–PG* (Landsberg and Waring 1997, Coops et al., 1998, Coops et al., 2001);
- the carbon accounting model for forests, *CAMFor* (Richards and Evans 2000a);
- the carbon accounting model for cropping and grazing systems, *CAMAg* (Richards and Evans 2000b);
- the microbial decomposition model *GENDEC* (Moorhead and Reynolds 1991; Moorhead et al., 1999); and
- the Rothamsted Soil Carbon Model, *Roth-C* (Jenkinson, et al., 1987, Jenkinson et al., 1991).

These models have been independently developed for the various purposes of predicting:

- soil carbon change associated with agriculture and forest activities (in the case of *Roth-C*);
- rates of decomposition of litter (in the case of *GENDEC*); and
- rates of growth in trees (in the case of *3-PG*).

The integration of the component models into *FullCAM* served two primary goals. The first was to provide a capacity to be able to operate at a level of conservation of carbon (i.e., closed cycle, or mass balance) at a site or other specified area. This includes all pools and transfers (net of atmospheric uptake and emissions) between pools to ensure that there are no significant instances of double counting or omissions in accounting. Potentially, such errors could occur if the dominant carbon pools (soil carbon, biomass and litter) were considered independently. The second goal is to provide a model with the capability to operate continentally as a fine resolution grid-based spatial application. A single efficient model is required to analyse the large input data sets, in a multi-temporal spatial context.

Figure 7.A6: The *FullCAM* model pool structure



7.A3.2 Sub-Model development

As part of the development of the NCAS, an implementation plan was developed by the Australian Government which included extensive consultation with national experts. The details of the implementation plan and results of the International review of the plan are reported in NCAS Technical Report No. 11 (AGO, 2000b). One of the key recommendations of the review was to take a holistic approach, with modelling and measurement continuous across all carbon pools and cognisant of the transfers between pools. Other, more specific recommendations from the Review which had direct implications for the development of the NCAS, and therefore *FullCAM* were:

- the adoption of a generic and widely applicable physiological growth model for forests;
- the adoption of a microbial litter decomposition model, with a suggestion to consider the GENDEC model of Moorhead et al., (1999); and
- support for national calibration of the Roth-C soil carbon model.

In selecting the models for integration, priority was given to the use of existing models that had a proven track record in Australia. In addition to model development, strategies for data accumulation and assimilation to allow spatially and temporally explicit carbon accounting and modelling at both continental and project scale (largely directed at satisfying the requirements of the Kyoto Protocol) were developed. Strategies were also developed to guide the fundamental data collections (field and analytic protocols), research program (targeted research objectives) and model calibration (including sensitivity and uncertainty analysis). As part of this development two new models were developed by the NCAS; *CAMFor* and *CAMAg*. These carbon accounting models make it possible to assess the impacts of management practices, such as fire, decomposition, harvest, cropping, and grazing on externally generated growth and decomposition rate inputs.

3-PG

A modified version of 3PG was implemented into *FullCAM* to estimate the plant productivity in turn used to model forest growth. This version is a simplified, spatial version of 3PG based on the work of Coops and Waring (2001) and described in Kesteven et al., (2004). Further details are provided in 7.A4.

The principal work required to implement this model was to compile the fundamental input data. This entailed:

- the development of slope and aspect corrected solar radiation direct and diffuse surfaces on a 250 m grid;
- the use of a digital elevation model of AUSLIG (2001) – Geodata 9 second DEM (version 2);
- access to CSIRO Division of Land and Water Fertility and Soil Moisture Continental Surfaces (McKenzie et al., 2000a);
- creation of monthly rainfall, temperature and radiation surfaces from ANUCLIM (software package) (McMahon et al., 1995) and data from the Bureau of Meteorology;
- derivation of a Normalised Difference Vegetation Index (NDVI) 10-year average; and
- the development of frost surfaces.

CAMFor

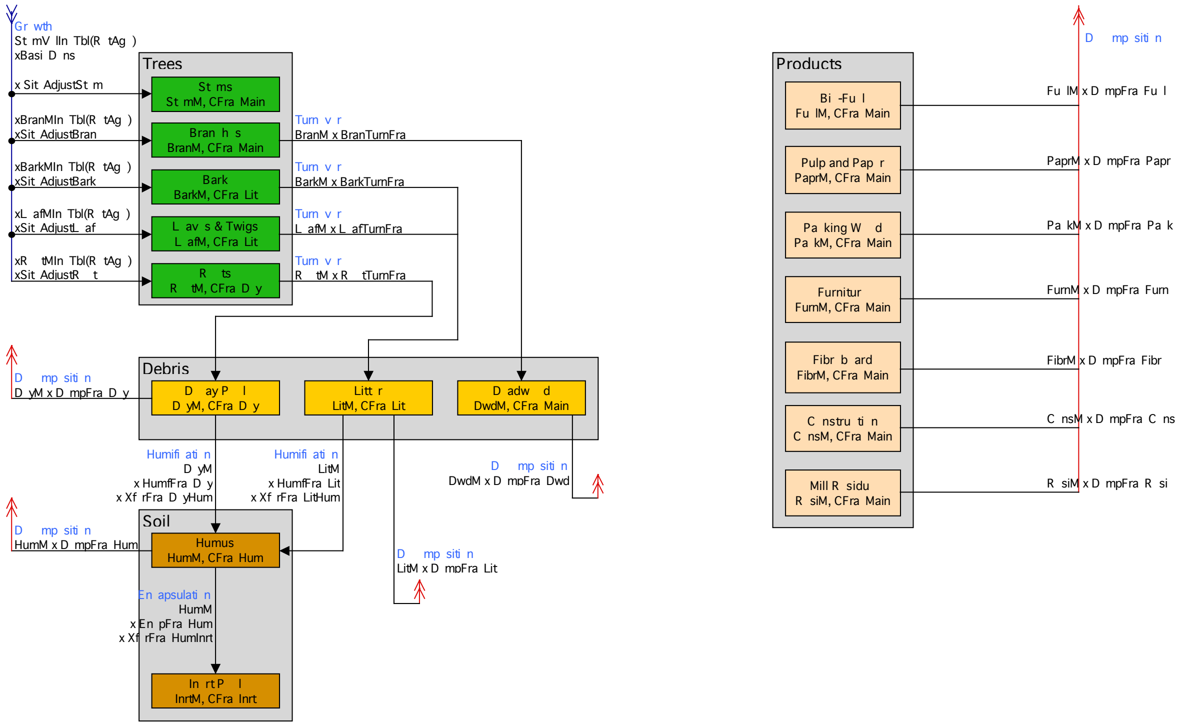
CAMFor (Carbon Accounting Model for Forests) (Richards and Evans, 2000a) was developed within the NCAS to provide capacity for both project and continental scale accounting (Figure 7.A7). *CAMFor* primarily focused on carbon sequestration in forests using basic species information and standard forestry yield tables entered by the user, with limited debris and soil carbon modelling capabilities. *CAMFor* has its origins in the 1990 CO_2 Fix model of Mohren and Goldewijk (1990). The published Fortran code for this model was converted to an Excel spreadsheet (sheet based, formula driven) format as reported in Richards and Evans (2000a). A subsequent series of modifications were made including:

- the introduction of an inert soil carbon pool, recognizing the nature of the carbon in Australian mineral soils, the high charcoal content and the potential long-term protection of fine organic matter through encapsulation and absorption by clays;
- addition of a fire simulation capacity that could deal with stand-replacing and/or regenerating fires, being either forest floor fires largely removing litter, or crown fires affecting the whole tree;
- enhancement of the wood products model to reflect the pool structures and life cycles described in the NCAS Technical Report Number 8 (Jaakko Pöyry Consulting 1999) (biofuel, pulp and paper, packing wood, furniture and poles, fibreboard, construction wood, and mill residue);
- the ability to move carbon in the on-site plant or debris pools to the relevant product pools at any harvest or thinning event;
- inclusion of the transfer of forest products to landfill and in-landfill decay parameters;
- greater resolution to the component distinctions of the standing tree material, splitting coarse and fine roots, branch and leaf material; and
- an added capability to use aboveground mass increment for accounting, as an alternative to stem volume increment.

Within *FullCAM*, the *CAMFor* sub-model can take its growth information from any one of four sources:

- a generalised productivity-driven growth model (see section 7.A4);
- measures of aboveground biomass increment;
- measures of stem biomass increment; or
- measures of stem volume increment.

Figure 7.A7: The CAMFor model pool structure



CAMAg

Within *FullCAM*, *CAMAg* serves the same roles for cropping and grazing systems as *CAMFor* does for forests. The *CAMAg* model reflects the impacts of management on carbon accumulation and allocates masses to various plant product pools and to decomposable and resistant organic residues. Yields need to be prescribed in the model, as either aboveground, total or product mass – as do above- and belowground turnover rates. The key factors that allow *CAMAg* to model emissions and removals due to agricultural practices are:

- growth of crops and grasses by component pools including leaves, GBF (grains, buds and fruit), stalks, fine and coarse roots;
- turnover and decay of plant material; and
- simulation capabilities for grazing, harvesting, ploughing, herbicide application and fire.

CAMAg also includes a products model (biofuel, grains, bud and fruit products, cane products, leaf products, root products, hay, straw and silage products, and animal products) that uses a similar structure to the *CAMFor* forest products model.

GENDEC

GENDEC is a microbial decomposition model developed by Moorhead et al., (1999) which considers the environmental and biological drivers of microbial activity, namely temperature, moisture and substrate quality. *GENDEC* addresses both carbon and nitrogen, relying on nitrogen-to-carbon ratios throughout the decomposition process and using available nitrogen as a factor which may constrain the rate of microbial activity. When *GENDEC* is brought into operation with *FullCAM*, it can replace the empirical decomposition routines which deal with the resistant decomposable fraction of each tree component embedded in both the *CAMFor* and *CAMAg* components of the model.

The impact of invertebrate activities on the breakdown of debris is addressed within *FullCAM*, whereby the microbial decomposition of *GENDEC* is paralleled by a breakdown factor which can account for losses in aboveground litter due to factors such as macro-invertebrate activity. Root material is incorporated directly into the soil carbon pools, and therefore is subject to the decomposition activities of the *Roth-C* component of the *FullCAM* model. *GENDEC* is the subject of ongoing calibration studies and will undergo further testing prior to implementation for the national accounting.

Roth-C

The Rothamsted soil carbon (*Roth-C*) is a soil carbon model developed by Jenkinson et al., (1991). *Roth-C* models changes in soil carbon based on the inputs of organic matter from dead plant material and soil carbon decomposition rates. Plant residues are firstly split into decomposable and resistant plant material. Soil carbon is fractionated into various soil carbon pools, generally defined by classes of resistance to decomposition. Turnover rates for each soil fraction are determined by rainfall, temperature, ground cover and evaporation. *Roth-C* is used in conjunction with both *CAMFor* and *CAMAg* to model soil carbon stocks in the national account. The model and its calibration and validation for Australian conditions are discussed further in section 7.A5.

GORCAM

Further to the product decomposition modelling, *FullCAM* also incorporates *GORCAM* (Schlamadinger et al., 1997) which allows modelling of the displacement of fossil fuel emissions due to use of bioenergy products and displacement due to the use of alternative products. This allows the relative merits of various types of forest and agricultural products to be assessed against other products (e.g., steel or cement) that may be used as a substitute. The inclusion of *GORCAM* allows *FullCAM* to consider a life cycle approach in carbon accounting.

7.A3.3 Sub-model integration

The models were fully integrated into the *FullCAM* model (Richards 2001; Richards and Evans 2004) which was developed in the programming language C++ with a graphical user interface. The individual models can be applied independently or in various combinations within the *FullCAM* framework. The integration of the agricultural and forest models helps ensure conservation of mass during carbon and nitrogen cycling by including all pools and transfers between pools, thus ensuring that there are no instances of double counting or omissions in accounting. The ability to change agricultural and forest species over time was also introduced into *FullCAM*. Further, by embedding both the forest and agricultural models within *FullCAM*, it is possible to represent completely transitional activities – afforestation, reforestation and deforestation (change at one site) – or a mix of agricultural and forest systems (e.g., agroforestry, discrete activities at separate sites) in a single, mass-balance model framework.

In addition to the integration of the sub-models *FullCAM* also provides the capacity for spatial (grid-based GIS) application, driven by data on land use change, climate, management and site conditions. The *FullCAM* model provides the framework for the integration of the model program calibration and verification activities, land use and management systems, remotely sensed land cover change information and collated (tabular) data such as crop yield.

Quality Assurance and Quality Control

The development of the *FullCAM* model included the incorporation of previously calibrated and verified models. In preparing these models for integration into *FullCAM*, each model (except for *CAMAg*) was translated from original source code to a common Microsoft Excel spreadsheet format. The Excel workbooks used only sheet-based formula with no 'Macros' or other code applied. This provided a consistent and transparent model platform from which to review and integrate the various models. Having a consistent structure and format for the models allowed for the independent calibration of various models while providing for ease of later integration. The transparency of the development process also facilitated review at a detailed level.

The integration into a single compendium model was initially undertaken in Excel as a test version. The prototype forest model derived, *GRC3* (Richards and Evans 2000c) (Figure 7.A8), was subsequently tested by CSIRO (Paul et al., 2002a). Several independent studies to test and calibrate the model were completed on various parts, integrations and applications of the models. When there was confidence that the Excel developmental models were giving the same results as the original source code versions, the Excel models were fully documented and returned for verification to the original authors or host organisations. Modifications were only considered subsequent to this initial review. These modifications were made for a variety of reasons including efficiency in code (computational speed and resources) and in recognition of Australia's different biophysical conditions.

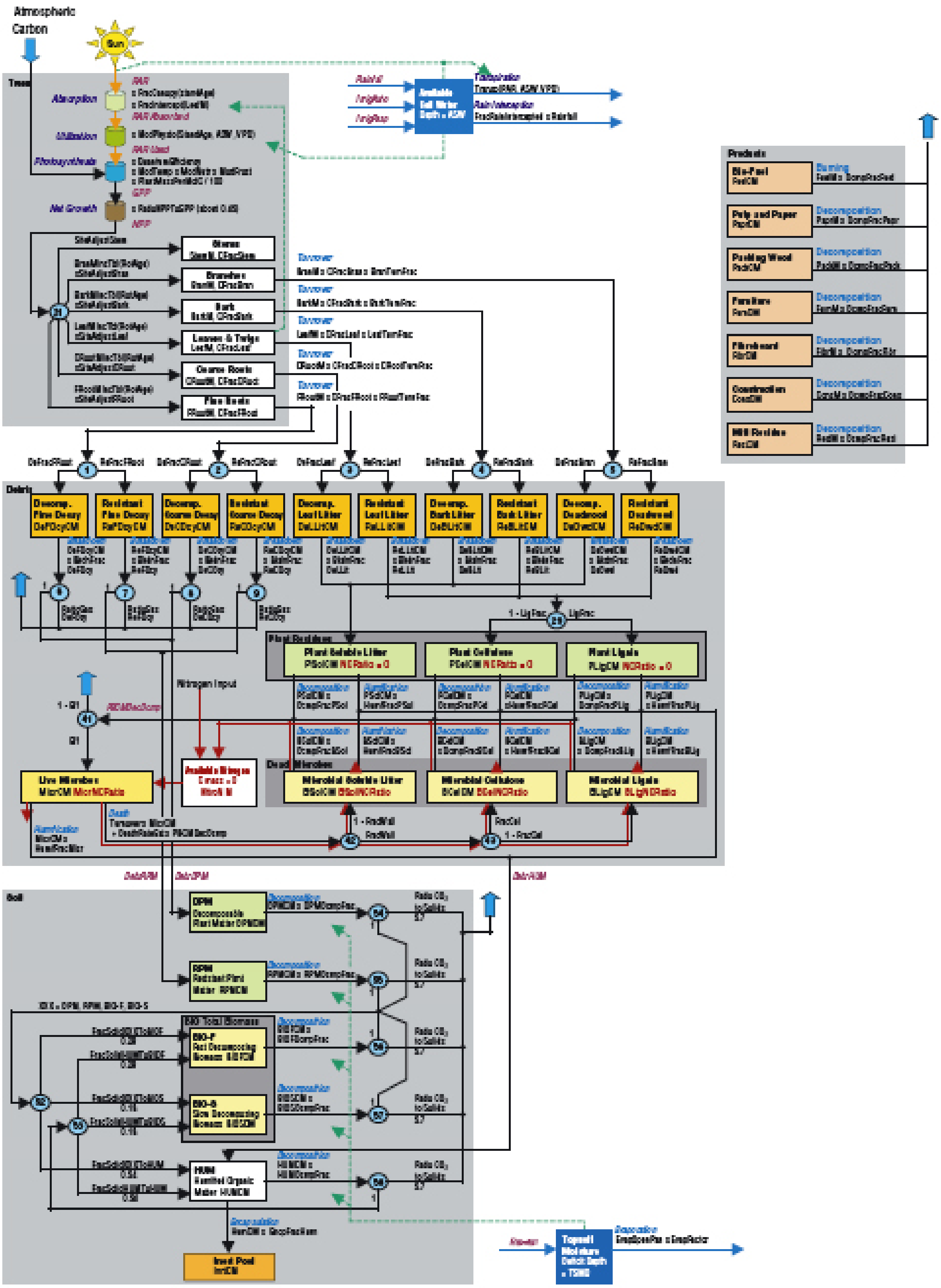
The incorporation into a single framework also allows for detailed testing of the model logic. For example, the total carbon both entering (though uptake), remaining (as stocks) and leaving (as emissions) the modelled system is checked for consistency (mass-balance) for every model simulation and at every time step. These continuous checks provide confidence that no double counting between pools can occur and that no carbon is artificially created or lost. To ensure that the continuing code updates (as part of the ongoing development of *FullCAM*) do not result in adverse affects on the model results, new code is checked using 'regression' testing techniques. These techniques allow any changes that are made to the model code to be rapidly checked against the outputs from a validated set of model results.

Wide-scale application in government programs (e.g., the Commonwealth Governments Greenhouse Gas Abatement Scheme, Greenhouse Friendly, and Bush for Greenhouse Programs) and commercial application along with independent reviews provide confidence in the robustness of the models. *FullCAM* is also publicly available as part of the National Carbon Accounting Toolbox with over 10,000 copies distributed.

Model calibration

The NCAS provided considerable investment into the calibration of each of the models for the range of conditions and management practices present throughout Australia. Over a 2–3 year period the total investment, including the data collection and process understanding for model calibration needed to prepare and complete the model for initial national application, was in the order of $9M AUS. Model calibration included the collation of a series of previous (quality audited) site measurements and the undertaking of additional field work and laboratory analyses. Separate data sets were maintained for model calibration and verification of model results. The subsequent implementation of the calibrated model into a spatial application requires the use of a range of spatially continuous and often multi-temporal input data layers. This includes data such as that on land cover change, climate and soil type described in previous sections. The calibration, validation and application of *FullCAM* is described in detail in later parts of this Appendix.

Figure 7.A8: The forest 'side' of the *FullCAM* model



APPENDICES

7.A3.4 Spatial application of *FullCAM*

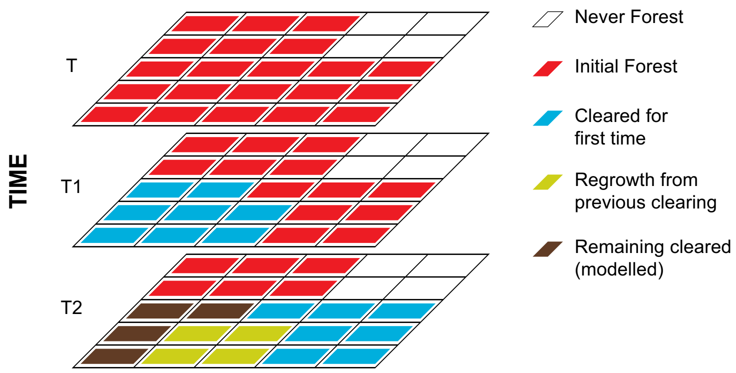
Entry of lands into the model

The fundamental analytic unit of the NCAS model is the land cover change pixel (25 m x 25 m) derived from the satellite remote sensing program. There are approximately 240 million pixels that are each individually modelled in *FullCAM* as part of the *Forest land converted* to *Crop* and *G*rassland categories.

The Approach 3, spatially explicit modelling method applied by the NCAS is shown in Figure 7.A9. Beginning in 1972, land clearing events are detected through the remote sensing program. The first time a land clearing event is detected for a pixel, the modelling of that pixel commences (the pixel becomes 'active'). For each year after 1972 an extra set of active pixels which represent new land clearing events are added to the previously accumulated set of active pixels in the modelling. Therefore, in any given year, there will be three classes of forest pixels represented in the model.

The first class of forest pixel is 'inactive' (red). This means that the forest cover has not been subject to a land clearing event since 1972 and is not in the model. The second class of forest pixel is 'active for the first time'. This means that the forest on that pixel has under-gone a land clearing event in that year (blue). The pixel now enters the model and remains there in future years. The model proceeds to calculate the emissions and removals on that pixel from the moment that the pixel becomes active and the accounting continues year on year into the future (brown and green). The third class of forest pixel is 'active in the model due to an earlier land clearing event'. This class represents the accumulated set of active pixels from previous years back to 1972. These active pixels may remain cleared (brown) or may temporarily regrow some forest cover as part of a cyclic clearing/reclearing management system (green).

Figure 7.A9: Diagrammatic representation of the fully spatially explicit modelling approach used in *FullCAM*



Modelling emissions and removals

Once lands enter the model through a land clearing event *FullCAM:*

a. randomly allocates date of clearing between the two times of the satellite images;

b. obtains site, climate, management and initial assumed biomass data for that pixel from a series of spatial grids and databases (see section 7.A4.2);

c. begins to model changes in living biomass, debris and soil carbon pools associated with the change in forest cover; and

d. sums the estimates for each pixel each year to estimate the emission/removals for the national account.

Where the forest has regrown after clearing (as identified from the remote sensing), *FullCAM* begins to regrow the forest. Where this regrowth is subsequently recleared the biomass at reclearing is based on actual age (through identification of time since regrowth) (see section 7.A4.4).

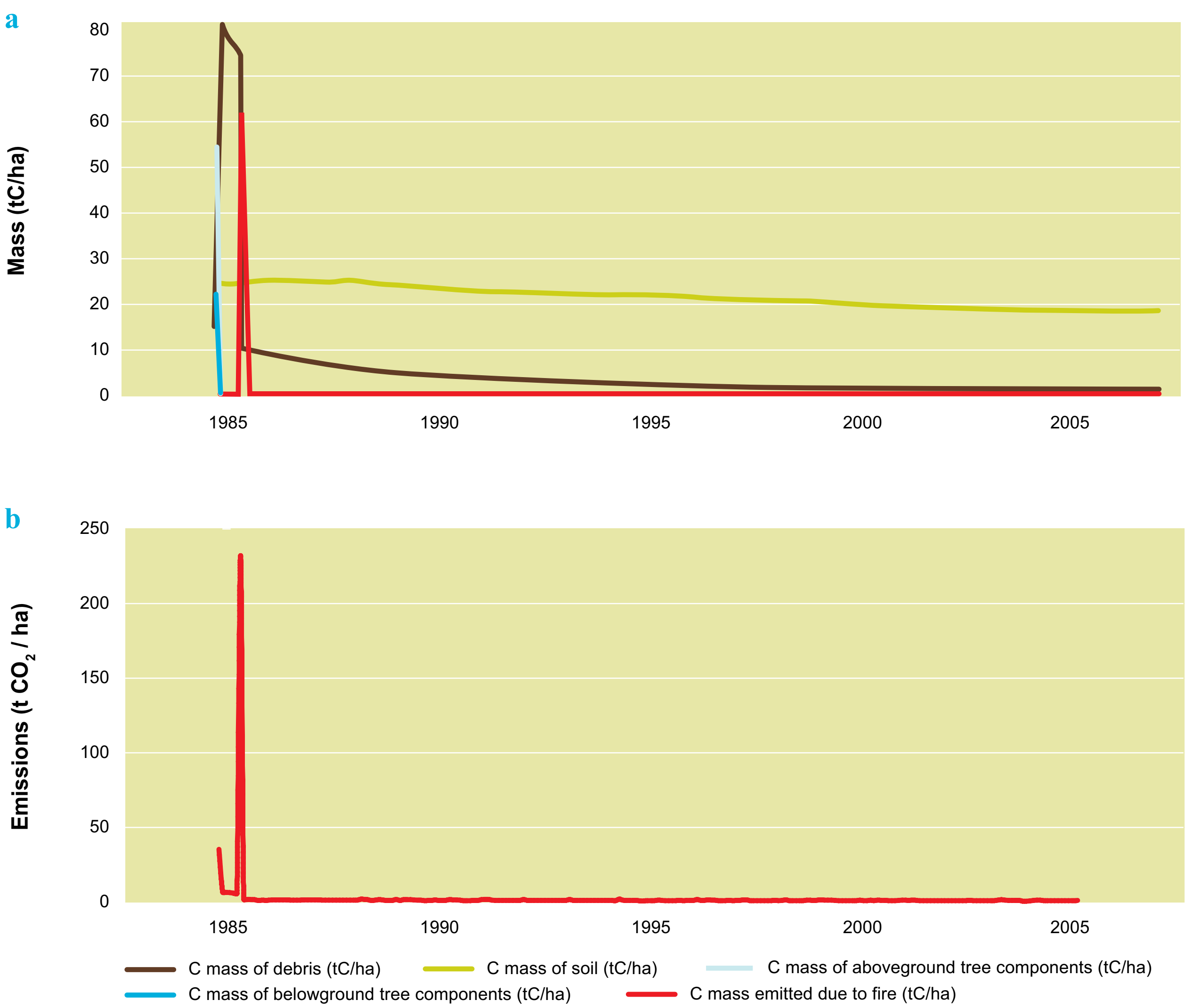
Accounting for lagged emissions

Lagged emissions are emissions in any given year that result from a land clearing event in a previous year. These emissions are associated with biomass, debris and soil.

As the NCAS tracks individual pixels through time, from the time of the initial clearing event, any lagged emissions are reported in the account in the years subsequent to the clearing event when the lagged emissions actually occur. Therefore for any given year, all sinks and sources including any lagged emissions, from all lands that have entered the account since 1972 are reported for every subsequent year to their entry into the account.

The lagged emissions profile in Figure 7.A10 shows that the greatest impact of lagged emissions on overall emissions estimates occurs within the first 2 years following a land clearing event.

Figure 7.A10: *FullCAM* outputs for a single pixel from a single model run showing a) carbon stocks for tree biomass, debris and soil; and b) emissions (CO_2-e) from all carbon pools



7.A3.5 Model Outputs

The *FullCAM* model provides a variety of outputs, developed with particular regard to the requirements of the 1996 IPCC (*Revised*) Guidelines and the *2003 IPCC Good Practice Guidance*. Depending on the model configuration there are currently over 700 possible outputs available. The outputs can be used for reporting emissions and removals by specific pools as well as for model testing and validation.

There are three general types of outputs from *FullCAM*: point-based, tabular (from spatial analyses) and spatial (grids). As well as being able to operate independently as a point-based model, when applied spatially (Figure 7.A10) *FullCAM* is able to generate point-based models (Figure 7.A12) from the spatial surfaces to produce files at a user specified frequency that are used for verification of the spatial model implementation.

The point-based models provide detail of all data drawn from spatial layers as well as constants set through the model interface and those parameters drawn from the relational database. Outputs can be graphical or tabular and can (optionally) describe the carbon stock in all pools, all pool transfers and atmospheric losses from each pool for each monthly time step.

Figure 7.A11: Spatial carbon stock change output (100 m grids)

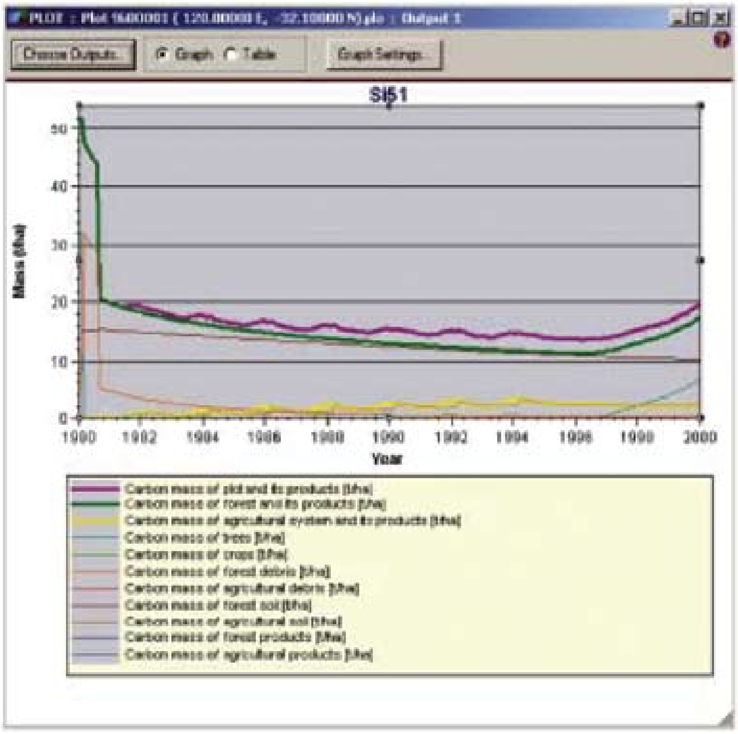
Note: Each 100 m grid has a unique carbon stock change value. The spatial array of source and sink values generally represents the 'proportions' of agricultural practices applied.

Tabular results output by the *FullCAM* model include summaries of input data across the spatial surface, for example, the areas of land cover change (clearing, regrowth, reclearing[9]) each year. The tabular carbon outputs include the total change in carbon stock (including all onsite and offsite carbon pools) due to the modelled activities for each 25 m pixel under consideration. Other carbon outputs of interest from a reporting perspective include the change in tree mass (of both above-and belowground pools), crop mass (total), soil carbon and offsite carbon mass. The amount of biomass burnt is also reported. These tabular outputs are in a form that can be readily used to report into Common Reporting Format (CRF) tables.

Spatial outputs (25 m or 100 m grids) are made up of the results from each 25m pixel being modelled. This produces a 'map' of the output of interest for a point in time (Figure 7.A11). These grid files can be easily read in most GIS systems and provide a visual check of the results. Change over a period of time can be determined by calculating the difference between carbon stock maps at the beginning and end of the period under consideration. Any *FullCAM* output can be produced as a spatial file.

[9] Reclearing is clearing for a second time on a land unit, subsequent to regrowth of an area identified as clearing in the land cover change record.

Figure 7.A12: An example point-based (25 m grid) model output from Western Australia



Having outputs of both the areas of land cover change and carbon stocks allows for consideration of the lagged emissions that arise from forest conversion. This is crucial to understanding the nexus between rates of land cover change and rates of carbon stock change, as policy response strategies against carbon losses typically focus on the reduction of rates of land cover change. The modelling of lagged emissions and their effect is discussed in section 7.A3.4. The output information on areas of land cover change distinguishes between first-time and repeat events on a land unit. Spatial overlays can be performed to consider a range of factors such as land cover change pressures on various locations, vegetation types, soil types and under particular climate patterns.

7.A3.6 Model coherence and validation

As previously noted, the fundamental analytic unit of the NCAS model is the land cover change pixel (25 m x 25 m) of which there are approximately 240 million in the land use change account. The results from each pixel are added together to give the total emissions account in the format of the CRF tables. The average estimate per hectare for the overall account (the implied emissions factor or; IEF) will not reflect any individual, or cluster of individual pixels. As the number of pixels active in the account accumulates over time, the IEFs for each of the accounts for each year will reflect a mix of area change and change in pixel output. The change in pixel output is also strongly affected by the amount of time since the land was cleared and climate variability. As there are multiple variable factors, the implied emissions factors from the overall inventory cannot be used to test the model's coherence as the model processes can no longer be observed in anything like their original analytic unit.

Testing for coherence in a Tier 3 (Approach 3) model-based pixel by pixel inventory method requires very different techniques to those applied to checks on trends and emissions factors in Tier 1 and Tier 2 models. Tests of model coherence and validation can only be meaningfully undertaken at the pixel level. This is the approach taken by Australia and is consistent with the good practice recommendations of the 2006 *IPCC Guidelines*. As the robustness of the national account simply flows from the correct summing of the outputs of the individual pixels, testing the results at the individual pixel scale will, by default, test the national results. Programs to test model cohesion therefore operate in two realms. The first is coherence testing by time series to validate model calibrations and verify the results at the pixel level. The second is quality control to ensure robust summation of the pixels to an aggregate national account.

Representative individual pixels in the NCAS model have been validated against field data. These validations have been undertaken by independent agencies. The results of these studies have shown that the model is robust. Examples of the independent biomass and soil carbon validation results are shown in sections 7.A4 and 7.A5 respectively.

Individual pixel models are internally checked to ensure that all emissions, removals and transfers of carbon between pools are accounted for. At each monthly time-step *FullCAM* reconciles removals due to photosynthesis, transfers between carbon stocks in pools, and emissions from pools for every pixel modelled. Taking a mass balance, full C-cycle approach for each pixel, and running this over an extended period, is a very rigorous way of testing the model's ability to appropriately reflect transfers between carbon pools, and hence the balance of emissions and removals. When multiple pixels are simulated, pixel results are consolidated and then reported at an aggregate level. These aggregate outputs are cross checked by both internal and external processes to ensure that the consolidation process accurately reports all spatial simulation results. The correct summing of model outputs is also critical to model performance and therefore internal and external quality control checks are made on this aspect of the model.

The results from the Tier 3 model have been compared with the results using a Tier 2 method. The Tier 2 method is based on country specific biomass data for three broad ecosystem types and uses the areas from the remote sensing analysis, applied using an Approach 2 method (i.e., not fully spatially explicit). The results from the two models are largely consistent. Variation in emissions and removals occur in the later years of the simulation (post the year 2000). This is because the Tier 3 model is sensitive to the effects of climate conditions over the period while the Tier 2 method is not.

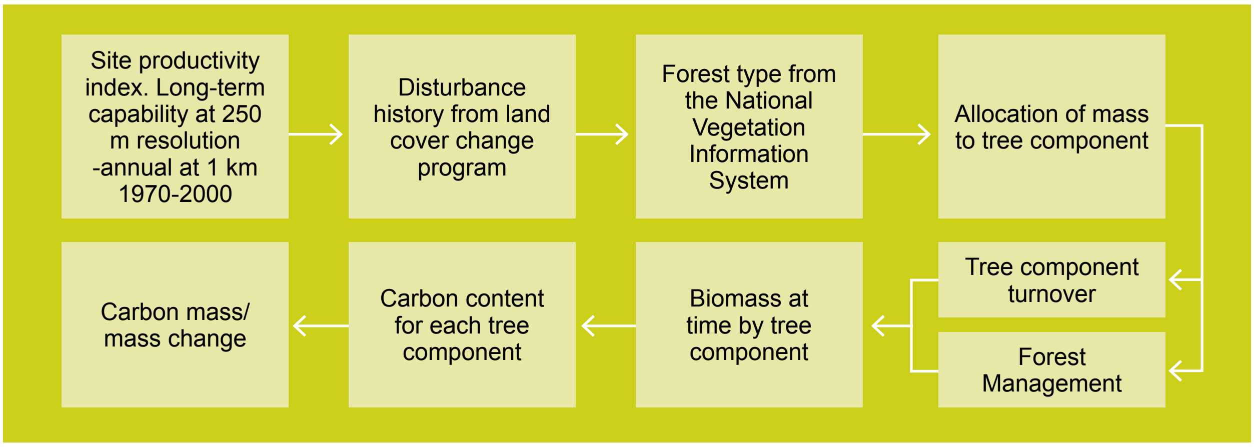
7.A4 Biomass estimation

A vital part of the NCAS is the ability to estimate the carbon stocks of mature forests and the rates of carbon accumulation in any forest regrowth, inclusive of both spatial and temporal variability. At the start of the NCAS program there was no comprehensive growth data or growth modelling capability (empirical or process-based, as either bole volume or total mass) available to support either biomass stock estimation or growth estimates with the required temporal and spatial disaggregation.

Providing a dynamic, disturbance and management responsive forest growth model for all of Australia's forests was particularly challenging. Eventually, a novel spatial modelling approach was used that combines the strengths of both empirical and processed based modelling. The forest growth model component of *FullCAM* can be described as either a hybrid of process and empirical modelling, or an empirically constrained process model. In the hybrid system process models estimate the initial aboveground biomass, forest growth, relative movements between pools and account for climatic variability while empirical data set the constraints within known ranges. It is the empirical data that constrains the model to reflect extensive field data (both existing and specifically collected).

To derive the spatial and temporal patterns of forest growth the derivative form of the *3-PG* model (Landsberg and Waring, 1997; Coops et al., 1998; Coops et al., 2001) was used to provide relative indices of growth potential (productivity indices[10]) at a 1 km grid scale on a monthly basis since 1970. The site-based, multi-temporal productivity indices are used to predict potential biomass at maturity and to support a generalised empirical growth model. All modelling is done on the basis of aboveground biomass with subsequent corrections to account for belowground (fine and coarse root) material.

Figure 7.A13: Overview of the Forest Biomass Programs



Source: AGO 2002

7.A4.1 Forest Productivity Index

The *3-PG* spatial model, as used in this study, is a truncated version of the full *3-PG* model (Landsberg and Waring, 1997), retaining the essential features of biomass net primary production (*NPP*) estimation, without the carbon partitioning procedures. The essence of the model is the calculation of the amount of photosynthetically active radiation absorbed by plant canopies (*APAR*). *APAR* is calculated (Equation 1) as half the amount of short-wave (global) incoming radiation (*SWRadn*) absorbed by plant canopies.

$$APAR = SWRadn \times 0.5 \times (1-e^{(-0\ 5 \times LAI)}) \times \text{days in month} \qquad (1)$$

Where *LAI* is the Leaf Area Index and the coefficient 0.5 is a general value for the extinction coefficient. *LAI* is derived by the expression *l*n(1-FPAR)/(-0.5) where FPAR is calculated by (NDVI * 1.0611) + 0.3431. *APAR* is multiplied by a factor that converts it to biomass.

This, in effect, amalgamates two steps, the conversion of absorbed CO_2 into initial carbon products (gross primary production) and the loss of a proportion of those products by respiration to give NPP. The value of the conversion factor (ε, *gm Biomass* MJ^{-1} APAR) used was obtained from literature (Potter et al., 1993; Ruimey et al., 1994; Landsberg and Waring 1997).

There is significant variation in ε values, but no clear pattern in relation to plant type, so a value of *1.25 gm Biomass* MJ^{-1} APAR was used based on expert judgement. As the resultant NPP is to be used as an index of 'productivity' (the Forest Productivity Index) and not as an absolute mass increase value, precision in the conversion factor is not critical. This NPP value assumes that there are no other constraints on growth. To account for the effects of other factors the potential NPP is reduced by modifiers reflecting non-optimal nutrition, soil water status, temperature and atmospheric vapour pressure deficits.

Calculation of Growth Modifying Factors

Modifiers are dimensionless factors with values between 0 (complete restriction of growth) and 1 (no limitation). Modifiers used in this way are discussed by Landsberg (1986), McMurtrie et al., (1992) and Landsberg and Waring (1997).

[10] A generic model of Net Primary Productivity, derived a classification of productivity, on a relative scale of 1-30. Temporal and spatial variability is identified by a change in classification. This is not a linear relationship with either biomass grow h increment or biomass at maturity.

The modifying factors are:

Soil fertility: Because of natural variation and the considerable uncertainty surrounding soil fertility values, only three levels of fertility were used; high (effective modifier = 1), medium (effective modifier = 0.8) and low (effective modifier = 0.6), giving ε values of 1.25, 1 and 0.75, respectively. These were applied for each pixel, depending on soil type, before environmental modifiers were applied. Information on soils and their characteristics was obtained from McKenzie et al., (2000a).

Vapour Pressure Deficit (*VPD*): VPD is a measure of atmospheric drought. VPD affects stomatal, and hence canopy conductance as trees regulate their water use. This can lead to reduced growth even where soil water content is high. The VPD modifier equation (2) used is:

$$\text{VPDmod} = e^{(-0\ 05 \text{ x VPD})} \qquad (2)$$

This modifier essentially acts as a control on the rate of water loss and is conditional upon soil water content (see below).

Soil Water Content: This is derived from water balance calculations, which take into account the maximum soil water holding capacity (Equation 6) in the root zone of plants. Plant water use (Equation 4) is calculated from the equation for equilibrium evaporation (Equation 3, see Landsberg and Gower, 1997; p. 79), modified by feed-back from current soil water content, and a conventional water balance equation (Equation 5):

$$\text{EqEvapn} = ((0.67 \text{ x NetRadn} *(1\text{-}0.05)) / 2.47) \text{ x days in month} \qquad (3)$$

$$\text{Transpiration} = \text{EqEvapn}_j \text{ x SWmod}_{j-1} \qquad (4)$$

$$\text{WaterBal} = (\text{Rain x } (1\text{-interception})) - \text{Transpiration} \qquad (5)$$

$$\text{SoilWaterContent}_j = \text{SoilWaterContent}_{j-1} + \text{WaterBal}_j \qquad (6)$$

Initial SoilWaterContent was taken as 0.75 x SWcapacity. SoilWaterContent carries over from one time step to the next. The soil moisture calculation sequence was run for 3 years, after which SoilWaterContent had essentially equilibrated to stable monthly values. SoilWaterContent values in year 3 were used in the analysis. The soil water modifier (*Swmod*, Equation 8) was calculated from the moisture ratio (*MoistRatio*, Equation 7), which is SoilWaterContent normalised to SWcapacity. The equation describes the variable effect of MoistRatio across the range from wet soil (MoistRatio ≈1) to dry soil (MoistRatio ≈0).

$$\text{MoistRatio} = \text{SoilWaterContent/SWCapacity} \qquad (7)$$

$$\text{SWmod} = 1 / (1 + ((1\text{-MoistRatio})/0.6)^{0.7}) \qquad (8)$$

The soil water and VPD modifiers are not multiplicative; the lowest one applies. The argument is that if plant growth (conversion of radiant energy into biomass) is limited more by VPD than soil water (i.e., if VPDmod<SWmod) then soil water is not a limiting factor, even if soil water content is relatively low. The converse applies, that is, if SWmod<VPDmod, soil water is the limiting factor.

Temperature: The growth of any plant species is limited by temperatures outside the optimum range for that species. Since plants are dealt with in a generic way the assumption was made that, in any particular region, the plants are well-adapted to the temperature range. The equation (9) describing the effect of temperature is:

$$\text{Tmod} = ((\text{Tav} - \text{Tlow}) / (\text{Topt} - \text{Tlow})) \text{ x } ((\text{Thigh} - \text{Tav}) / (\text{Thigh} - \text{Topt})) \qquad (9)$$

Tav is the average monthly temperature, Tmin is the monthly average temperature below which plant growth stops, Tmax is the monthly average temperature above which plant growth stops and Topt is the optimum temperature for growth (Tmin + Tmax)/2. The temperature modifier (TempMod) is 1 when Tav = Topt.

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Equation (9) gives a hyperbolic response curve, with Temp Mod = 0 when Tav = Tmin or Tmax. Tmin is set to 1/2 the minimum temperature of the coldest month (if the minimum temperature of the coldest month is greater than or equal to 0^oC, Tmin was set to the minimum temperature of the coldest month plus 1/2 the minimum temperature of the coldest month if the minimum temperature of the coldest month is less than 0^oC). Tmax is set to 5^oC above the maximum temperature of the hottest month of the year and Topt as equal to the average of Tmin and Tmax. Consequently, TempMod generally had relatively small effects on the calculation of NPP.

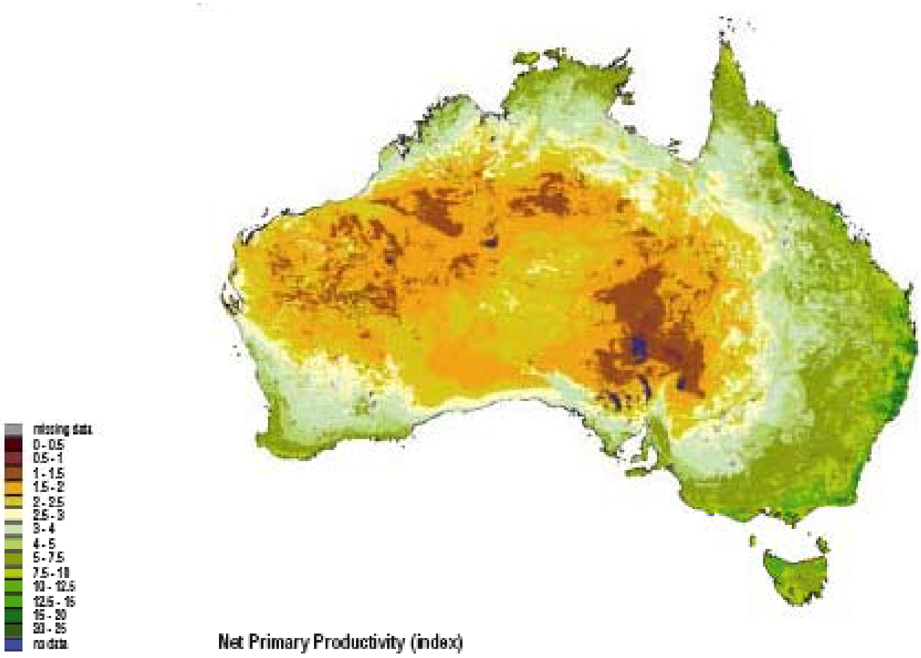
A frost modifier is included, using the simple assumption that frost temporarily inactivates the photosynthetic mechanism in foliage, so there is no growth on a frost day. The modifier is, therefore, simply the ratio of number of frost days/month to the number of days in the month.

Calculation of the Forest Productivity Index

The Forest Productivity Index (FPI) is calculated both temporally and spatially using the monthly (since 1968) 1km grid climate and site information described in section 7.A6. A further 250 m long-term average FPI is also calculated, using a slope and aspect corrected APAR calculation (Figure 7.A14).

These productivity maps are used to describe the spatial and temporal variation in forest biomass and growth.

Figure 7.A14: 250 m Slope and aspect corrected productivity index map



7.A4.2 Initial assumed biomass

Calibration

The assumed initial biomass is applied to all first time clearing events whenever they occur. It is modelled from site productivity and field measurements reflecting a range of potential prior disturbance histories.

The assumed initial biomass for a pixel which is subject to first time land clearing is calculated from the site productivity of that forest pixel. Field biomass measurements used in the calibration represent all forest conditions except those with visible evidence of recent disturbance. Mature forests were defined as having no identifiable major disturbance events since 1970 such as clearing, harvest or fire (Richards and Brack 2004a). The lands may, however, still be experiencing ongoing low level disturbance such as grazing and low intensity fires. As the NCAS model assigns an actual value to regrowth of forest cleared after 1972, forests containing young regrowth were excluded from the assumed initial biomass calibrations to avoid an underestimate.

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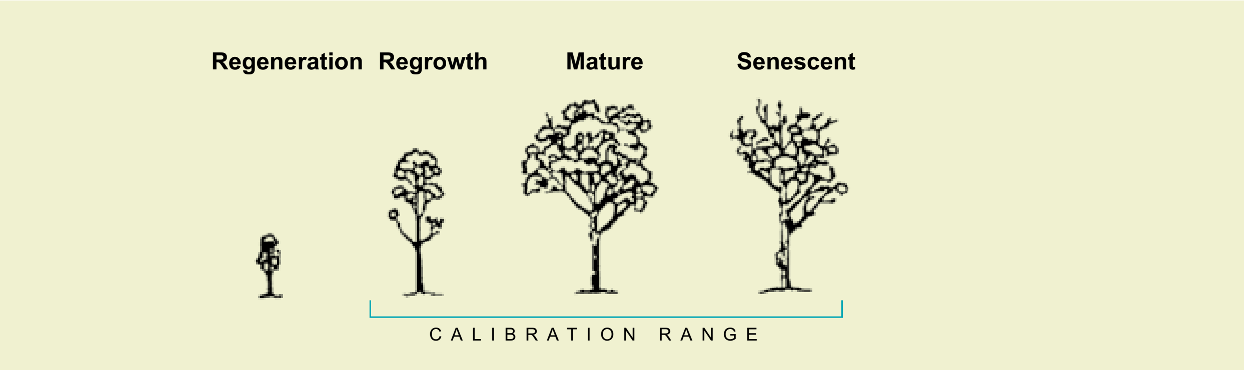
The calibration data covers the mix of age classes from regrowth to senescent (old-growth) (Figure 7.A15) and therefore the potential variation in field biomass conditions. To develop this relationship a collation of available biomass data for forests was conducted by CSIRO (Raison et al., 2003). This data collection by CSIRO combines all the field studies that were available and of the required standard at the time the NCAS methodology was built.

Figure 7.A15: Diagram showing the range of data used in the calibration of the model.



Regeneration	Includes juvenile and sapling stages where tree is very small and crown exhibits apical dominance.
Regrowth	Tree has well developed stem with crown of small branches, but below maximum height for stand, apical dominance apparent in vigourous trees.
Mature	Tree has reached maximum height and crown reached full lateral development. Branch thickening can occur.
Senescent	Crown form contracting, decrease in crown diameter and crown leaf area.

Source: Base image and text from Florence. (1996)

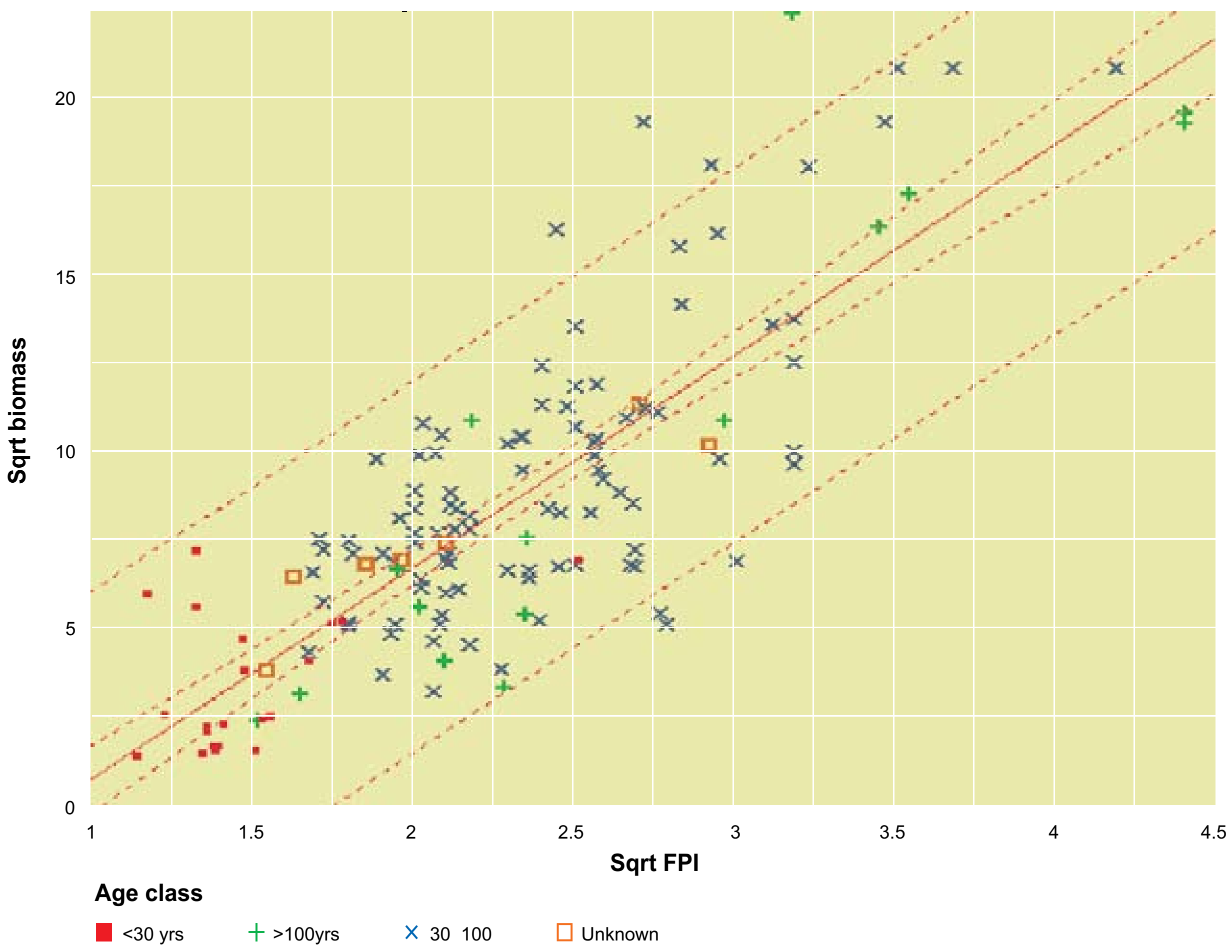
In the collection of the calibration plot data, caution was exercised to exclude plots that were drawn from forest 'gaps'. Plots taken as part of fixed-grid or transect systems could potentially fall in gaps in sparse forests. As the remote sensing program at 25 m resolution is capable of separating such forest gaps from clearing events, the forest carbon mapping needs to represent the biomass of forested plots, not of that averaged over the gaps.

To determine the initial forest biomass for an individual forest site the geo-referenced calibration data set was fitted to the productivity map. The red line in Figure 7.A16 is the line of best fit for predicting the initial forest biomass of an individual forest site.

A regression found a significant correlation ($p < 0.01$, $r^2 = 0.68$) between the stand biomass previously described (*M*) and the Long-Term Forest Productivity Index (*P*) (Equation 10). A square root transformation was required to meet assumptions of normality and homogeneity (Figure 7.A16).

$$M = (6.011 \times \sqrt{P} - 5.291)^2 \qquad (10)$$

Figure 7.A16: The assumed initial biomass relationship

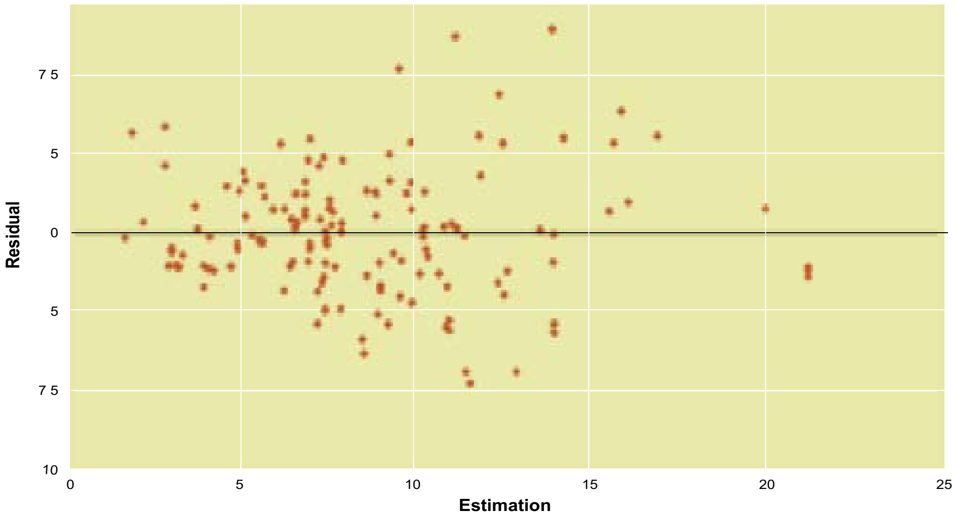


The goodness of fit of Equation (10) ($r^2 = 0.68$, $p < 0.01$) to the measured data confirms that a robust relationship exists between the productivity mapping and measured aboveground biomass estimates. The outer 95% confidence limits (outer pair of dotted lines) show the reliability for predicting biomass at any individual site. The inner 95% confidence intervals (inner pair of dotted lines) show the high degree of confidence in the line of best fit being able to represent the variability in the field data at the national scale. It applies throughout the continuum of productivity across the forest estate as a whole. The model shows that the assumed initial biomass is an accurate and unbiased representation of the forest estate (excluding young regrowth) as can be gauged from available data.

The initial assumed biomass at a chosen resolution for the entire continent can then be calculated by applying Equation (10) to the FPI mapping. A key benefit of the hybridisation of process modelling (through the productivity mapping) and empiricism (through known measures), is that estimates will be constrained to actual conditions (measured mass estimates) and actual growth, not that of optimal growth.

While the goodness of fit and lack of bias in error estimates (Figure 7.A17) provides confidence in the application of Equation (10) as a model to predict biomass at maturity, there is an obvious scatter in the data. This is attributable to the range of age classes and forest histories used in the model, the differing methods used in the field estimation and to an inherent variability between the 'plot' locations used to scale to one hectare mass estimates compared to the average condition reflected in the 250 m resolution productivity estimation.

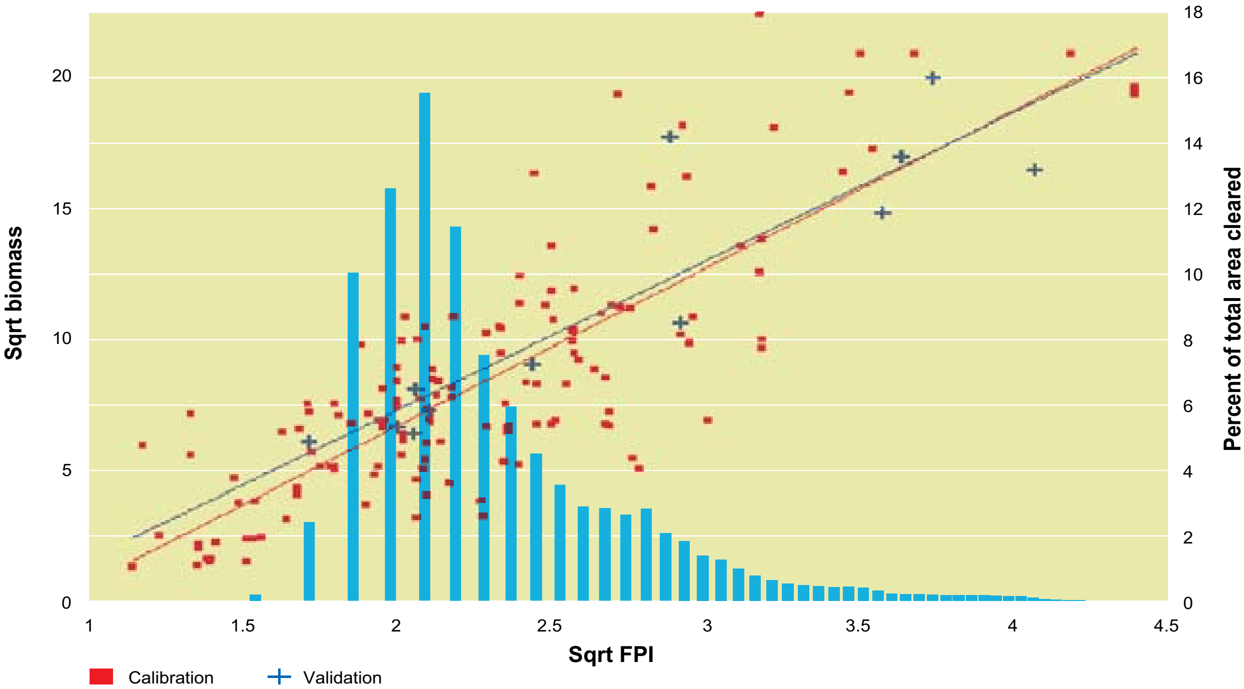
Figure 7.A17: Error distribution for equation 10



Validation

The NCAS runs a continuous improvement and validation program and is subject to wide independent review through the data and methods used in the NCAS being publically available. Calibration of the biomass model used in the NCAS has been validated by using independent research and field studies of biomass estimates, excluding forest areas with young regrowth. For example, the NCAS sponsored researchers to weigh all trees at three forest sites of varying productivity but with similar disturbance histories (Ximenes et al., 2005, 2006). Other independent research studies in Australia have provided additional data that also validate the model. Since the model was first developed data collection from 15 new field sites has since been completed that meet NCAS standards (Snowdon et al., 2002) and are available for validation. These data points cover a wide range of forest types and represent forests that are near mature to mature with little evidence of recent disturbance. Validation tests show no significant difference between the validation and calibration data (Figure 7.A18). The validation data yielded slightly higher biomass estimates within the range of forest that was most frequently cleared (when comparing the calibration data sets with the more recent validation data sets). This was not a statistically significant difference.

Figure 7.A18: Calibration and validation data for the initial assumed biomass estimates



Note: The background histogram represents percentage of the area cleared by forest productivity index.

7.A4.3 Key concepts in the initial assumed biomass model

Key Terms used in the biomass model

Maximum potential biomass – the highest biomass value that the model will assign to any forest area and is an ***average*** of the range of measured biomasses (field) for a range of forest disturbances. It ***is not*** the upper limit of the measured biomasses.

Calibration data – field measurements collated nationally to represent the range of forest conditions, except those with visible recent disturbance. The initial condition (maximum potential biomass) is the central estimate of this data spread for any given site productivity.

Field maximum and minimum observed values – reflect the range of measured biomass for any point along the site productivity continuum. The maximum measured values typically represent situations that are least disturbed. The minimum values represent a higher degree of disturbance (but exclude young regrowth sites).

Validation data – data that is independent from the calibration data and is used to test models built on the calibration data.

Site productivity – an estimate of the ability of a site to produce biomass (Kesteven et al., 2004).

Land clearing event – A land clearing event (deforestation) involves deliberate human actions that remove the forest cover for land management purposes (typically agricultural production). It produces a fundamental disturbance to the forest condition.

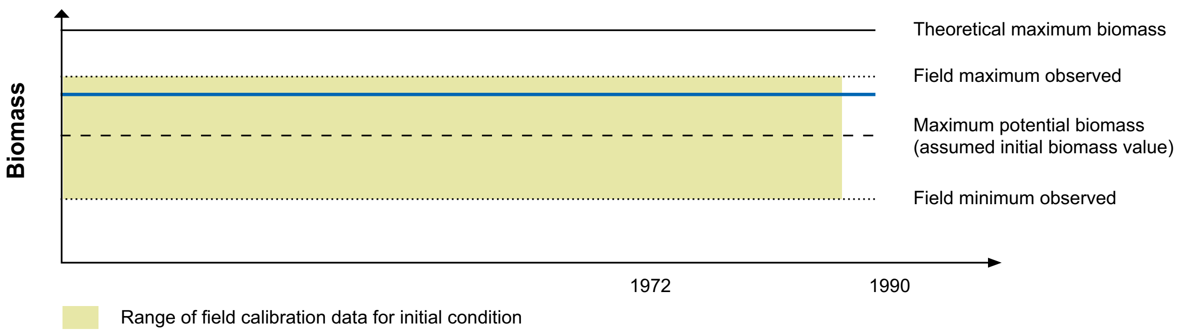
Natural Forest Disturbance – Natural climate variability (for example, bushfire and drought periods) affects the forest condition to a lesser extent in the long term as there is a natural recovery to this cyclical natural pattern.

In developing the initial assumed biomass model it was important to consider the way in which the initial biomass values fitted within the modelling framework as a whole. The biomass condition in any individual forest site in Australia is based on its history of both human and natural disturbance, whereas in a national emissions account it is human disturbance that is most significant. The history of human disturbance will fit into one of three different cases:

- Case 1: The forest site was undisturbed/uncleared prior to 1972 and remains undisturbed/uncleared until the first land clearing event.
- Case 2: The forest site was cleared prior to 1972 and is currently regrowing.
- Case 3: The forest site was cleared sometime after 1972 but has since regrown.

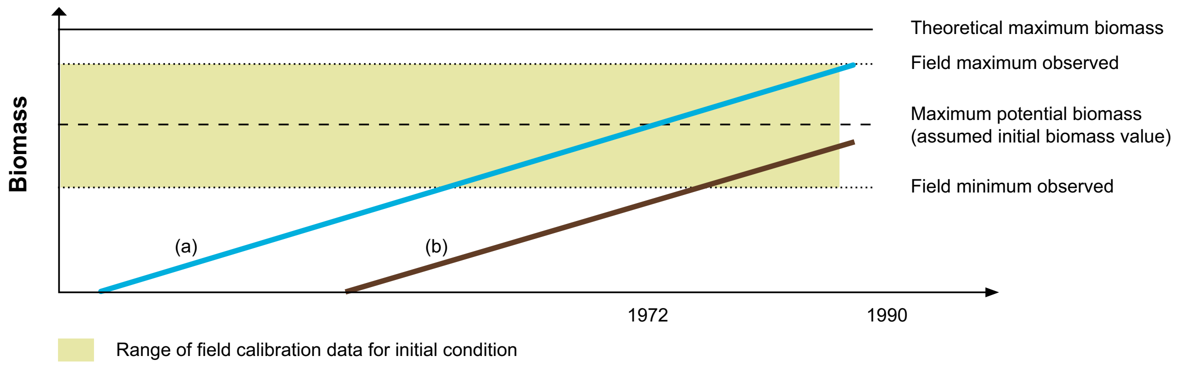
Figures 7.A19 (a) to (c) (below) show the relationship between the model's assumed initial biomass and the likely biomass in each of the three historical disturbance cases.

Figure 7.A19: (a) Biomass of forest undisturbed prior to 1972



In Case 1 (Figure 7.A19a) the forest site was undisturbed prior to 1972, (as represented by the continuous blue line) and remains in that condition until a time of a first clearing event. The field biomass is represented by the example blue line in Case 1 and will almost certainly be higher than the maximum potential biomass because it was calibrated from sites representing a range of disturbance histories. This reflects the absence of prior disturbance in forest sites fitting into Case 1.

Figure 7.A19: (b) Biomass of forest cleared prior to 1972

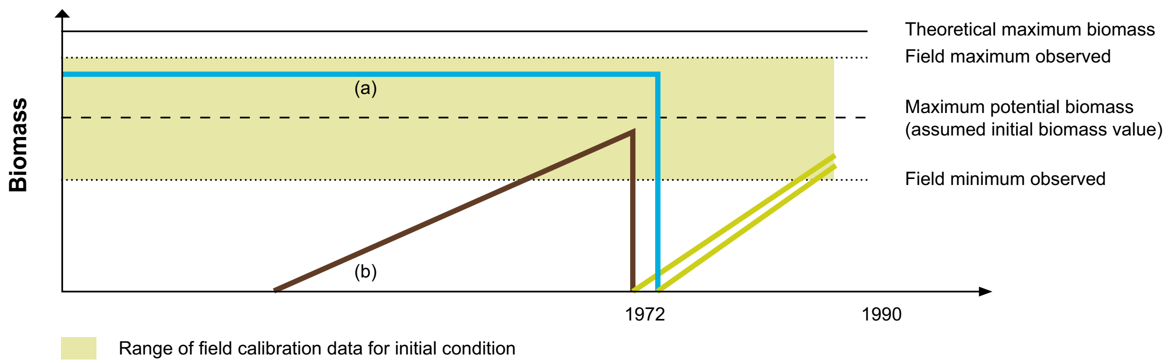


In Case 2 (Figure 7.A19b), the forest area was cleared at some time prior to 1972, but was not cleared between 1972 and 2006 and at the time of clearing the forest was still growing. For the majority of forests in this case, the biomass in 1990 will have recovered to be within the range of observed values used in the model calibration but may not have reached the assumed initial biomass value.

For Case 2(a) the actual biomass for the site may exceed what would be assigned as the assumed initial biomass condition by the model. This is because of the length of time that the forest has had to regrow means that it resembles the Case 1 scenario. Where the initial clearing occurred soon before 1972 (Case 2b), the biomass for the site will be below that which would be assigned as the assumed initial biomass condition.

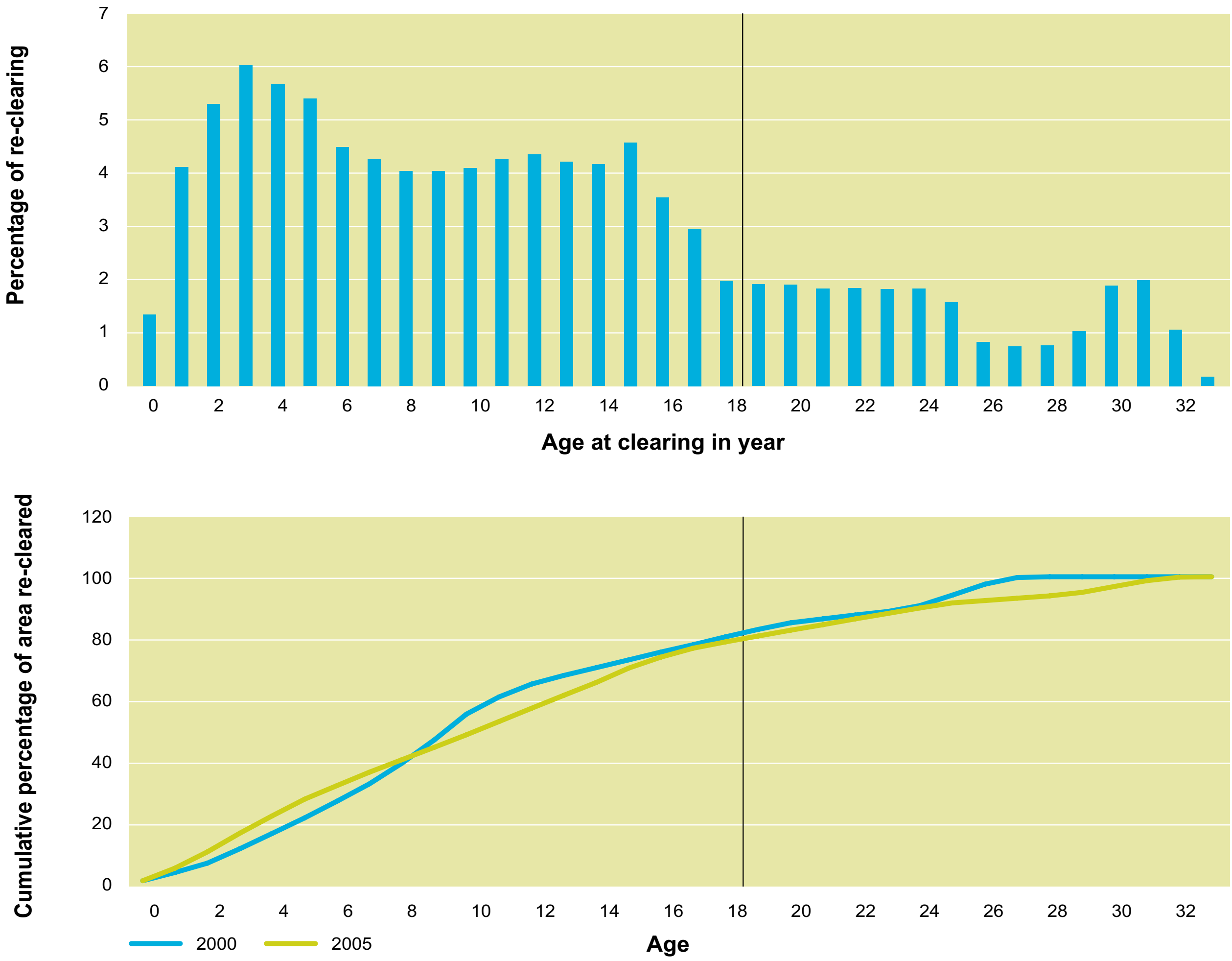
Both Cases 2(a) and 2(b) are relatively rare occurrences. This is because the average reclearing cycle is 8-11 years, with 80% of reclearing happening within 18 years of the last regrowth event (Figure 7.A20). This means that of the forests possibly in Case 2a and 2b (that is previously cleared and regrowing at an unknown time before 1972), around 80% would likely have a reclearing event before 1990 and would actually be in Case 3b below. For those forests that are not recleared and are actually in Case 2, the assumed initial biomass may overestimate or underestimate, depending on when the initial (unobserved) clearing took place. There is no basis for presuming that any individual pixel is more likely to be either 2(a) or 2(b).

Figure 7.A19: (c) Biomass of forest cleared post-1972



In Case 3 (Figure 7.A19c) the forest is interpreted from the post- 1972 remote sensing data to have been ‘cleared for the first time’ after 1972 and has subsequently regrown. In this case the age of the forest is known and the biomass is modelled directly using the age of the forest and site productivity (see Biomass Growth Increments section 7.A4.4). The green lines in both (a) and (b) represent biomass that can be calculated by the model because the age of regrowth can be observed. The assumed initial biomass is not used for any subsequent reclearing event as the age of regrowth forest is known at the time of reclearing. Prior to 1972, the forest may have been undisturbed (represented in the blue line (a)) or disturbed (represented in the red line (b)). Regardless of whether the situation was (a) or (b) the initial biomass assumption at time of first clearing will not affect the biomass estimates for a reclearing event after an initial clearing has been identified.

Figure 7.A20: Percentage of reclearing by age



7.A4.4 Biomass increment for regrowing forests

As not all forest areas are in a ‘mature’ state, the remote sensing of land cover change is used to identify disturbance history and, therefore, forest age. The forest type mapping is subsequently spatially overlaid on the multi-temporal productivity maps to determine, for every 25 m pixel, the forest type, productivity and age (inferred from disturbance history using the land cover change data). The following formula (Equation 11) is then used to provide an estimate of growth of those forests which have regrown since 1972 using the spatial productivity index (mass at maturity and forest type) and multi-temporal spatial data (productivity and land cover change).

$$\text{Aboveground Tree Mass at age a} = M \times e^{(-k/a)} \qquad (11)$$

Where: (a) is the age of the tree stand

(M) is the biomass predicted by the assumed initial biomass model, and

(k) is an estimated constant that determines the rate of approach towards M.

The value of k sets the rate of growth. By differentiating the above equation it can be found that the age of maximum biomass increment in this model is 0.5k. In *FullCAM* this value is known as BI_a, the age of maximum aboveground biomass increment.

Given Equations (10) and (11), the long-term average annual increment between a and $a+1$ years (I_a) for a stand can be estimated from the Long-Term Average Productivity (P):

$$I_a = (6.011 \times \sqrt{P} - 5.291)^2 \times (e^{(-k/a)} - e^{(-k/a+1)}) \qquad (12)$$

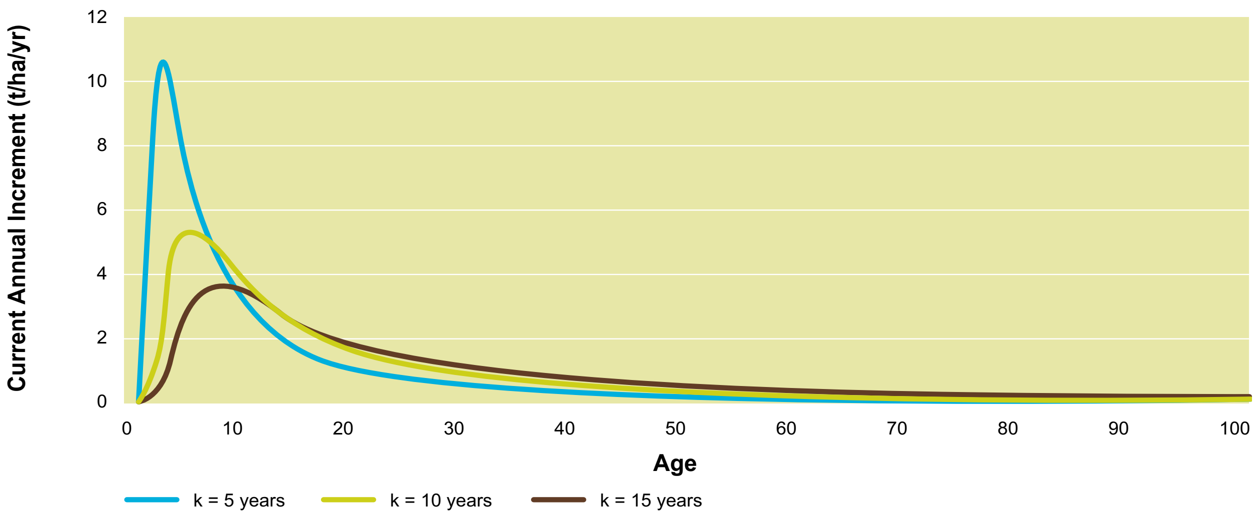
However, as productivity in any given year may vary around the average due to non-average weather or other factors, the average annual increment may be adjusted by the productivity in a given year (P_a) as a ratio with the average productivity (P):

$$I_a = I_a \times P_a/P \qquad (13)$$

This approach provides biomass stock estimates for a given land unit at any point in time that recognises prior forest disturbance, and the rates of growth for a land unit at any point in time, specific to site condition and age. The patterns of growth will show variability according to the spatial and temporal patterns of the main process drivers, e.g., water balance, captured in the productivity modelling. This ensures that the estimates of biomass in areas of regrowth are then both spatially and temporally relevant.

Figure 7.A21 provides an analysis of the effects of varying age of maximum aboveground biomass increment between the ranges of 5 to 15 years. While the early age growth increments are very sensitive to BI_a, even by age 18 there is little difference in the annual aboveground biomass growth increment. The effect of BI_a on any modelling at the national scale will depend on the age, quantity and location of regrowing forest and is discussed separately in Appendix 7.E.

Figure 7.A21: Effects of varying age of maximum current annual increment

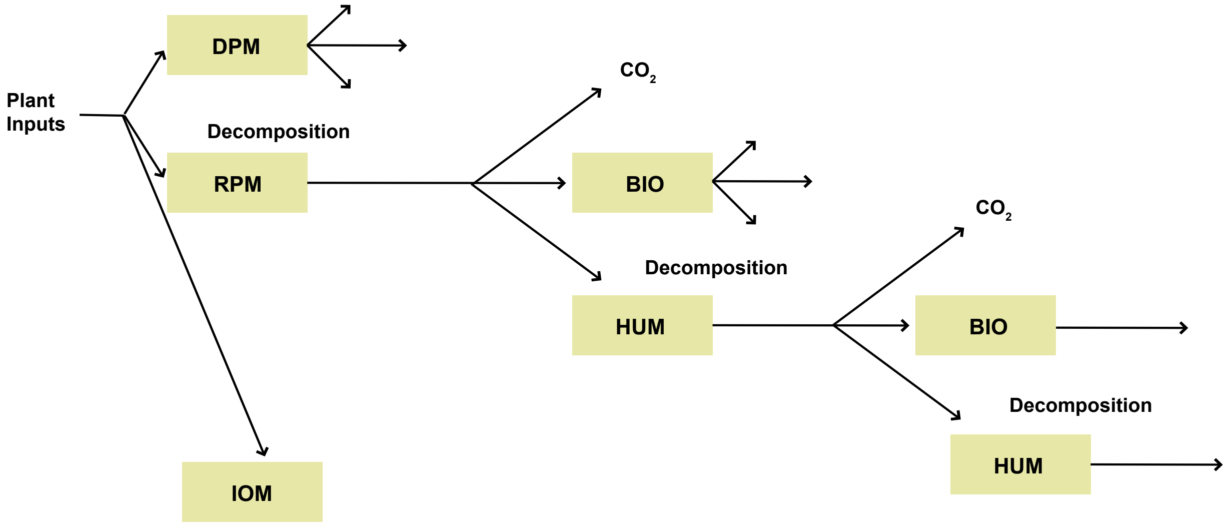


7.A5 Estimating changes in soil carbon

To perform spatially and temporally disaggregated accounting for soil carbon, it was necessary to calibrate and verify a robust and widely applicable soil carbon model. On the basis of previous successful testing in a range of environments in Australia, the *Roth-C* (Jenkinson et al., 1987, Jenkinson et al., 1991) soil carbon model was chosen (Webbnet Land Resources Services Pty. Ltd. 2000) for implementation in the NCAS and integrated into the *FullCAM* model. The structure of the model is represented in Figure 7.A22.

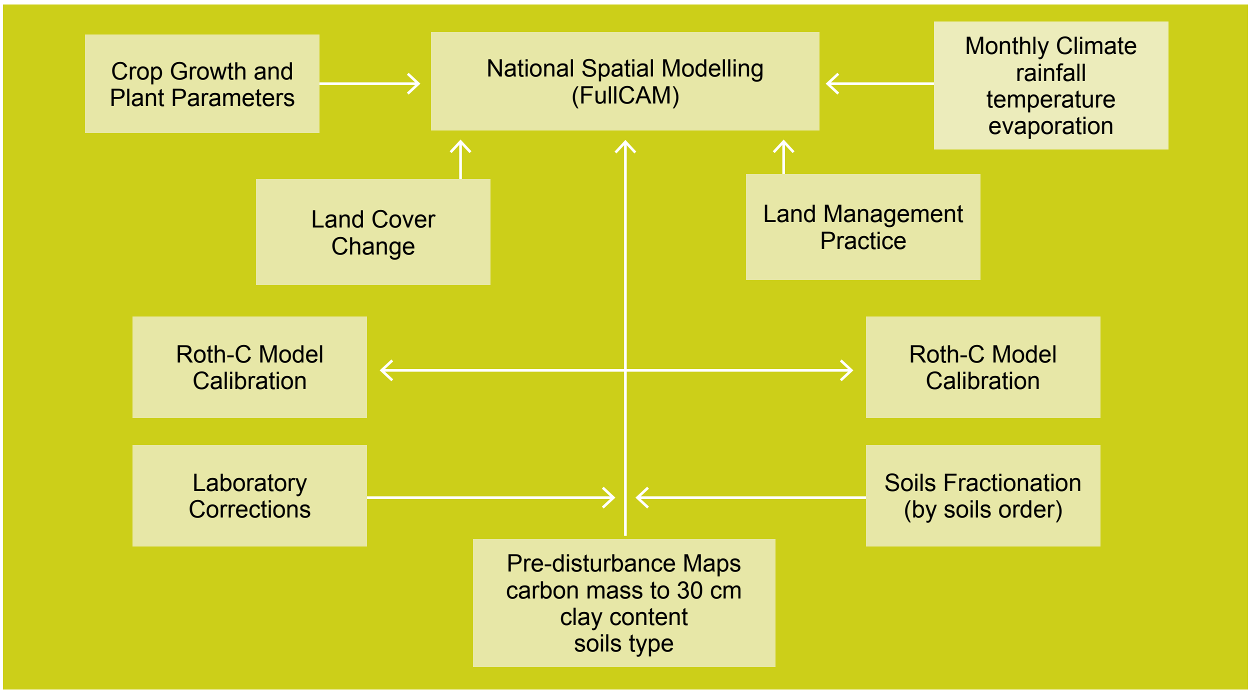
The overall soil carbon program developed both resource inventory (mapping) descriptions and model calibration and verification. The integrated soil carbon program for the NCAS is shown in Figure 7.A23. The background to the selection of methods and design of the program can be found in Webbnet Land Resource Services Pty. Ltd. (2000).

Figure 7.A22: Structure of the Roth-C soil carbon model as implemented in *FullCAM*



Source: modified from Jenkinson 1990

Figure 7.A23: The NCAS Soils Program



Source: AGO 2002

7.A5.1 Soil Mapping and Inventory

The modelling of soil carbon change by the NCAS uses an initial condition map which defines the pre-disturbance soil carbon content. To develop this map the NCAS collaborated with the relevant agencies of State and Territory Governments and the CSIRO to access the best available soil mapping and site sample data specific to this purpose. To provide comparability between site sample (inventory) results collected over various time periods from a variety of analytic laboratories, typically using different methods, correction factors were derived by standardising methods to the results derived from a dry combustion methodology (Skjemstad et al., 2000). Correction factors were derived by re-analysing, via a dry combustion method, archival soil samples and then comparing results to the known results from the original methods.

The mapping of soil units was completed at a level of precision which could be supported by available data. This approach led to variable resolutions in the mapping, generally determined by the regional data availability and heterogeneity of soil landscapes. The results of this project are reported in Webbnet Land Resource Services Pty. Ltd. (2002). Figure 7.A24 shows the derived pre-disturbance map derived.

In conjunction with the development of the pre-disturbance soil carbon map, a map of clay content was also developed (Figure 7.A25) using the same map base. The mapped soil units provide pre-disturbance carbon (organic) content, clay content and soil type. The soil types (Table 7.A2) allow for the mapping to subsequently (via the *FullCAM* relational database) be ascribed proportions of the starting carbon within the pools described in the soil carbon model. These pools are defined by their differing turnover times (resistance to decomposition). The proportion of material in each soil pool (fractionation) was established by laboratory analysis of soil samples held in CSIRO and State/Territory Government archives.

Additional studies carried out to support this work included the setting of a national soil carbon sampling and analysis protocol (McKenzie et al., 2000a) and a standardisation of existing archival data to this new national analytic protocol (Skjemstad et al., 2000).

Figure 7.A24: Pre-disturbance soil carbon map

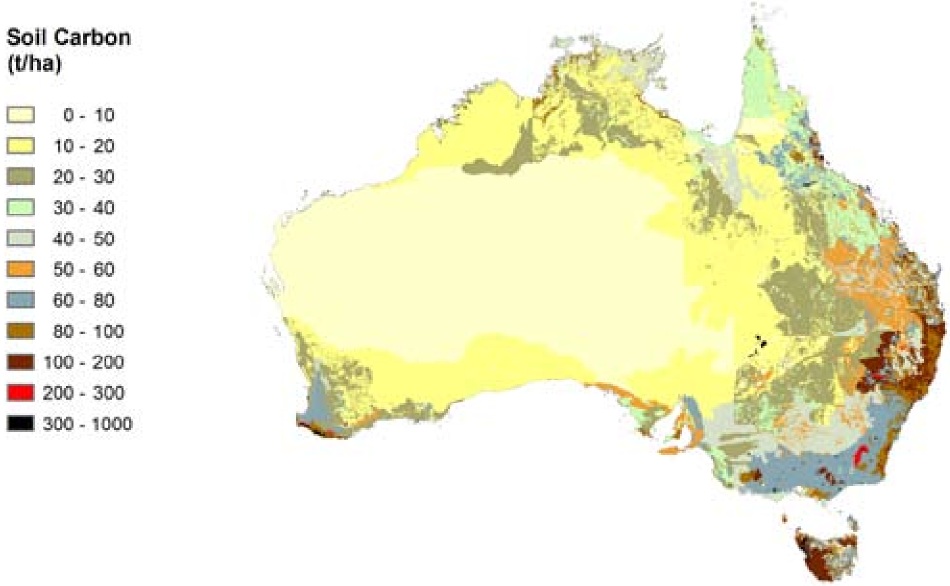
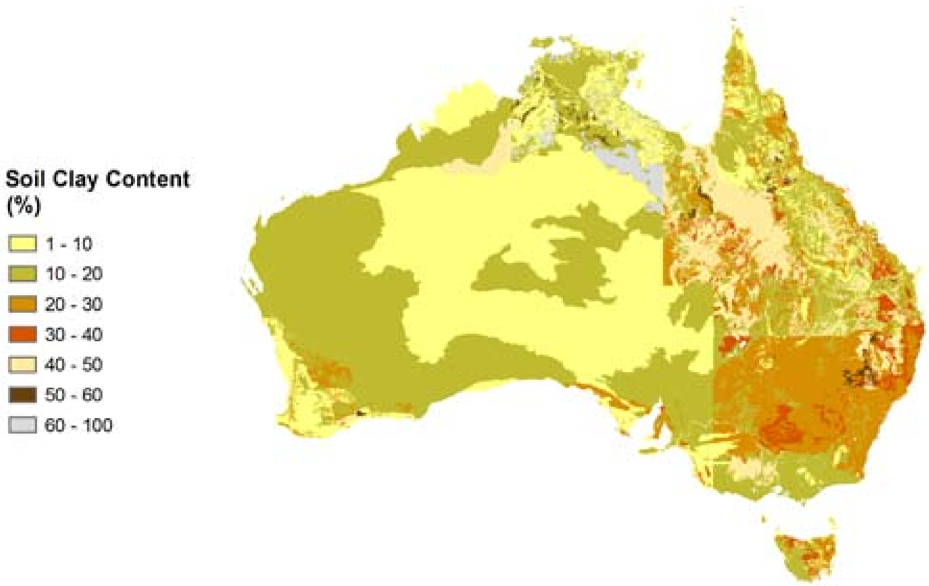


Figure 7.A25: Clay content map



APPENDICES

Table 7.A2: Soil classification used in the modelling

Soil no.	Location	Soil type
s1	TAS	Structured earths
s2	TAS	Bleached sands with subsoil pans
s3	TAS	Other soils
s4	NSW	Clay
s5	NSW	Loam
s6	NSW	Sand
s7	QLD	Duplex – woodland
s8	QLD	Clay – brigalow and gidgee
s9	QLD	Clay – open downs
s10	QLD	Clay – brigalow and belah
s11	QLD	Gradational
s12	QLD	Clay
s13	QLD	Other soils
s14	QLD	Gradational – spinifex
s15	QLD	Clay – mitchell grass (30%) and gidgee
s16	QLD	Duplex – black spear grass & a\b woodland
s17	QLD	Duplex
s18	QLD	Gradational and duplex
s19	QLD	Clay – gidgee
s20	QLD	Open downs
s21	QLD	Earths
s22	QLD	Sands and loams
s23	QLD	Clays and red loams
s24	NT	Kandosol
s25	NT	Other
s26	NT	Tenosol
s27	SA	Sub area 1 -DD
s28	SA	Sub area 2 – Lb5
s29	SA	Sub area 3 – Sandy
s30	SA	DD2/Lb5/E6
s31	VIC	Deep sands
S32	VIC	Calcarosols
s33	VIC	Cracking clays
s34	VIC	Yellow duplex soils
s35	VIC	Leached sands
s36	VIC	Brown duplex soils
s37	VIC	Black duplex and gradational soils
s38	VIC	Red-brown earths
s39	VIC	Bleached sands
s40	VIC	Organic soils
s41	VIC	Gradational Red earths
s42	VIC	Non-Cracking clays
s43	VIC	Red duplex soils
s44	VIC	Organic loams
s45	VIC	Red earths
s46	VIC	Brown earth
s47	VIC	Grey Cracking Clays
s48	WA	Coloured sands
s49	WA	Gravels
s50	WA	Loams and clays
s51	WA	Non saline wet
s52	WA	Other
s53	WA	Pale sands
s54	WA	Sandy duplexes
s55	WA	Saline

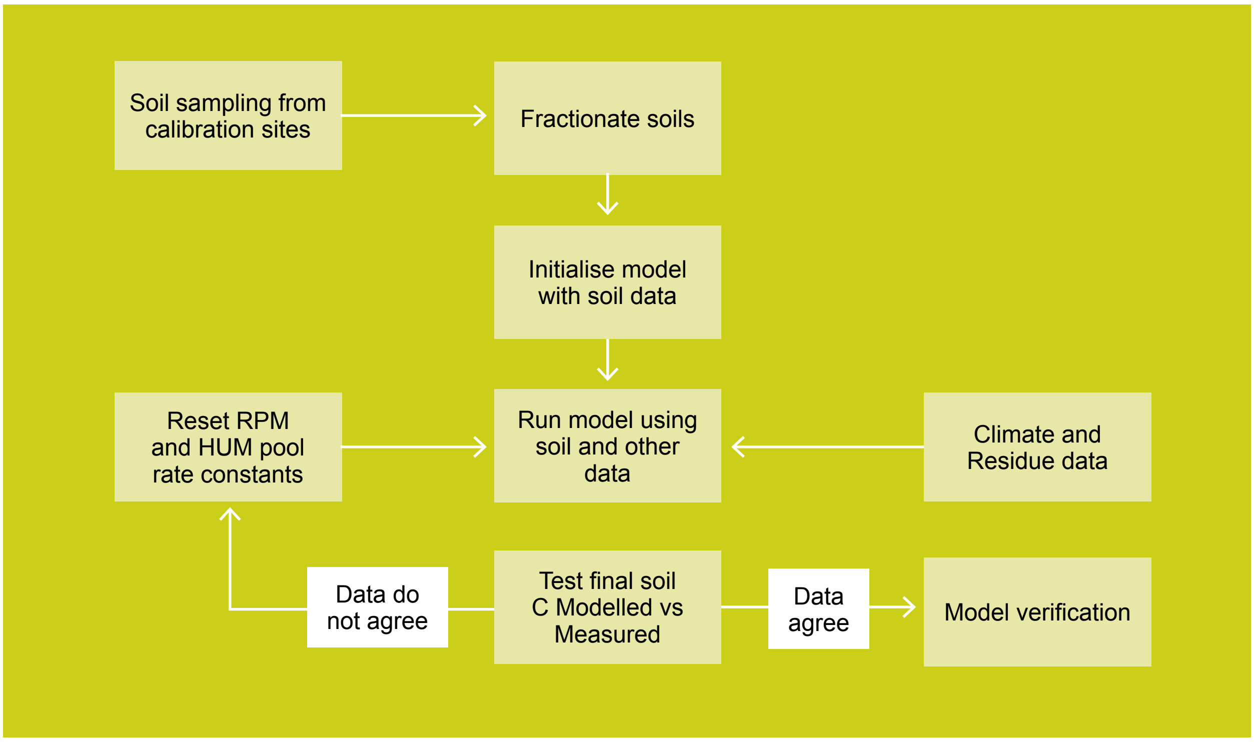
7.A5.2 Roth-C Soil Carbon Model Calibration and Validation

Early policy and technical analysis of the requirements for the carbon accounting under the IPCC Inventory Guidelines, the Kyoto Protocol, and of the national data and methodological capacity available for the task, led to the development of a model-based methodology underpinned by the *Roth-C* soil carbon model. The model calibration and verification program identified available long-term field trial data, a subset of which had sufficiently detailed and complete long-term data to enable calibration of the model against long-term field measurements. Only a minimum of data supplementation was accepted at these calibration sites. Other sites with incomplete long-term data, but providing a robust temporal pattern of carbon change under known management and climate, were used for model verification (Skjemstad and Spouncer 2002).

In addition to this long-term trial data, approximately 75 new soil pairs (an undisturbed site paired with a cleared site) were sampled to provide a range of verification targets for model testing. Sites were established, in collaboration with State Agencies in Queensland, New South Wales and Western Australia, in the areas of major forest conversion activity. Sites were selected to cover a variety of crop type, soil type and time since change (e.g., clearing) in areas subject to most intensive activity. Sampling of sites was completed according to the standardised soil sample protocol developed for the NCAS (McKenzie et al., 2000b).

Calibration of the soil carbon model was completed around a structured procedure as shown in Figure 7.A26.

Figure 7.A26: Procedure for the calibration of the Roth-C soil component of *FullCAM*



After investigation of sites that met the requirements for model calibration, two agricultural and seven forestry sites were selected. One agricultural site is on a monsoonal subtropical environment with heavy clay soil and the other is in a temperate Mediterranean climate with a light textured soil. At each agricultural site, soil samples (0-30 cm depth) from the beginning and end of the trial as well as some in between were fractionated into particulate organic carbon (POC), charcoal (char-C) and humic (hum) pools (Skjemstad and Spouncer 2002). These pools, measured in the archival soil samples, were then used to initialize the model (RPM set to POC, IOM set to char-C, HUM set to TOC minus POC minus char-C) at the first time of sampling. Other pools were set to zero but were quickly generated by the model. It was found that at both sites, adjusting the *Roth-C* default resistant plant matter (RPM) pool decomposition rate modifier from 0.3 to 0.15 yr^{-1} rectified any divergence in the results. No other changes were necessary.

Calibration of the forestry sites was completed subsequent to the agriculture calibration in seven locations:

- *Eucalyptus globulus* in the low rainfall region, south-west of Western Australia
- *E. globulus* in the high rainfall region, south-west of Western Australia
- *Pinus radiata* in the Green Triangle region of South Australia and Victoria
- *E. grandis* in south-eastern Queensland and north-eastern New South Wales
- *P. radiata* in the south-eastern highlands of New South Wales
- *E. globulus* in south-eastern Gippsland, Victoria; and
- *E. nitens* in the Tasmanian highlands

The testing in the forestry sites confirmed the model calibrations for both forestry and agricultural sites.

Both the model calibration and verification studies are reported in Skjemstad and Spouncer (2002). Validation of the NCAS soil carbon model used a combination of time-series measurements at research sites (independent of those used for model calibration) and paired site sampling. The reports of the paired site studies can be found in Harms and Dalal (2002), Murphy et al., (2002) and Griffin et al., (2002). Given the diversity of systems tested and the inherent problems with paired sample approaches, the model results were good, with the only model parameter altered from the *Roth-C* recommended defaults being the decomposition rate for Resistant Plant Matter (*RPM*) (from 0.30 to 0.15).

7.A5.3 Examples of soil carbon calibration and validation results

Pre-clearing soil carbon map.

As part of the validation of the soil carbon model, 32 new paired sites were established in the ranglelands of central and southern Quensland (Harms et al., 2005). Queenslands's rangelands have been subject to signficant clearing over the past 20 to 30 years and represent a large proportion of the total area cleared in Australia each year. As part of the Harms et al., 2005 study the initial soil carbon measurements from the paired sites (average of 29.5 tC ha^{-1}) were compared to the pre-clearing soil carbon values used by the NCAS (average of 29.6 tC ha^{-1}).

Soil carbon under Cropland

As discussed in Skjemstad and Spouncer (2003) and Skjemstad et al., (2004), a distinction was made between model calibration sites and model validation sites. For model calibration sites, complete data for all aspects of the model was available. For validation sites, there was typically some missing data element, such as yield measurement, land management practice etc. Figures 7.A27 and 7.A28 are a selection of the model calibration and verification sites reported by Skjemstad and Spouncer (2003) and Skjemstad et al., (2004) for both continuous cropping and crop-pasture rotations. These sites covered a broad representation of climates, soils, crop types and management systems. The model testing applied initial measured estimates. Models were then run to test their ability to predict subsequent measured results.

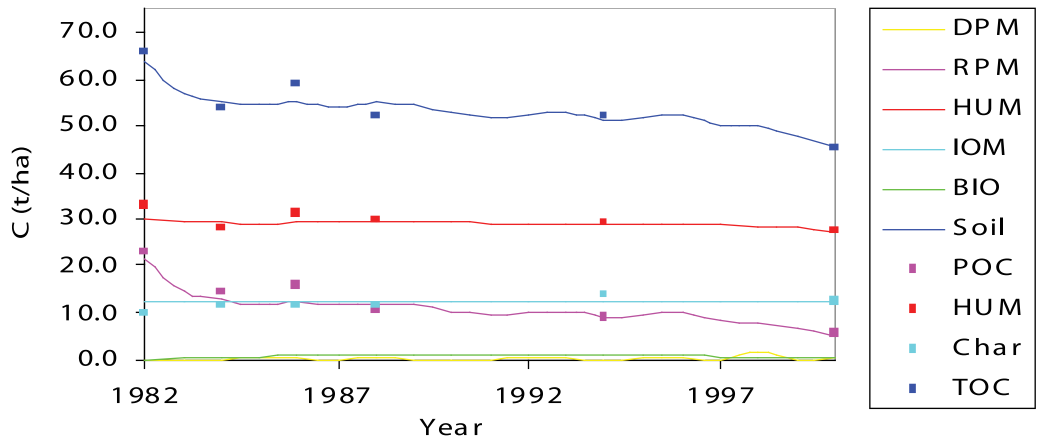
The extensive verification data collected during the model development also provides guidance on the general results to be expected under different cropping systems. In most southern Australian continuous cropping systems there is a loss of soil carbon which stabilises within 10 to 30 years (see Figure 7.A27). Conversely, the crop/pasture rotational systems typically yield a removal to the soil (Figure 7.A28).

In the north of Australia some continuous cropping systems frequently show increases in soil carbon with the introduction of irrigated crops particularly in areas of low rainfall (and low initial soil carbon stock) using management techniques such as green trash (mulch) blankets to retain soil moisture and build soil carbon.

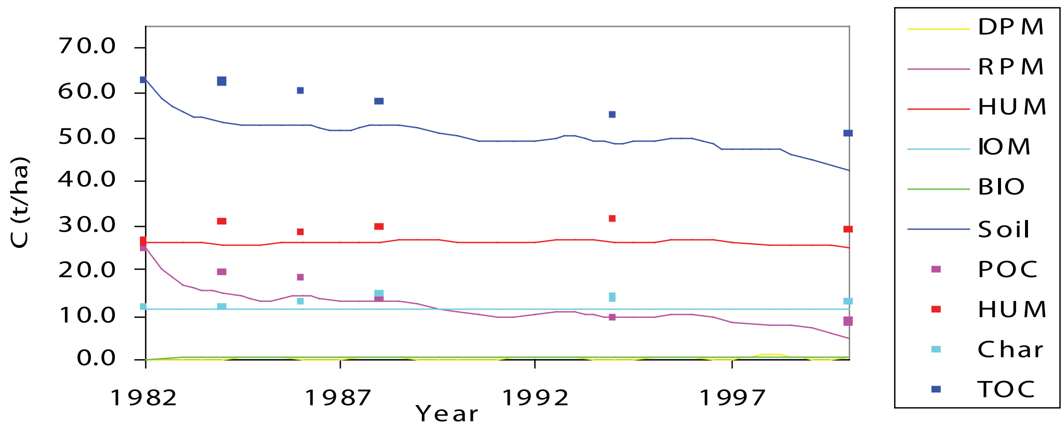
Figure 7.A27: (a)-(f) Changes in soil carbon (▪ measured and – modelled) under continuous cropping

(Key: DPM – decomposable plant material; RPM – resistant plant material; HUM – humic matter; IOM inert organic matter; BIO- biological matter; Soil – total soil carbon; POC – plant organic carbon; HUM – humic matter; Char – char; TOC – total organic carbon)

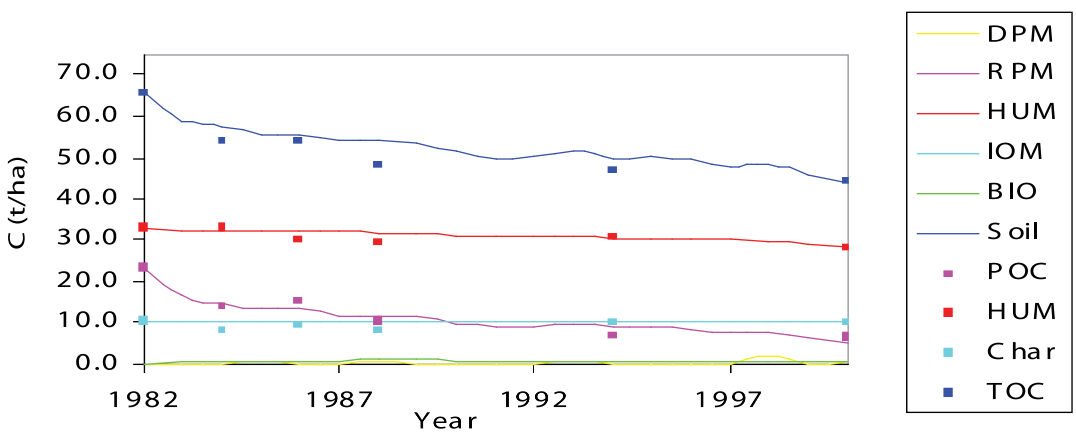
(a) Brigalow cropping (soil 64)



(b) Brigalow cropping (soil 65)

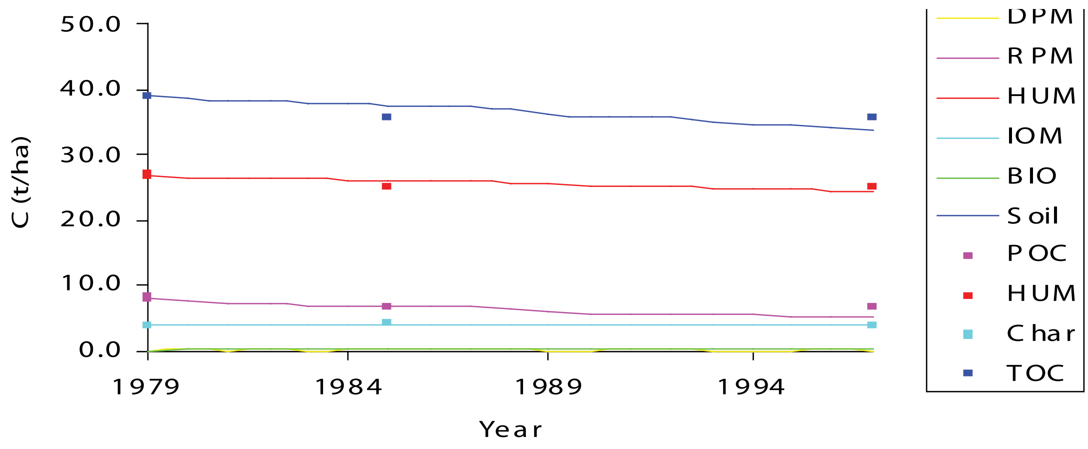


(c) Brigalow cropping (soil 66)

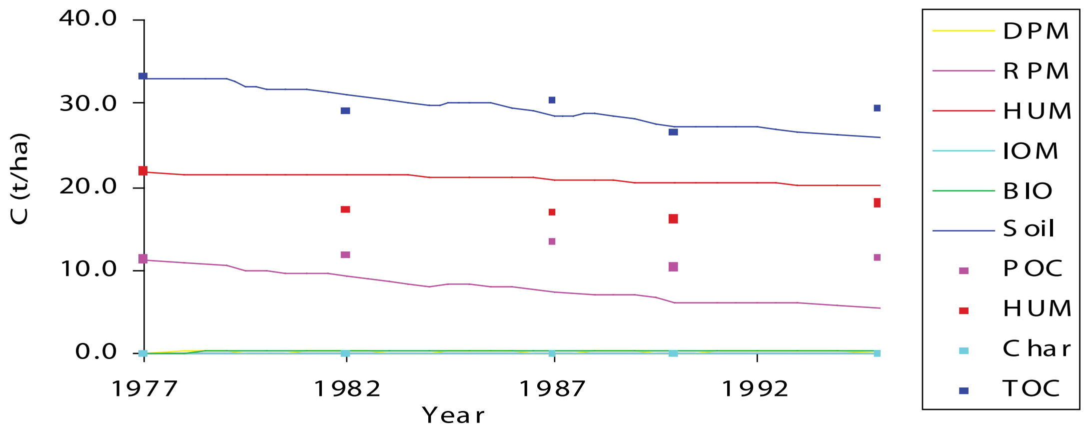


APPENDICES

(d) Tarlee continuous wheat



(e) Gibson continuous wheat



(f) Salmon gums continuous wheat

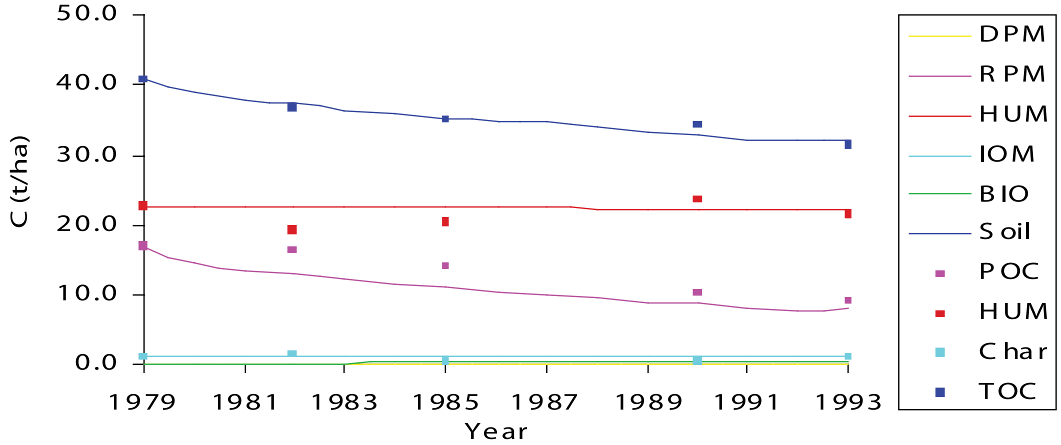
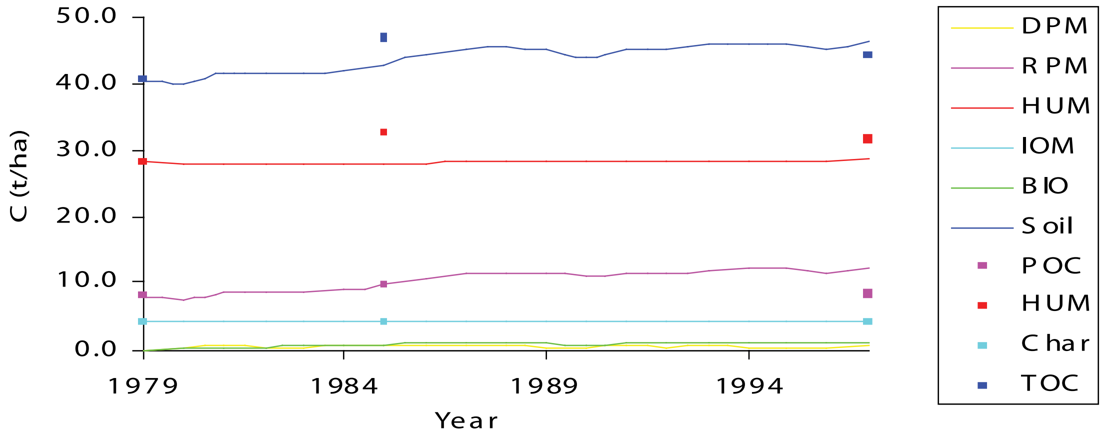


Figure 7.A28 shows changes in soil carbon under crop and pasture rotation systems. Unlike the continuous cropping systems shown in Figure 7.A27, the crop-pasture systems typically show an increase in soil carbon. The amount of increase will depend on the pattern of the rotations and the crop types used. In almost all systems there is an initial loss from land use change, but this loss moderates over time and is often replaced by a net uptake. Once the losses due to land use change have begun to stabilise, the predominant changes come from changed management, and from annual variability in crop production. Changes in crop production affect both living biomass, and subsequently, the flow-on to dead organic matter and soil carbon.

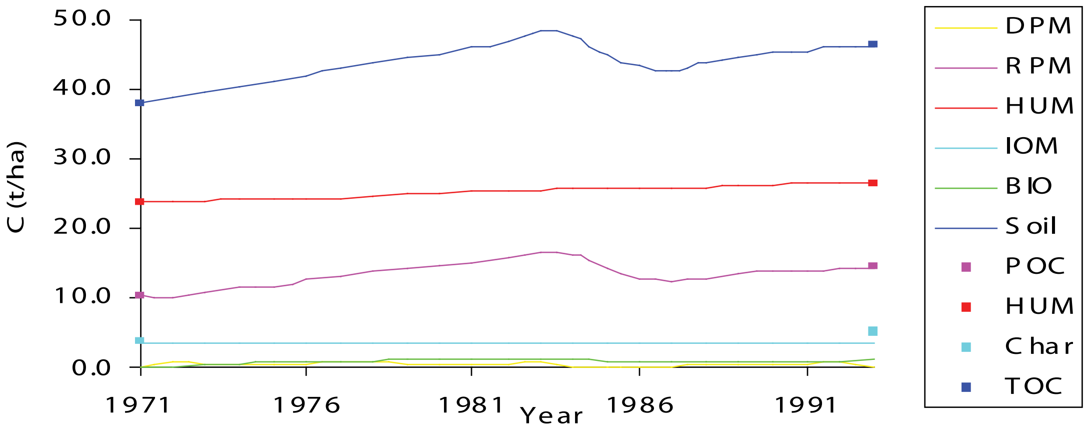
Figure 7.A28: (a)-(i) Changes in soil carbon (▪ measured and – modelled) under crop – pasture rotations

(Key: DPM – decomposable plant material; RPM – resistant plant material; HUM – humic matter; IOM inert organic matter; BIO- biological matter; Soil – total soil carbon; POC – plant organic carbon; HUM – humic matter; Char – char; TOC – total organic matter)

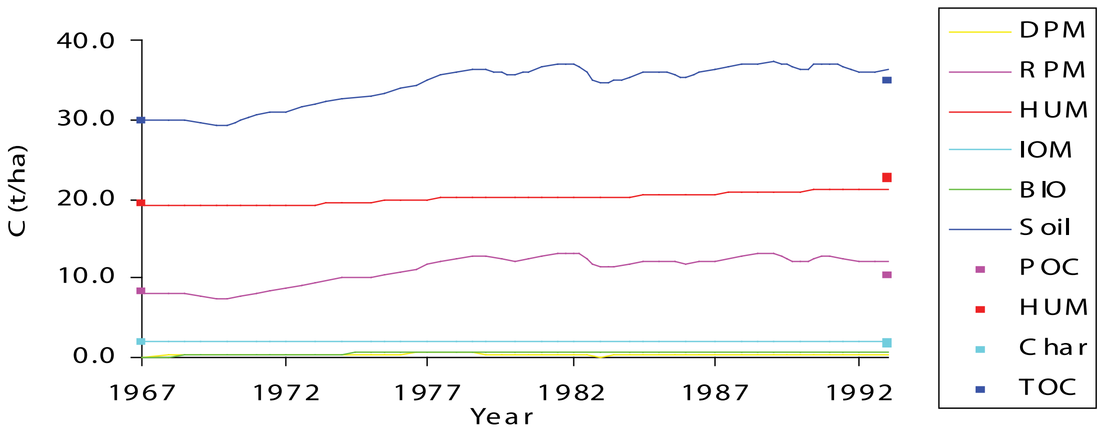
(a) Tarlee wheat / pasture



(b) Glenorchy wheat / pasture

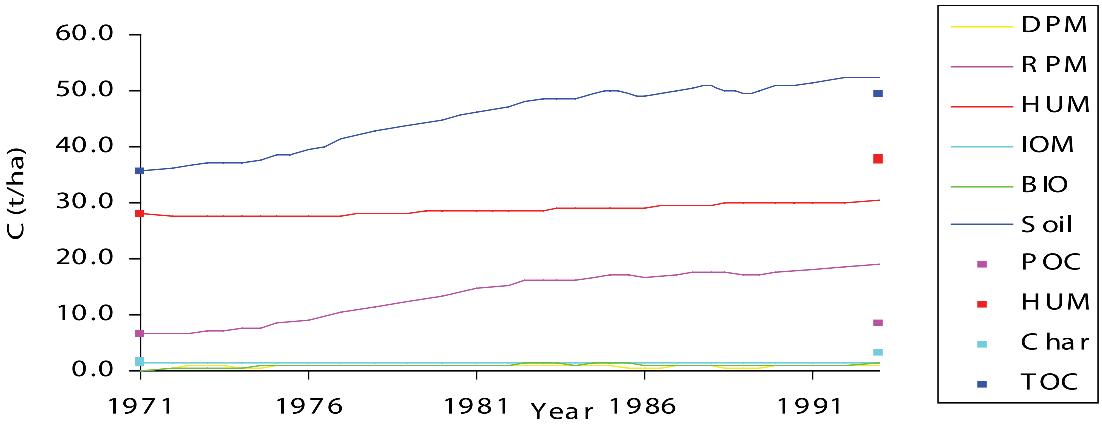


(c) Freeling barley / pasture

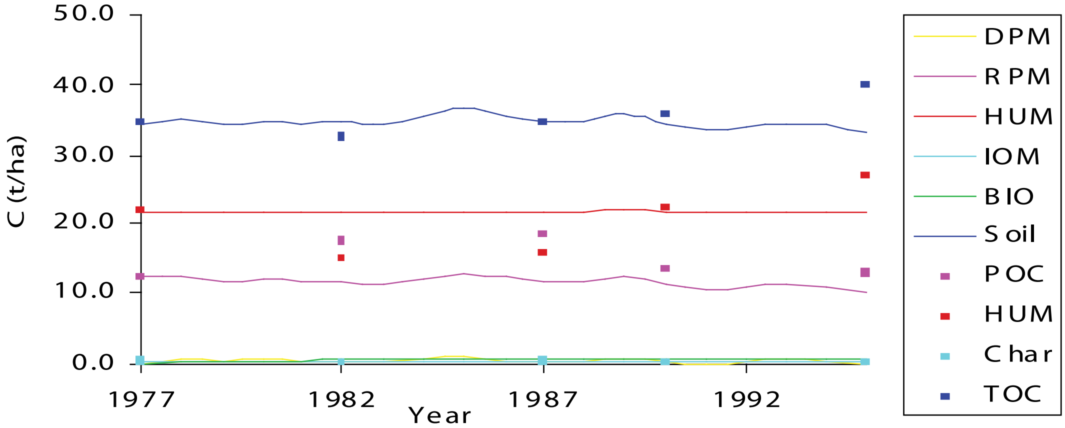


APPENDICES

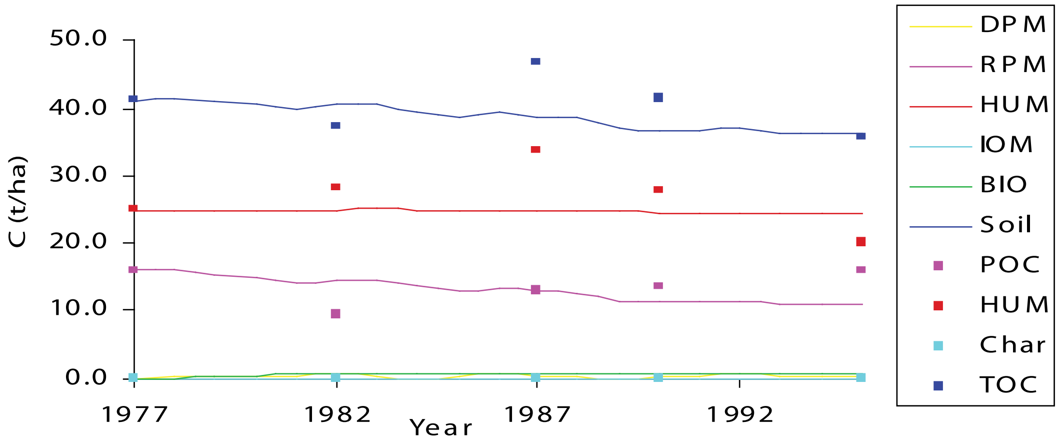
(d) Padthaway wheat / pasture



(e) Gibson pasture / wheat / lupins plot 16



(f) Gibson pasture / wheat / lupins plot 27



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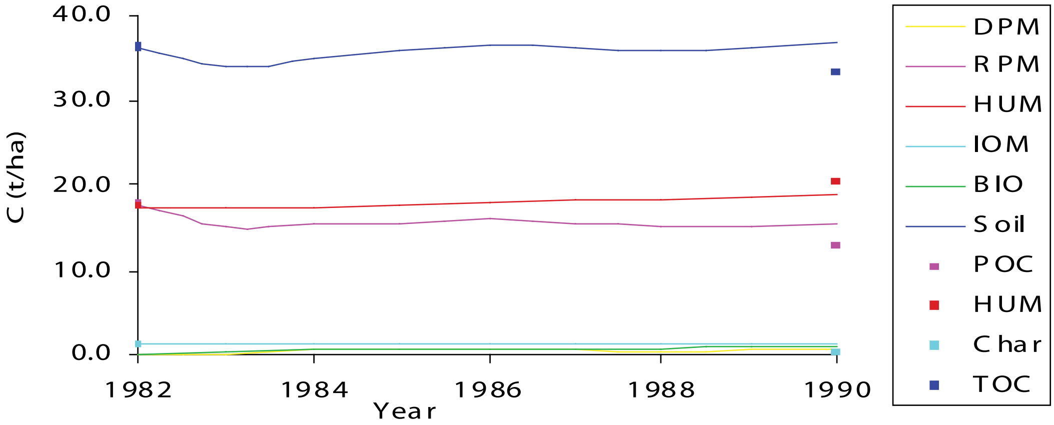
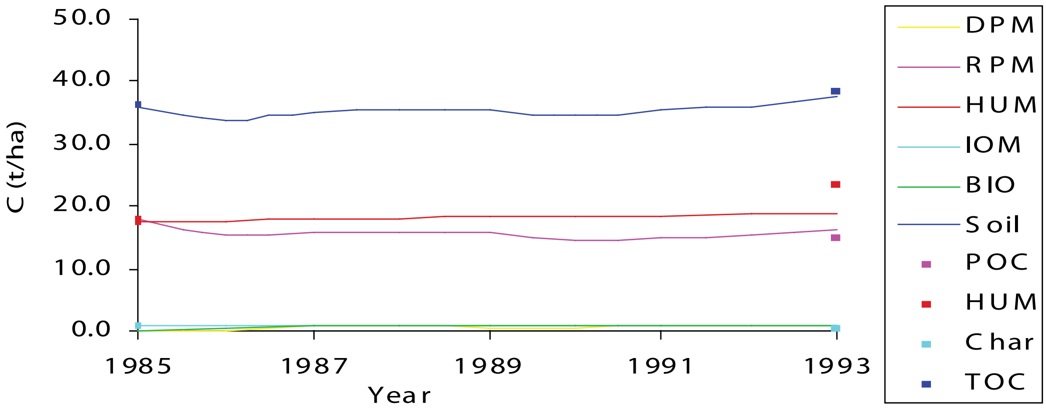
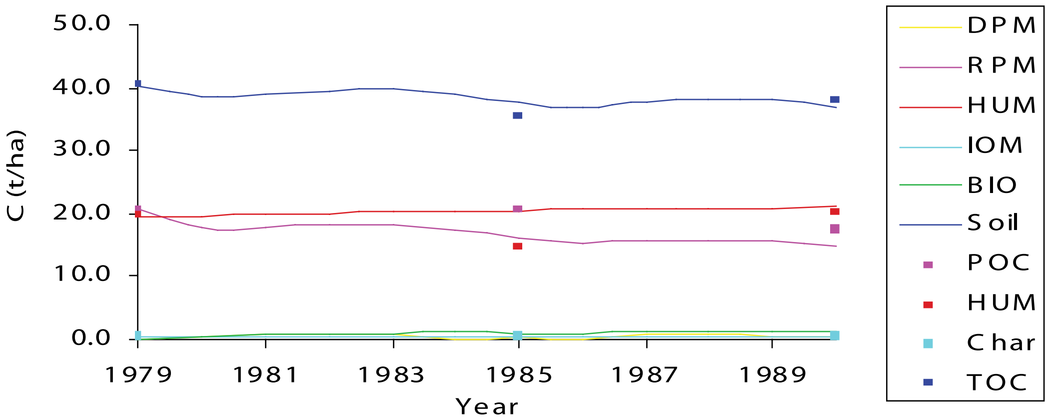
(g) Salmon gums wheat / 3 pasture



(h) Salmon gums wheat / 3 pasture



(i) Salmon gums 3 wheat / 3 pasture



Soil carbon under Grassland

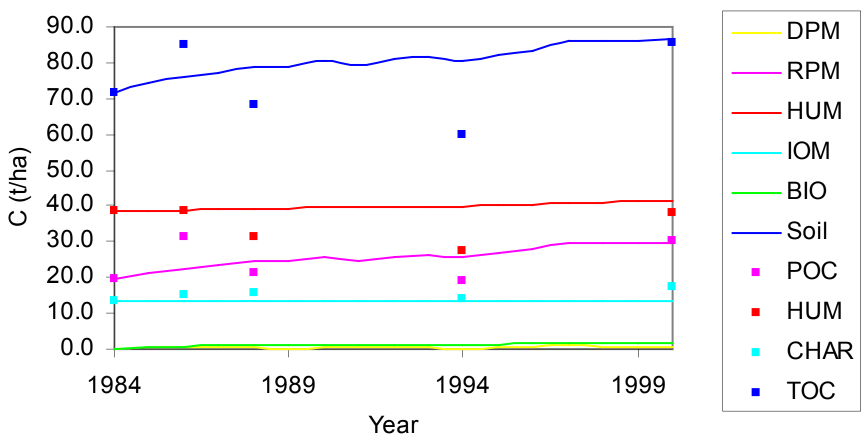
The Grassland category covers a much wider range of climates and soil types than Croplands. Figure 7.A29 is a selection of the model calibration and validation sites reported by Skjemstad and Spouncer (2003) and Skjemstad et al., (2004). These sites covered a broad representation of climates, soils, pasture types and management systems. The model testing applied initial measured estimates. Models were then run to test the ability to predict subsequent measured results.

As discussed in Skjemstad and Spouncer (2003) and Skjemstad et al., (2004), a distinction was made between model calibration sites and model validation sites. For the model calibration sites, complete data for all aspects of the model was available. For the validation sites, there was typically some missing data element, such as yield measurement or land management practice history.

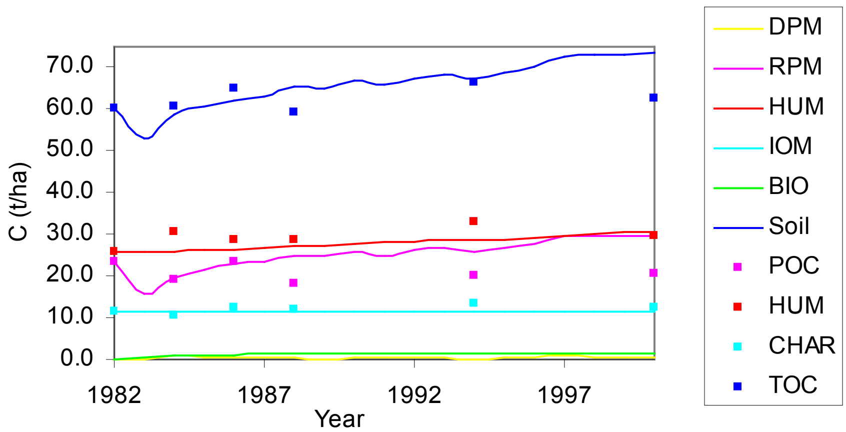
Figure 7.A29 (a)-(o) Changes in soil carbon (▪ measured and – modelled) under continuous pasture

(Key: DPM – decomposable plant material; RPM – resistant plant material; HUM – humic matter; IOM inert oganic matter; BIO- biological matter; Soil – total soil carbon; POC – plant organic carbon; HUM – humic matter; Char – char; TOC – total organic matter)

(a) Brigalow pasture (soil 67)



(b) Brigalow pasture (soil 68)



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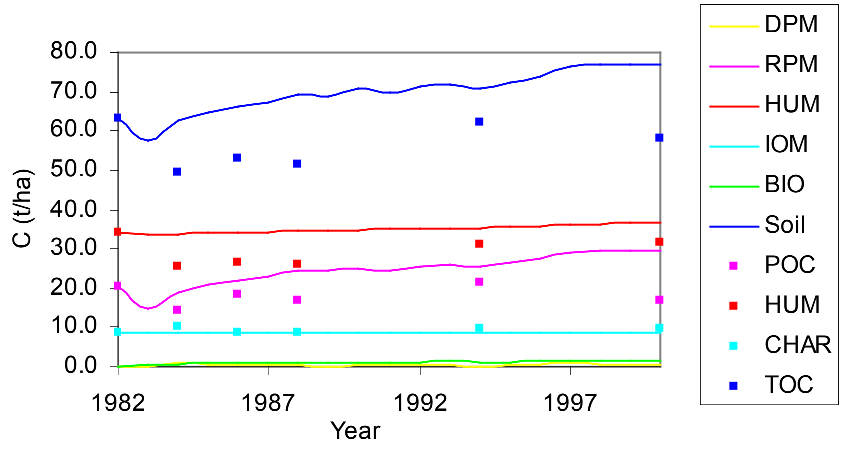
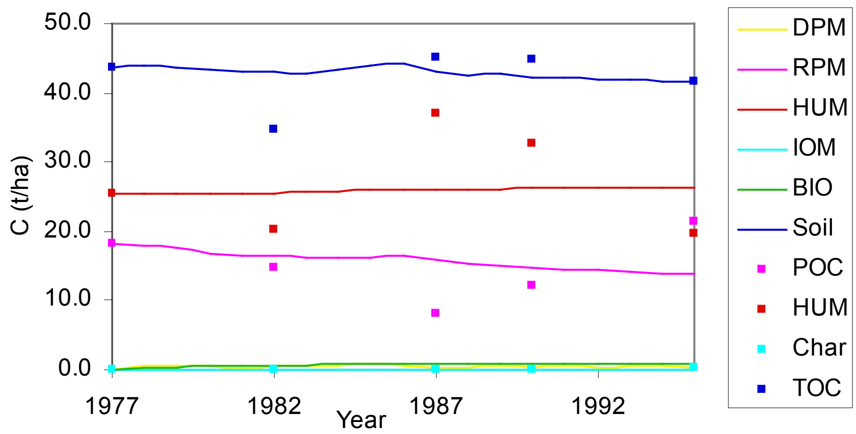
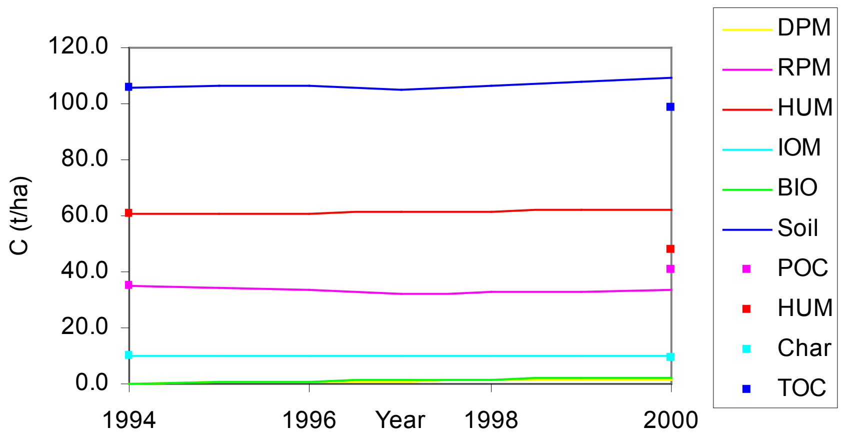
(c) Brigalow pasture (soil 69)



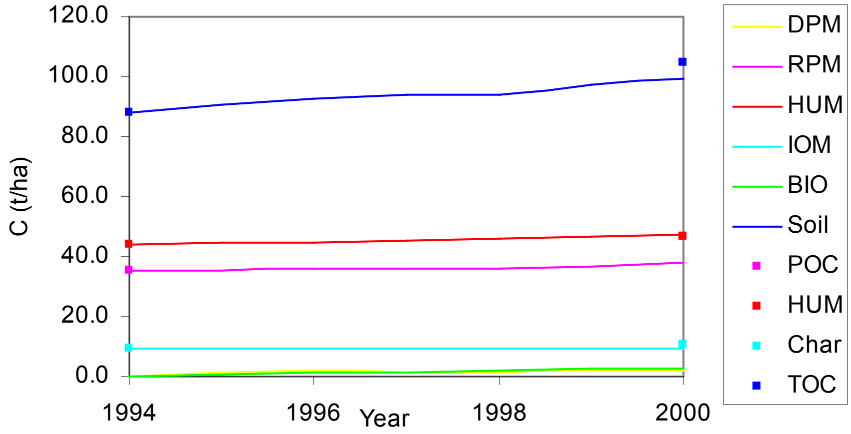
(d) Gibson continuous pasture



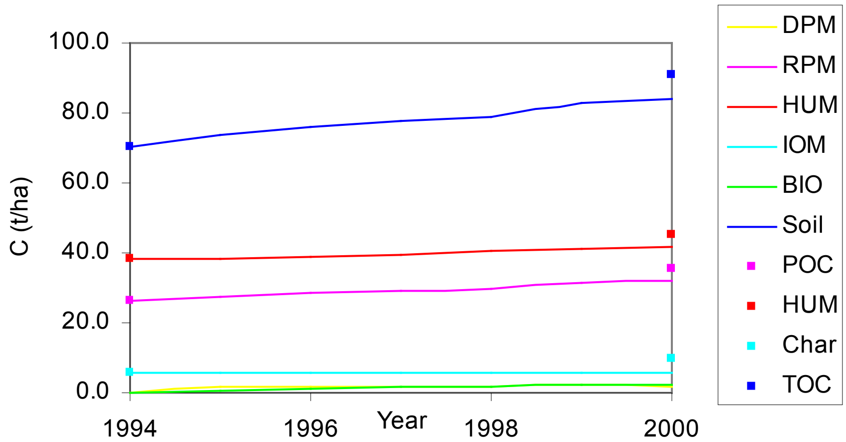
(e) Hamilton permanent pasture, Plot 10



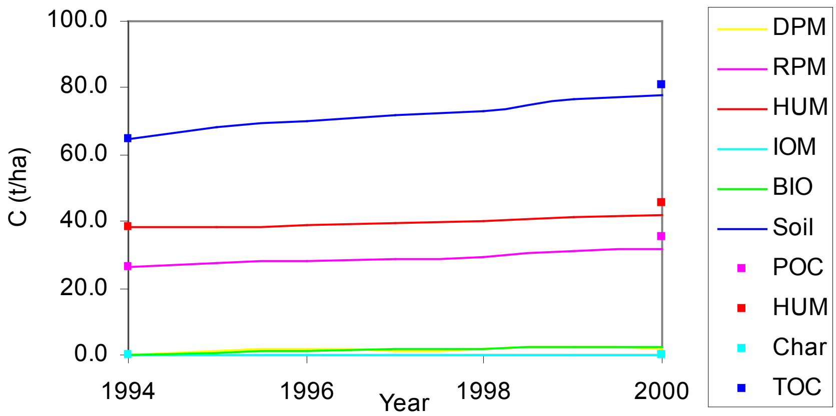
(f) Hamilton permanent pasture, Plot 11



(g) Hamilton permanent pasture, Plot 12



(h) Hamilton permanent pasture, Plot 12 (Char-C corrected)



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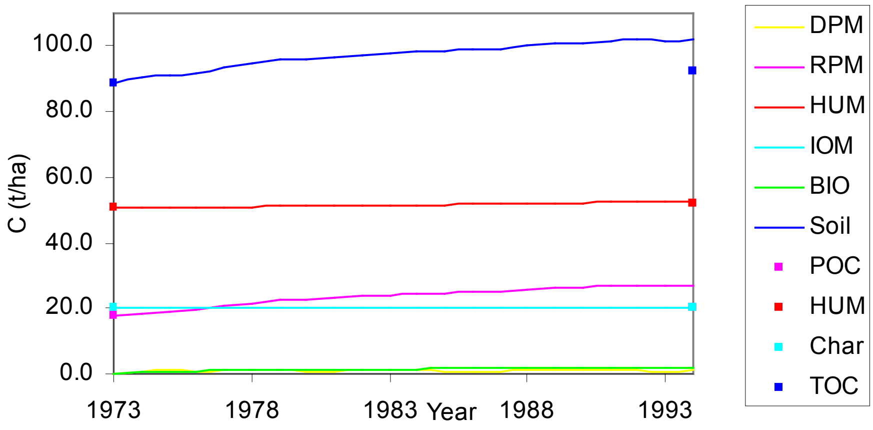
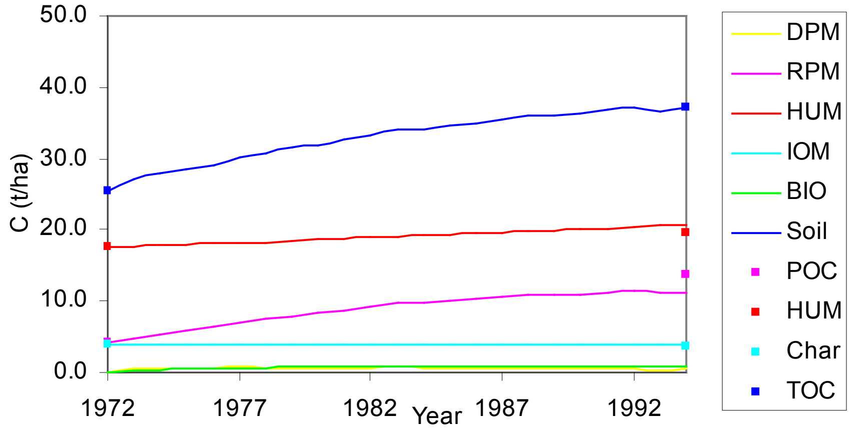
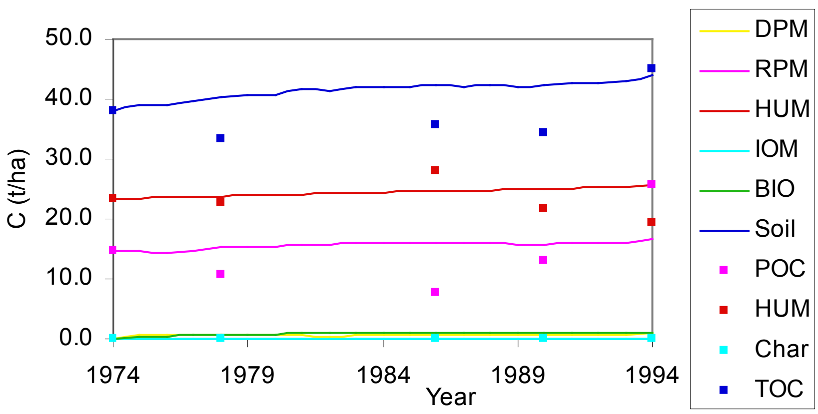
(i) Glencoe permanent pasture



(j) Victor Harbour permanent pasture wheat



(k) Newdegate continuous pasture



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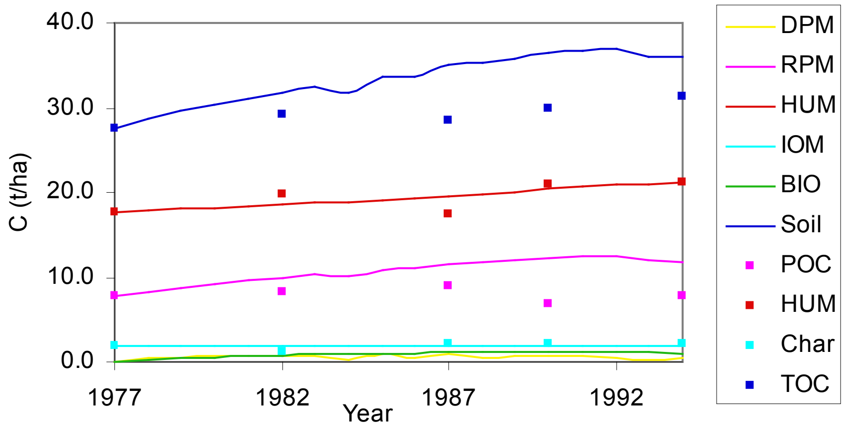
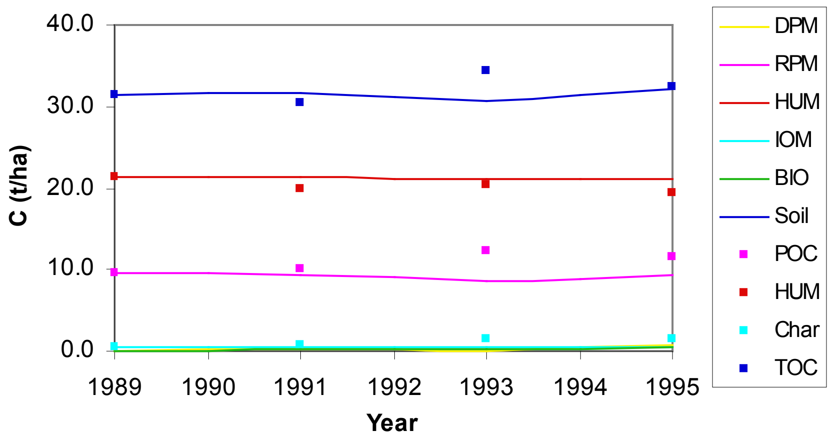
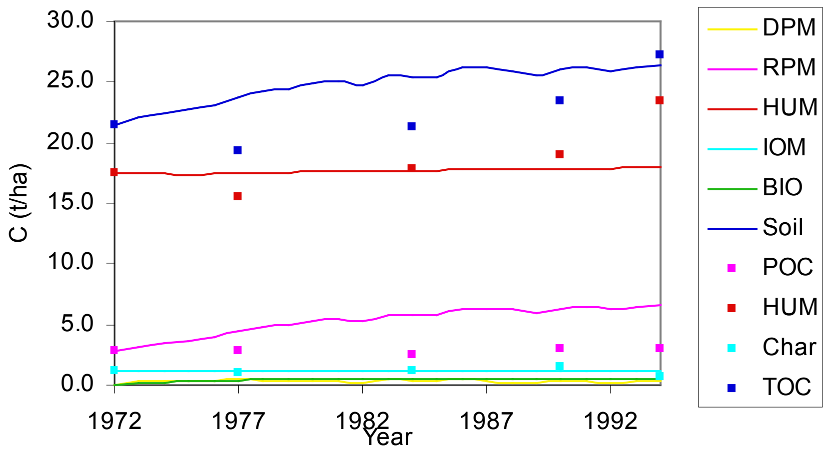
(l) Merredin (heavy) continuous pasture



(m) East Beverley continuous pasture



(n) Chapman continuous pasture



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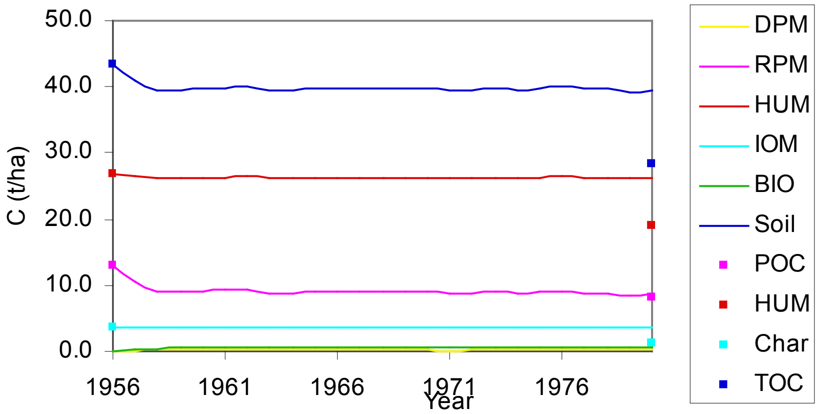
(o) Billa Billa pasture for 25 years



7.A5.4 Quality Assurance and Quality Control

The data for the development of soil type maps was extracted from the best available resource inventory information held by State and Territory Governments and was subject to expert review prior to being incorporated. The clay contents were also taken from these inventories and supplemented with available research data as part of the same process. Carbon contents were corrected to methodological standards where the initial method of measurement was known, otherwise the data was considered unusable and was not included in the final products.

The application of standardised field and laboratory protocols ensured that robust and consistent data was obtained from any sampling undertaken for the NCAS. Extensive field calibration and independent site verification were used to develop and confirm model performance. Use of the paired sites and long-term trial data over a wide range of systems meant that spatial applications were largely interpolations within well understood and field verified ranges.

Testing the ability of the models to predict change in other locations, based on these calibrations was independently verified. This was done through an independent measurement program. The verification program needed to measure fewer parameters (e.g., total soil carbon change rather than change in fractions) and therefore could be applied to more sites. Calibration data was drawn from a series of both forestry and agricultural research sites. Such sites were sparse, but were ideally suited to the model calibration task having well recorded, comprehensive and time-series consistent measurements of key model parameters.

Model verification used a mix of existing time-series data and new paired-site comparisons to test model predictions of change. The model calibration and verification results for agriculture can be found in Skjemstad and Spouncer (2002) and for forestry in Paul et al., (2002b) and Paul et al., (2003b).

7.A6 Data sources

An initial task in the implementation of the NCAS was to bring together all the available data, review its utility and synthesise data of various origins. Pre-existing national data, such as the vegetation groups of the National Vegetation Information System (NLWRA 2001) were used where available. Where such national compilations were not available (e.g., soil carbon content and clay content), national collation and synthesis of available inventory and research data was undertaken (Skjemstad et al., 2000; Webbnet Land Resource Services Pty. Ltd. 2002).

7.A6.1 Climate

Model sensitivity testing for the NCAS identified that interannual climate variability has a significant effect on both soil (Janik et al., 2002) and forest (Brack and Richards, 2002) carbon stock change. The use of long-term (temporal) average and regionally (spatial) averaged climate data was shown to be inadequate to support spatially and temporally disaggregated carbon modelling, frequently generating spurious results when tested. To provide spatially mapped monthly climate data over the modelled period, 1970-2007, the NCAS obtained weather station data from the Bureau of Meteorology for rainfall, minimum and maximum temperature, evaporation and solar radiation. Monthly climate surfaces (maps) for each attribute were derived using the ANUCLIM (McMahon et al., 1995) techniques.

Raw Data

Within the Bureau of Meteorology database there are approximately 1,200 weather stations recording temperature, 13,000 stations recording rainfall, 300 stations recording evaporation and 700 recording frost days. Precise location data were available for some 2,500 weather stations, providing a quality reference set of points from which to spatially interpolate climate surfaces. Version 2 of the 9 second (approximately 250 m) national digital elevation model (AUSLIG 2001) was used to provide terrain (elevation and aspect) mapping to support the spline functions used in the ANUCLIM software.

Derived Outputs

The weather station climate data is interpolated (modelled) using mathematical (multi-variate spline) functions that reflect influences on micro-climate such as elevation. Climate maps are derived at variable resolutions (grid sizes), again using the ANUCLIM software (see Kesteven et al., 2004). The list of outputs and their resolution is shown in Table 7.A3. Figures 7.A30 to 7.A33 illustrate national long-term annual average climate maps generated using the ANUCLIM software, noting that the NCAS methods apply the climate maps at the specific spatial and temporal resolutions as presented in Table 7.A3.

The surface interpolation from weather station data provides climate mapping which is both temporally (monthly) and spatially (at select resolution) relevant to the application of the *FullCAM* modelling.

Table 7.A3: List of climate maps developed for the NCAS

Climate Variable	Description
Rainfall	1 km resolution continentally, monthly 1968-2007
Temperature	1 km resolution min., max., and average continentally, monthly 1968-2007
Evaporation	1 km resolution continentally, monthly 1968-2007
Frost Days	1 km resolution continentally, monthly 1968-2007
Solar Radiation	1 km continentally, monthly direct and diffuse 1968-2007, 250 m resolution continentally, slope and aspect corrected diffuse and direct
NDVI	Normalised Difference Vegetation Index, Fortnightly 1992-2004
Long-term productivity	250 m resolution
Annual productivity	(sum of monthly) 1 km resolution (1970-2007)

Figure 7.A30: Long-term average rainfall

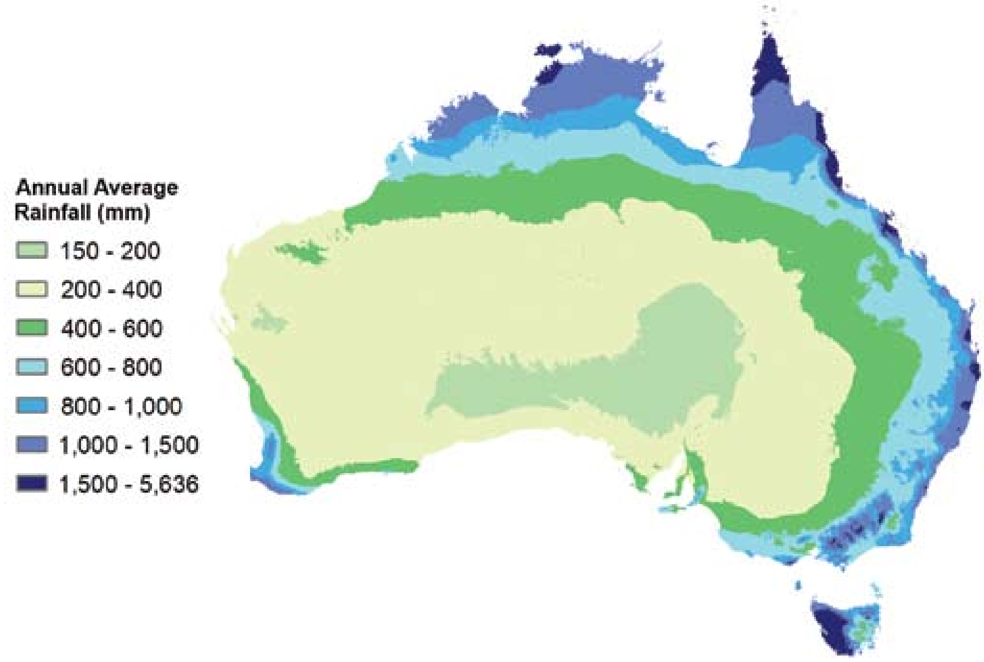


Figure 7.A31: Long-term average annual temperature

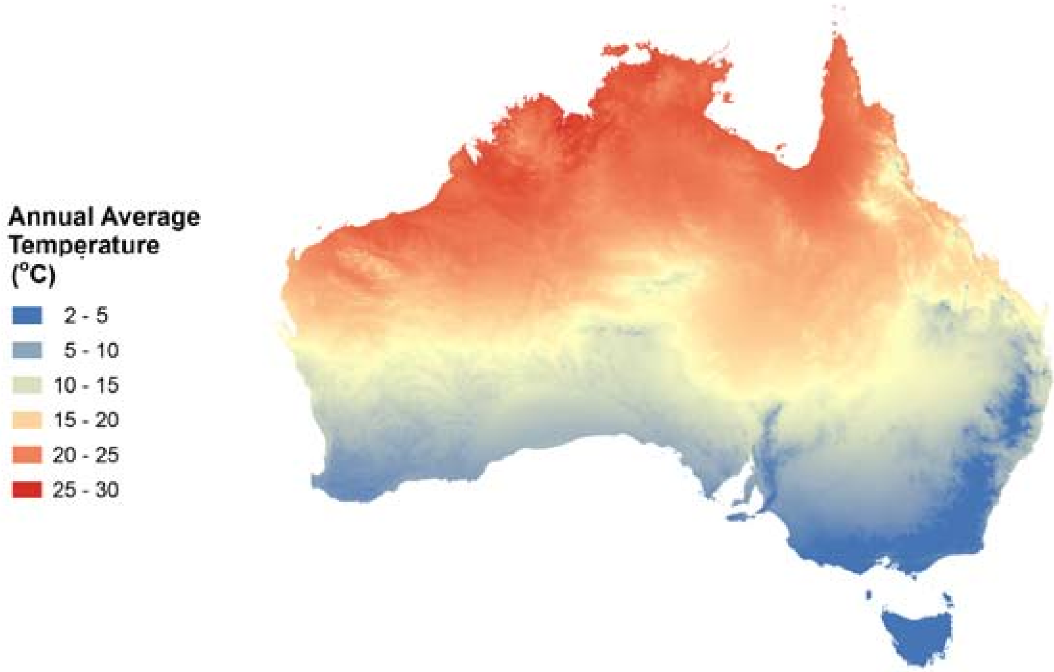


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Figure 7.A32: Long-term average annual evaporation

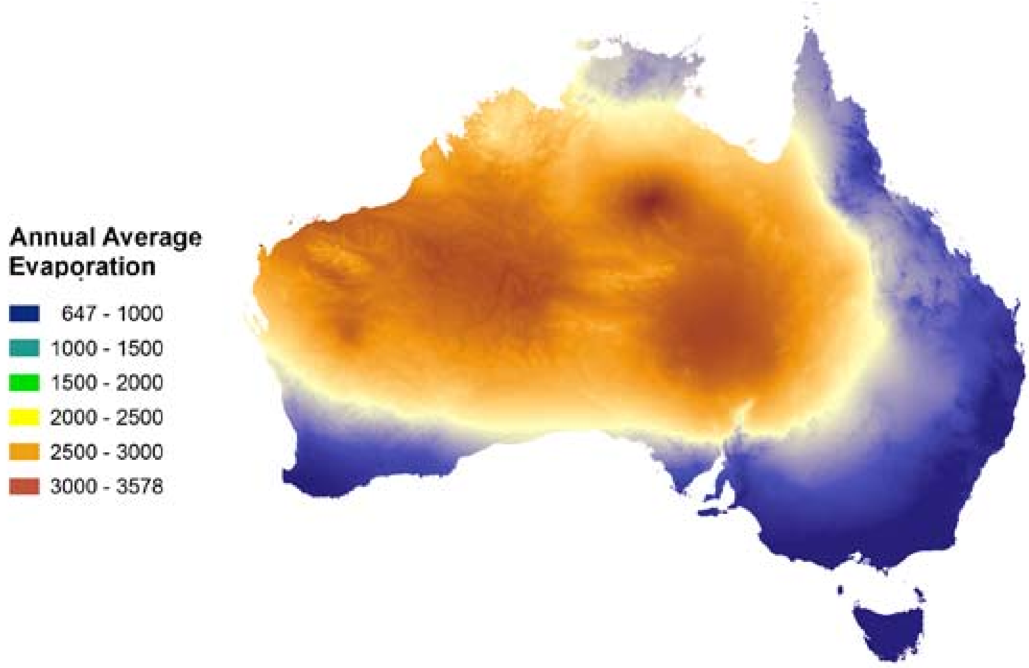
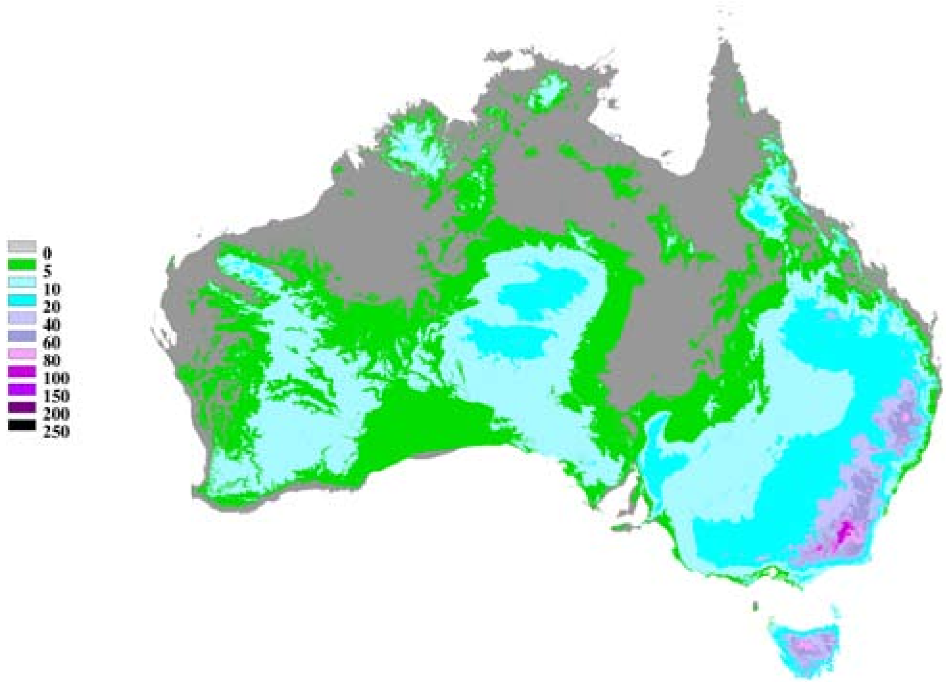


Figure 7.A33: Long-term average number of frost days per year



Quality Assurance and Quality Control

The climate surface modelling output includes variance statistics that can be used to assess the extent of difference between the modelled result and actual weather station data. The predictive capability of the climate map is tested against actual weather station data. The climate program, including all model results, was submitted for independent QA/QC to the Australian National University's Fenner School of Environment and Society (formerly the Centre for Resource and Environmental Studies). Detailed checking of procedures and output statistics led to the conclusion that the development of the models represented application of best practice and yielded robust results.

7.A6.2 Soils and other spatial data

Soils

As described in section 7.A5, several soil maps are required for use by the *Roth-C* model including soil type, carbon content (pre-disturbance) and clay content. Maps of these parameters were developed through a synthesis of resource inventory data, predominantly available from State Governments. Clay content was a consistent measure and relatively easily drawn into national synthesis. Soil type descriptions varied according to jurisdiction, but within the modelling framework these differences could be accommodated (Webbnet Land Resource Services Pty. Ltd. 2002). Considerable additional analytic work was required to achieve consistency in data on pre-disturbance soil carbon contents. This need was primarily derived from the differing analytic techniques used to assess carbon content in soil samples. To provide a common and consistent national map, archived samples of soil were reanalysed and correction factors to a *Leco* dry combustion standard were derived (Skjemstad et al., 2000). Fractionation schemes were also derived for partitioning soil carbon into the pool structures used in the soil carbon model.

To calculate the Forest Productivity Index, soil fertility and water holding capacity were obtained from the spatial map of Australian soils provided by CSIRO (McKenzie et al., 2000a).

Land Tenure

To separate out forestry activities from relevant land cover change events, a national tenure map is applied, masking out areas with a dedicated public forestry land use as well as National Parks. This tenure map is supplied by the National Forest Inventory (1997a) of the Bureau of Rural Sciences. Areas of deforestation associated with forest harvest on private land were separately identified by visual interpretation of the land cover change sequences. Masks are created to distinguish these events from those associated with forest conversion.

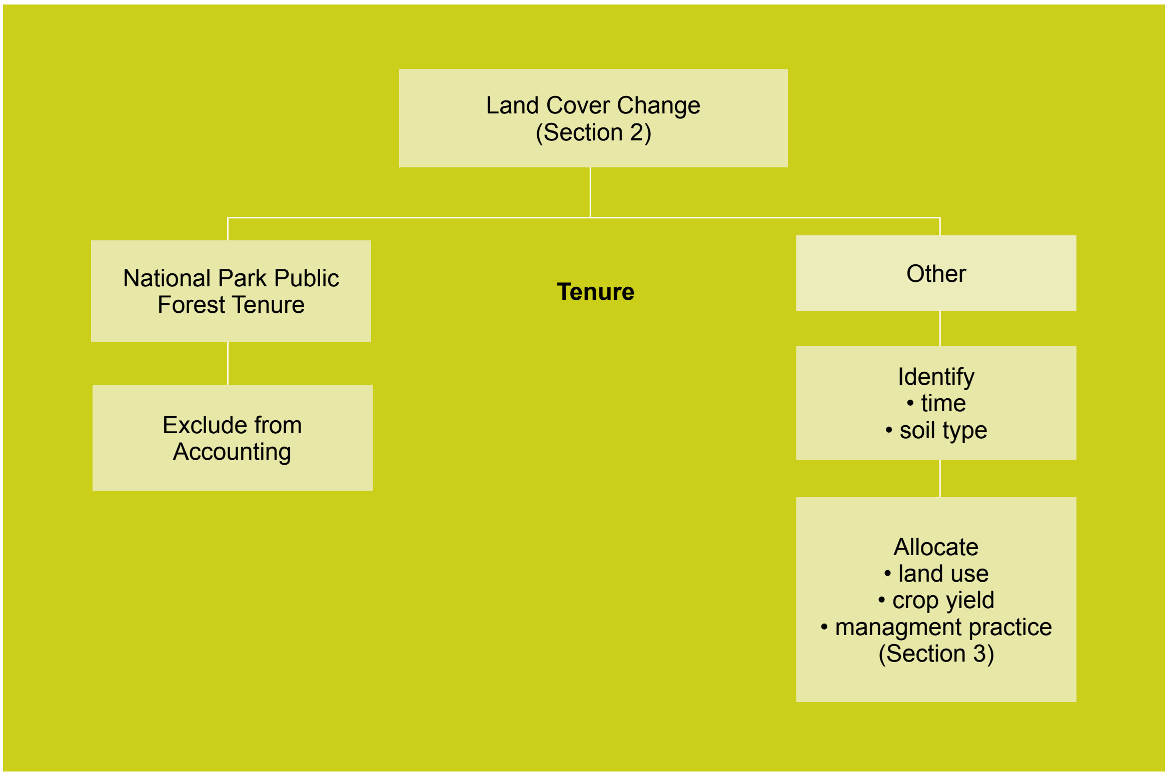
7.A6.3 Land Use and Management Data

Land management practices in both agriculture and forestry in Australia have varied considerably over time depending on species, region, desired products and site conditions. However there was no consistent, nationally available compilation of this information and separate programs to compile the required information were undertaken. While there was no overlap between the forest and agricultural management data programs, the methods used were similar. In both instances, a focus group was established comprising researchers and practitioners to give all management issues (e.g., forest and crop type, burning, harvesting and thinning) a jurisdictional (geographic) and temporal coverage. All available information was collated and supplemented with expert knowledge to give completeness where records were not available. The information gathered by these groups for use in the management databases is documented in Swift and Skjemstad (2002) and Squire and Raison (2008).

Land cover change has the obvious effect of removing existing tree biomass, resulting in the release of greenhouse gas emissions. The impact of the subsequent land use (e.g., crop or pasture type) and management practices (e.g., tillage, use of fire, grazing intensity) can also impact significantly upon ongoing emissions from that land. Depending on the land use (including forest regrowth) and management practices, the rate of change in carbon stock subsequent to land cover change will vary, and in some instances the direction of change (sink or source) will also be affected. Greenhouse gas emissions from land use and management practices are also affected by the soil type on which they are applied and the climate at, and subsequent to, their application.

The NCAS land cover change data allows each event (i.e., land use change) to be attributed a location and time. This information can be spatially overlayed on the soils map derived for the NCAS so that each event can be attributed to any other spatial data. From a management perspective, soil type is a major driver of land use practices. Data on management practices are therefore able to be linked to units of land that have undergone forest conversion via unique identifiers of soil type and time. Land use and management types are then apportioned within the soil type strata.

Figure 7.A34: Overview of the Land Use and Management Program



To obtain the agricultural land use and management information, the NCAS commissioned CSIRO Land and Water to collect relevant growth and management information via survey and literature searches for each Interim Biogeographic Regionalisation of Australia (IBRA) (Thackway and Cresswell 1995) region, based on soil type, crop type and crop regime (rotations), management type and time (Table 7.A4). This included time-based crop yield estimation for each identified land use and management type. The results of this study can be found in Swift and Skjemstad (2002), reported by IBRA regions (Figure 7.A35) as a primary stratification, with soil type used as a secondary strata. Initial data collection covered the period from 1970 to 2000. This dataset is updated annually by CSIRO Land and Water with data drawn from a variety of sources including statistical and industry holdings, crop growth modelling and expert opinion.

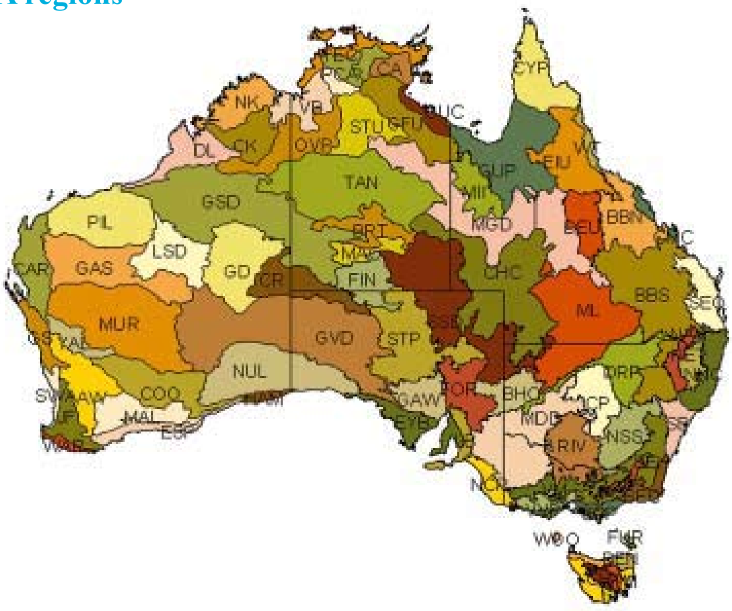
The information collected describes 141 grazing and cropping systems, with associated management practice data also held within the *FullCAM* model relational database. Allocation to a land use and management system is designated according to the relative frequency of land use and management for each soil type in each IBRA region in each year. For each of these systems the key management practices, such as the use of fire, when grazing is applied (months, intensity), ploughing and herbicide treatment are implemented in the model.

Table 7.A4: Example land use table

1	2	3	4	5	6	7	8	9	10
Soil type	% of cell	Land use	% of soil	Management practices	% of Land use	Phase	% of Managment practices	Yield t/ha	Residual
Clay	75	Developed pre-1970	45						
		Naturally clear at end of the time period	29						
		Uncleared forest at end of the time period	5						
		Developed for cropping	10	stubble burnt					
				- Summer	22	crop	80	1.6	
				- Autumn	5	pasture	20	4	
						long fallow	0		
				stubble retained	73	crop	80	1.6	
						cereal	20	4	
						long fallow	0		
		Irrigated cotton	0	trash burnt	0	crop		0	
						cereal		0	
				trash retained	0	crop		0	
						cereal		0	
		Dedicated for pasture	11		100		100	5	
Loam	25	Developed pre-1970	45						
		Naturally clear at end of the time period	0						
		Uncleared forest at end of the time period	23						
		Developed for cropping	15	stubble burnt					
				- Summer	22	crop	80	1.1	
				- Autumn	5	pasture	20	3	
						long fallow	0		
				stubble retained	73	crop	80	1.1	
						pasture	20	3	
						long fallow	0		
		Irrigated cotton	0	trash burnt	0	crop		0	
						cereal		0	
				trash retained	0	crop		0	
						cereal		0	
		Dedicated for pasture	17		100		100	4	
Sand	0								

Source: Swift and Skjemstad 2002

Figure 7.A35: IBRA regions



Code	Name	Code	Name
CH	Central Highlands	MII	Mount Isa Inlier
AA	Australian Alps	EYB	Eyre and Yorke Blocks
WT	Wet Tropics	SEQ	South Eastern Queensland
LB	Lofty Block	DEU	Desert Uplands
CA	Central Arnhem	BRT	Burt Plain
SB	Sydney Basin	FIN	Finke
GS	Geraldton Sandplains	FOR	Flinders and Olary Ranges
VM	Victorian Midlands	MAL	Mallee
JF	Jarrah Forest	CAR	Carnarvon
VB	Victoria Bonaparte	NSS	NSW SouthWestern Slopes
CK	Central Kimberley	RIV	Riverina
DL	Dampierland	SEH	South Eastern Highlands
NK	Northern Kimberley	STU	Sturt Plateau
CP	Cobar Peneplain	CYP	Cape York Peninsula
AW	Avon Wheatbelt	DRP	Darling Riverine Plains
CR	Central Ranges	BBN	Brigalow Belt North
GD	G bson Desert	LSD	Little Sandy Desert
ML	Mulga Lands	GFU	Gulf Fall and Uplands
WAR	Warren	OVP	Ord-Victoria Plains
WOO	Woolnorth	EIU	Einasleigh Uplands
HAM	Hampton	COO	Coolgardie
CMC	Central Mackay Coast	PIL	Pilbara
SWA	Swan Coastal Plain	GAS	Gascoyne
DAB	Daly Basin	STP	Stony Plains
SCP	South East Coastal Plain	GUP	Gulf Plains
WSW	West and South West	NUL	Nullarbor
GUC	Gulf Coastal	MDD	Murray-Darling Depression
VVP	Victorian Volcanic Plain	SSD	Simpson-Strzelecki Dunefields
NCP	Naracoorte Coastal Plain	CHC	Channel Country
NAN	Nandewar	MUR	Murchison
NET	New England Tableland	BBS	South Brigalow
SEC	South East Corner	TAN	Tanami
YAL	Yalgoo	MGD	Mitchell Grass Downs
MAC	MacDonnell Ranges	GSD	Great Sandy Desert
ESP	Esperance Plains	GVD	Great Victoria Desert
PCA	Pine-Creek Arnhem	DE	D'Entrecasteaux
TEC	Top End Coast	TM	Tasmanian Midlands
GAW	Gawler	BEN	Ben Lomond
BHC	Broken Hill Complex	FRE	Freycinet
NNC	NSW North Coast	FUR	Furneaux

Crop Yield

Crop yields are used in the model to determine several factors in the model calibration. In almost all instances where crop yields are used, their impact on carbon and nitrogen cycling is determined in concert with the management approach applied. The uses of the crop yield information include:

- determining plant biomass (crop or grass) at a point in time, via the use of 'harvest indices' that relate total plant biomass to the yield commodity of interest (e.g., grain);
- determining how much plant biomass is removed from the site as product;
- determining the amount of root slough as input to soil from plant growth coupled with management practices; and
- determining the post harvest/grazing residues burnt, decomposed on soil surface or incorporated into soil.

Data on crop yield and management practice are jointly collected because management practices will affect the crop yields as well as the fate of crop residues.

Quality Assurance and Quality Control

The land use and management information was subject to review at State-based workshops for verification. The information has also been published and is available via hardcopy (Swift and Skjemstad 2002) and website (http://www.greenhouse.gov.au/ncas/files/ publications.html). No concerns about the veracity of the information were identified as a result of either review or publication.

This data represents a composite of the best available information. Establishing a more detailed 'reference' sample for accuracy assessment over time was not feasible. A high degree of confidence can be placed in the data given the varied sources of information and direct regional knowledge of sub-contractors involved in collating the data. This confidence is furthered by the concurrence given during State-based workshops used for reviewing the data, thus providing a measure of QA through expert review. Publication of the results has also provided transparency and the opportunity for ongoing review.

7.A6.4 Other non-spatial data

Plant characteristics

Species and ecosystem characteristics required for modelling have been systematically collected and documented in the publicly available NCAS technical report series. These include:

- Wood density (Illic et al., 2000; Polglase et al., 2004);
- Carbon percentages of plant components (Gifford 2000a,b);
- Expansion factors and root: shoot ratios (Snowdon et al., 2000);
- Decay rates (Mackensen and Bauhus, 1999); and
- Spatial estimate of forest biomass (Raison et al., 2003; Ximines et al., 2005).

Coarse woody debris and litter

Coarse woody debris and forest floor litter is particularly difficult to estimate using measurement techniques because it is highly variable and dynamically related to forest productivity and disturbance history (particularly fire and harvest). Data was collected from available literature, but was sparse, particularly for forests without timber harvest. Supplementary data was collected during field sampling (Harms and Dalal 2002; Murphy et al., 2002; Griffin et al., 2002).

Estimates of coarse woody debris and litter are used to frame the initial model estimates to reflect typical species and management scenarios. *FullCAM* can then be run in from the initial estimates with inputs to the debris and litter pools based on turnover from live pools (based on the forest growth model) and the imposition of a known disturbance history (from the land cover change data). This allows the conversion of an uncertain historic initial estimate to a site and species specific estimate.

Given the complex and dynamic nature of this pool, it was concluded that verification could not rely on the measurement of inputs, transitions and losses due to disturbance. Instead, the mass balance cycling model approach was used to determine the quality of model calibration. If inappropriate or poorly calibrated parameters of inputs, transfer and losses were used, the mass balance model would, over a long period of time, predict clearly inappropriate pool size (too large or too small in this or surrounding pools). Estimates of coarse woody debris were made from literature and field studies to frame the initial model estimates that reflect typical conditions.

7.A7.A Quality Assurance and Control within the NCAS

Australia's National Carbon Accounting System (NCAS) uses Tier 3 methods (ecosystem model) of emissions estimation and an Approach 3 (full spatial enumeration) method of representing most land categories (IPCC 2003). Unlike the Tier 1 and Tier 2 methods, Tier 3 uses integrated ecosystem modelling combined with remotely sensed data on land cover change to estimate emissions in a way that fully represents both annual and spatial variability. Tier 3 methods do not use the emissions factors approaches of Tier 1 and Tier 2 inventory methods. Tier 1 and Tier 2 methods do not represent annual variability in emissions (except in activity data) with the same emissions factor being used over time, and encompass limited spatial variability.

Tier 3 and Approach 3 methods were chosen because the causes of most emissions in Australia (forest conversion) are from rare events (a small fraction of the forest estate). A simple and generalised emissions factor approach cannot, with confidence, reliably estimate emissions from rare events in a spatially and temporally variable overall 'population'. Further, climate is a significant driver of emissions in Australia and Tier 3 models allow these effects to be assessed. Tier 3 methods are more complex, and therefore require different and more intensive attention to quality control, quality assurance, sensitivity and uncertainty analysis, and verification. The checking of emissions estimates can still be facilitated by transparency and peer review.

Flowing from the change in approach from 'activity' data (typically either areas of land use or land use change) multiplied by 'emissions factors' as used for Tier 1 and Tier 2 is a need to reconsider how the cross-cutting issues are treated in Tier 3 inventories. As the methods no longer rely on emissions factors, basing an approach to the QA/QC issues on those used for emissions factors is not appropriate.

The following describes the way in QA/QC and related activities are addressed by the NCAS, in particular:

- Quality Assurance and Quality Control;
- Verification;
- Sensitivity and Uncertainty Testing; and
- Transparency and Peer Review.

Quality Assurance and Quality Control

The methods in this Appendix include a summary of the quality assurance activities undertaken in this full application of NCAS spatially explicit ecosystem model-based approach. Being a part of the complete and systematic NCAS approach the estimation is subject to the quality assurance processes embedded within each program area of the NCAS. Also, quality assurance benefits from the ability to benchmark activities against the detailed specifications, protocols, testing and verification procedures outlined in the NCAS technical report series. Periodic external review of program application is also carried out to ensure that the quality assurance programs meet current best practice in method and application.

Verification

The verification processes of the NCAS focus on the detailed checking of land areas and modelled emissions estimates. The testing of the NCAS results is typically against actual field/ground truth measures that have a 'certain' outcome. Extensive application of this approach provides benefits that cannot be derived from other approaches such as model inter-comparison. This is made possible by the quantum of resources available for NCAS development. Had fewer resources been available to the NCAS, an approach such as model inter-comparison would likely have been pursued as a verification approach.

The benefits of verification by direct measurement are, first, the detailed data derived can be used to determine the model and land area estimation performances in general (e.g., by region, soil type, vegetation type) and in detail, for example, by carbon pool (e.g., litter, fast turnover soil organic matter). Second, having actual measures allows for continuous improvement whereby the verification data can subsequently be used to enhance model calibration, which is then tested again in subsequent verification using further independent data. This ensures a growing base of data for model calibration while also ensuring that calibration and verification data remain independent.

Sensitivity and Uncertainty Testing

The methods of uncertainty analysis described by the IPCC Good Practice Guidance 2003 are typically designed for Tier 1 and Tier 2 emissions factor based approaches. More complex methods for dealing with potential error propagation and inter-correlation of parameter uncertainties needs to be applied to the process model forms of inventory used in Tier 3. However, the fundamental approach of using *Monte Carlo* forms of analysis for both sensitivity and uncertainty analysis remains relevant and has been applied.

The sensitivity and uncertainty analysis of the NCAS are used to determine:

- that the best estimate (most likely outcome) is not subject to bias;
- the parameter sensitivity, to understand the drivers of uncertainty and guide improvement programs and verification priorities; and
- the probability distribution of possible outcomes.

The sensitivity and uncertainty analyses undertaken for each reporting category are described in detail in each of the Appendices. To enable these analyses a *Monte Carlo* analysis capability has been integrated into the modelling framework and is routinely applied.

Uncertainty analyses using *Monte Carlo* techniques are also supplemented by the determination of accuracies of spatial data through verification programs. Verification can also be used to identify if there is any potential bias in the spatial inputs to the emissions modelling.

Transparency and Peer Review

As with the methods for uncertainty and sensitivity analysis, the approach to transparency and peer review will differ for a Tier 3 (spatially explicit) approach from those used in a Tier 1 or Tier 2 (area by emissions factor) approach. For Tier 1 and Tier 2 the focus is on the determination of area estimates and the selection of appropriate emissions factors. For the complex methods, models and large datasets used in Tier 3 model-based systems, different approaches to transparency and peer review are required. The basis of transparency and peer review for the NCAS are founded on:

- published specifications, protocols and methods;
- published verification results;
- public release of models, tools and data (see section 7.A9); and
- publication in peer reviewed literature.

7.A8 Planned Improvements

Development of the NCAS is ongoing, with new reporting capabilities being added as the methods are developed and quality assured. Since the 2006 inventory this development program has resulted in the inclusion of emissions estimates for the *Cropland remaining Cropland*, *Grassland remaining Grassland* and *Other Native Forest* categories.

Development of a comprehensive estimation capability for future reporting is ongoing and will be released once the national implementation has been fully calibrated, verified, quality assured and peer reviewed. This is consistent with the approach to inclusion of NCAS results in the national inventory only after all appropriate cross-cutting processes have been completed.

Remote sensing

The remote sensing programme is currently further developing methods to identify:

- areas of plantation established prior to 1988 using Landsat MSS data;
- areas subject to harvest in the *Harvested Native Forests*, and
- areas of sparse vegetation and change in sparse vegetation since 1988.

Modelling

The development of spatial modelling techniques for lands converted to *Forest land* and *Plantations* and *Harvested Native Forest* is also ongoing. Once completed, the full Tier 3 model will be applied to these subcategories. This will include the calibration and verification of the soil carbon model to estimate emissions and removals from soils in the *Forest lands* category.

The carbon cycling approaches used in the *FullCAM* model are similar to those implemented in the *Century* model (Parton et al., 1987). This has allowed *FullCAM* to be further developed to include nitrogen cycling, using the *Century* approach as a basis. Inclusion of nitrogen cycling serves two functions. The first is to constrain growth where there is insufficient nitrogen available to plants to support that growth. This is often important in Australian conditions (Dalal et al., 2002). The second is to estimate the amount of nitrogen volatilised, or lost to nitrification and denitrification. These estimates are of specific interest for modelling emissions of N_2O under differing management. The N-cycle component of *FullCAM* is currently in the final stage of development prior to final testing.

7.A8 Public tools and data availability

As part of the NCAS program a public release version of *FullCAM* combined with electronic copies of the technical report series and Landsat imagery (the DataViewer) has been made available. This provides a valuable resource to land managers while ensuring greater transparency for the NCAS.

The DataViewer contains five of the sixteen national composite Landsat satellite sensor images (1972, 1980, 1989, 2000, 2004) obtained and registered by the NCAS; continental maps of long-term average rainfall; minimum, average and maximum temperatures; evaporation; and number of frost days. Recent improvements in image compression technology allowed all of this data to fit onto a single DVD. The associated program allows users to locate and zoom into any area of Australia and compare images to help determine changes in land use from 1972-2004. All of these images can be easily imported into more complex GIS systems.

Although a useful tool, the image compression used in the DataViewer does lead to some reduction in visual quality. The archive of Landsat data has been made publicly available through Geoscience Australia (www.ga.gov.au) for the cost of data transfer.

The National Carbon Accounting Toolbox (NCAT) contains a public release version of *FullCAM* and all of the NCAS Technical Reports which outline how and why the system was established, the data used in the development of the system and the results of continental simulations. The public release version does not contain nitrogen cycle modelling capabilities or other model aspects currently under development or restricted to research use.

As part of the NCAT development, *FullCAM* was fitted with a Databuilder function. A single *FullCAM* plot file typically requires over 1,500 inputs, including monthly climate records and species and management information making it difficult and time consuming to develop a single model. The Databuilder function simplifies this process by downloading all the required data for a point from a webserver that contains all the climate, species and management data as used in NCAS continental simulations. Users simply select the type of system they wish to model (forest only, agriculture only or transitions between the two), enter a latitude and longitude (obtainable from the Dataviewer) and click a button to download the spatial data. The model then accesses the webserver and obtains the required climate and site information for the specific location from either 250 m or 1 km grids depending on the data type. Users then further decide what species and management actions they wish to model and further download the required parameters from the server. Hence users can quickly build a *FullCAM* plot using the best available data at the national level. These models can then be saved, shared with other users and run at any time without a web connection. As the full model is provided, advanced users can also adjust any parameter in the model to better fit their exact circumstances.

All the data and models are publicly available via the internet and they form the basis of many scientific and commercial programs – more than 10,000 copies of the model and supporting documentation (user manual, technical publications and functional specifications) have been distributed. The wide distribution and accessibility of the data and model means that there is an informal 'test' community numbering in the thousands, a share of which represent well developed scientific and commercial interests. Therefore, for any one specific pixel or group of pixels in Australia, anyone could model the changes as would be represented in the national model by testing them against field measurements.

Attachment A1:The *FullCAM* Model

Naming Conventions

Abbreviations used in names

Actv	Active soil carbon
Avg	Average B Microbes (dead) (see P, Micr)
Bkdn	Breakdown C Carbon Material whose every atom has six protons
C	Coarse (see Dcy, Root)
Cel	Cellulose (see Lig, Sol)
CM	Carbon mass of material Mass of carbon atoms in the material
Conp	Consumption (of fodder by animals,which emits methane)
Cons	Construction wood
Dcmp	Decomposition
De	Decomposable (see Re)
Debr	Debris
Dec	Decrease (due to)
Decomp	Decomposable
Dcy	Decay (sloughed off root), either CDcy (coarse decay) or FDcy (fine decay)
Dwd	Deadwood
Eff	Assimilation efficiency of microbes
Evap	Evaporation
F	Fine (see Dcy, Root)
Fibr	Fibreboard
Fodd	Fodder (inside animal stomachs)
Foli	Foliage Leaves and twigs of tree
Frac	Fraction of a specified part of a whole (a number from 0 to 1, inclusive)
Furn	Furniture

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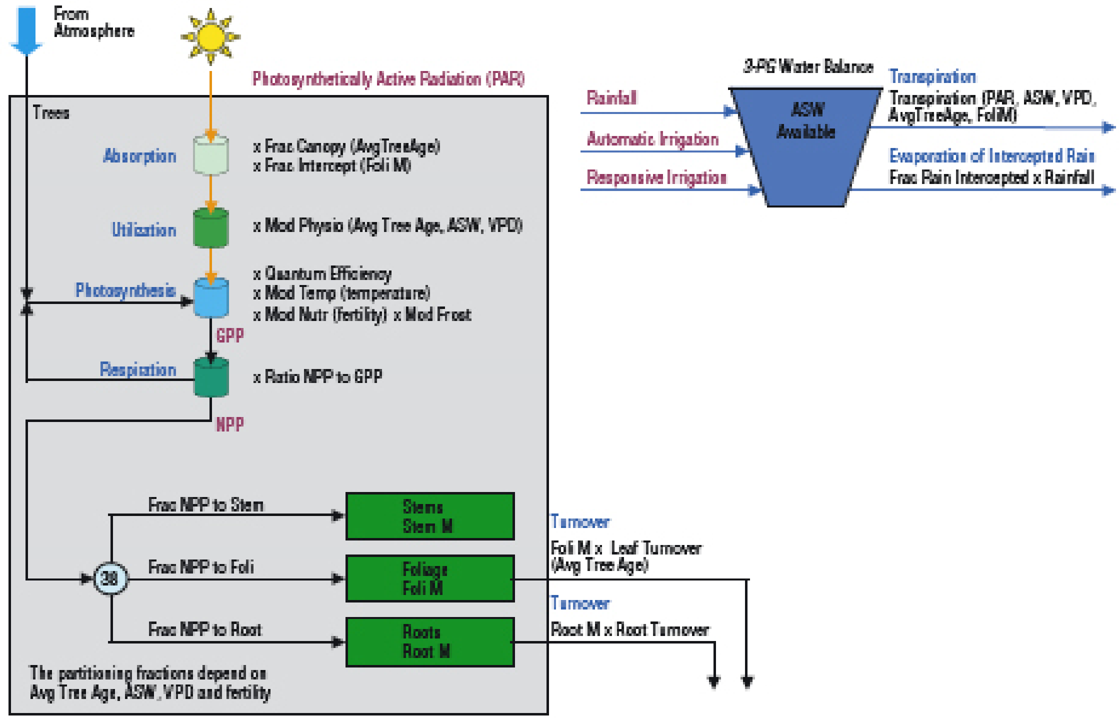
Grth	Growth (of trees or crops)
Humf	Humification Inc = Increase (due to)
Inrt	Inert soil carbon
Lig	Lignin (see Cel, Sol)
Lit	Litter, either LLit (leaf litter) or BLit (bark litter)
M	Mass (dry weight)
Micr	Microbes (live) (see B, P)
Mod	Modifier
N, Nitro	Available) nitrogen
NCRatio	Ratio of nitrogen mass to carbon mass
NM	Nitrogen Mass
Nutr	Nutrition
P	Plant matter (dead) (see B, Micr)
Pack	Packing wood
Papr	Pulp and paper
PB	Plant matter and microbial matter
Rel	Relative
Resi	Residue (from wood product mill)
Root	Root, either CRoot (coarse root) or FRoot (fine root)
RotAge	Rotation age (years since trees were planted)
Sol	Soluble litter (see Cel, Lig)
Tbl	Table
Temp	Temperature
Turn	Turnover
Wall	Microbe cell wall

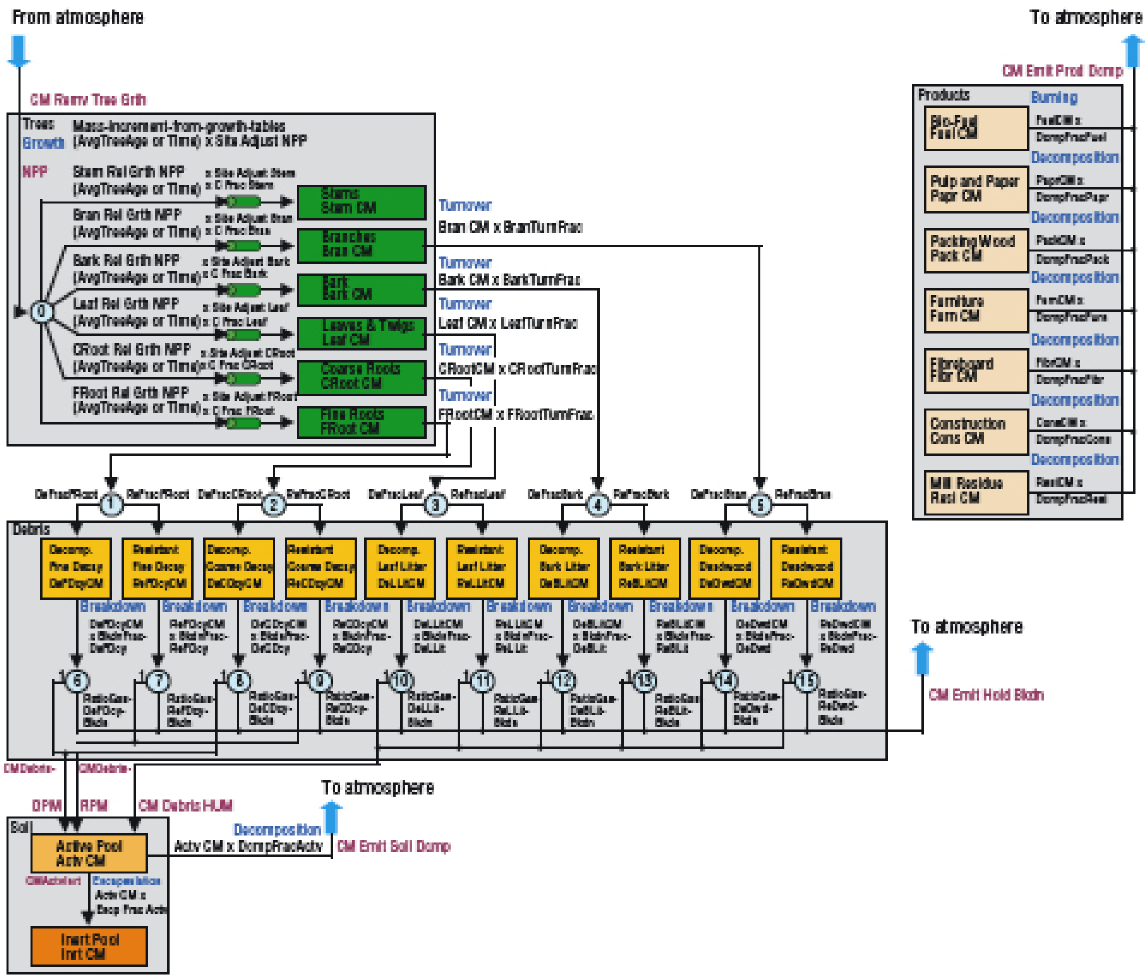
Abbreviated Quantities

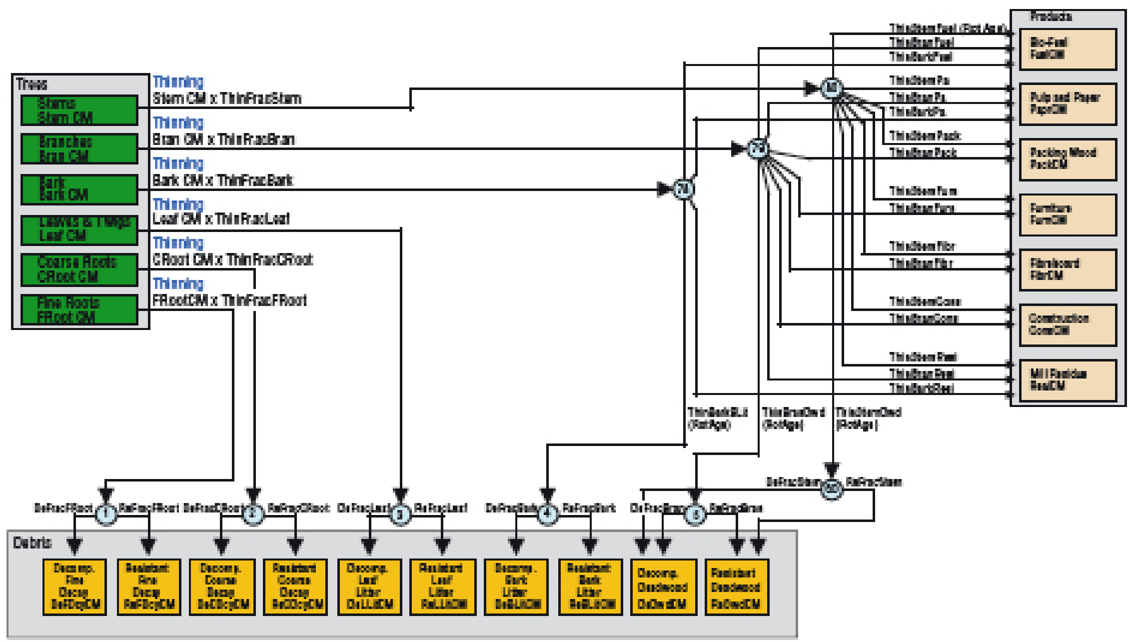
ASW	Available soil water (in mm of rainfall or irrigation) (*3-PG* only)
BIO	Microbial biomass = Fast and slow decomposing biomass combined (BIO-F + BIO-S) (Roth-C only)
BIOF	BIO-F Fast decomposing biomass (Roth-C only)
BIOS	BIO-S Slow decomposing biomass (Roth-C only)
CO2	Carbon dioxide
DPM	Decomposable plant material (Roth-C only)
GBF	Grain, buds, and fruit
GBFP	Grain, bud, and fruit products
GPP	Gross Primary Production = Overall production of tree or crop biomass in tonnes of carbon
HSS	Hay, straw, and silage
HUM	Humified organic matter (Roth-C only)
NPP	Net Primary Productivity = GPP – carbon lost in respiration
PAR	Photosynthetically Active Radiation (*3-PG* only)
RPM	Resistant plant material (resistant to decomposition) (Roth-C only)
TSMD	Topsoil moisture deficit
VPD	Vapor Presure Deficit (in kPa) (*3-PG* only)
XXX	DPM, RPM, BIO-F or BIO-S (all active soil carbon categories except HUM)

The *3-PG* Model



The *CAMFor* Model (a) Thinning





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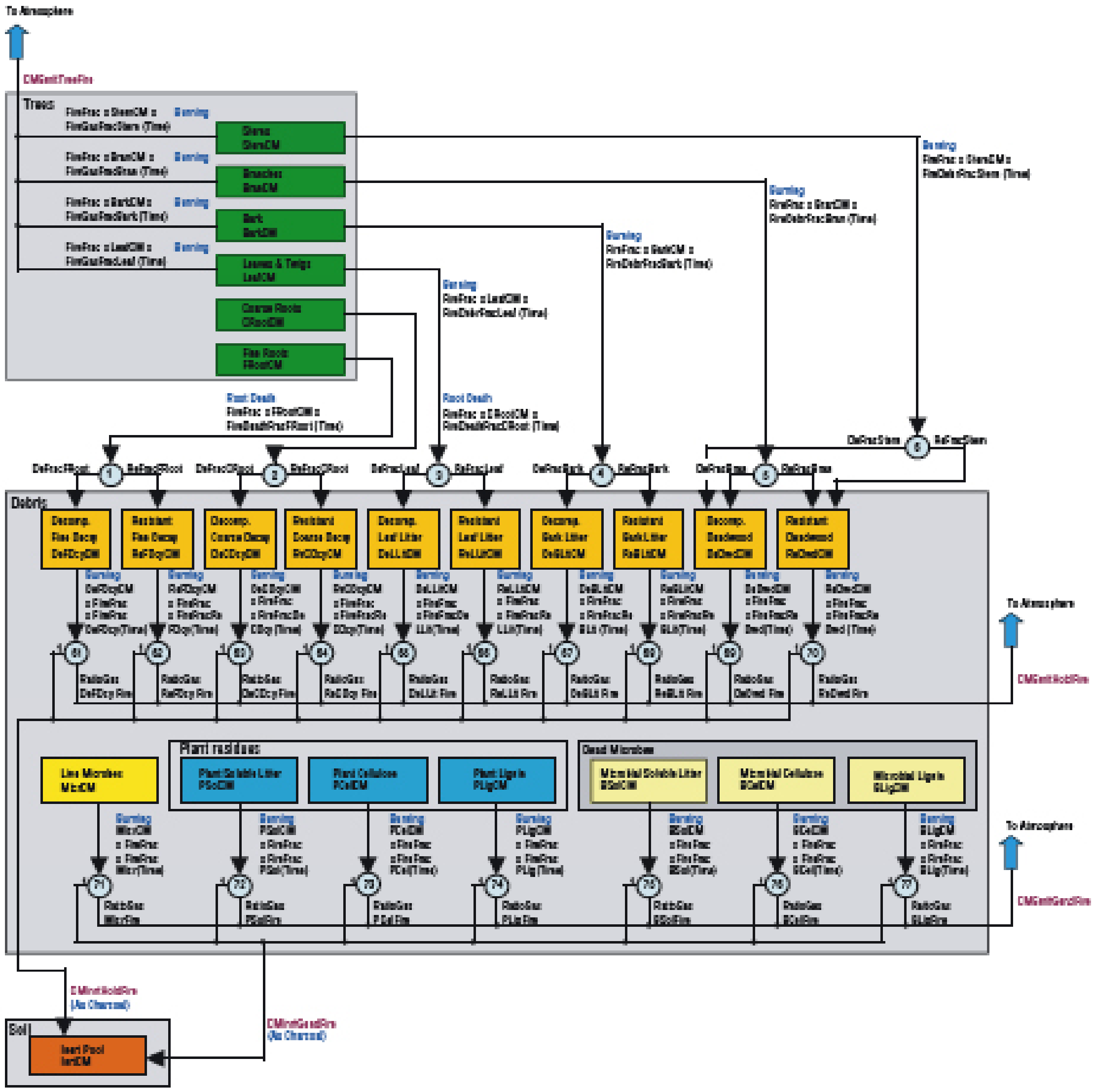
The *CAMFor* Model (b) Fire



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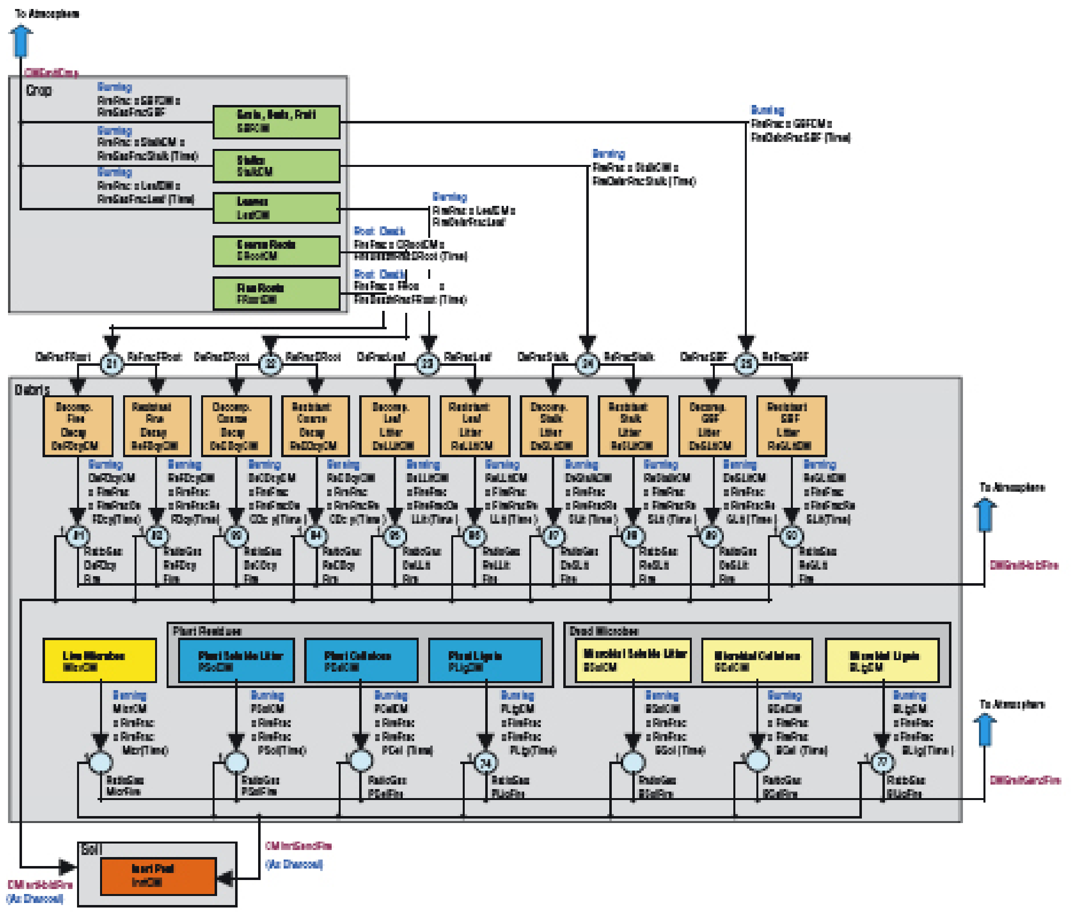
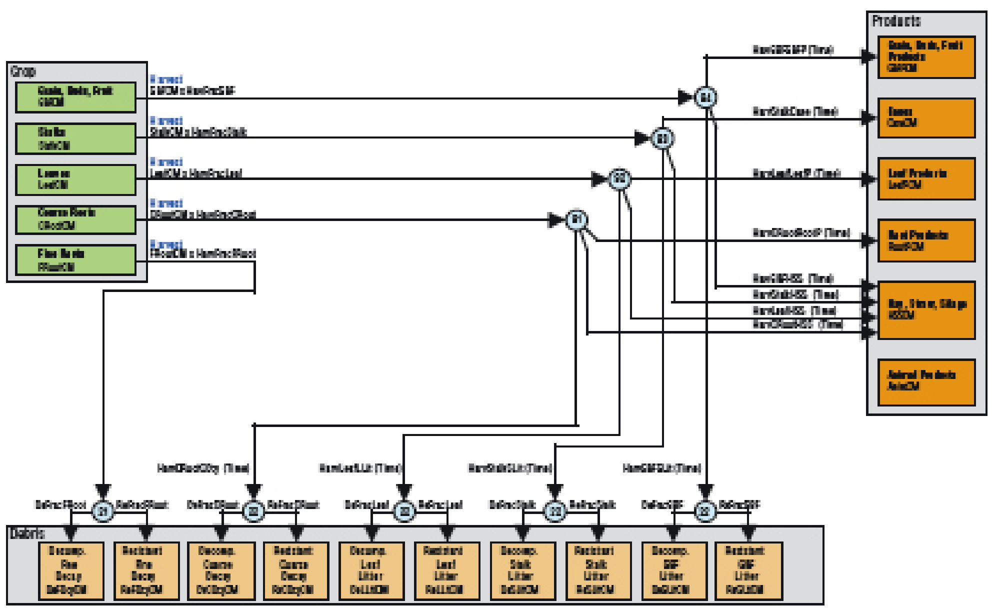
The *CAMAg* Model



The *CAMAg* Model (a) Fire



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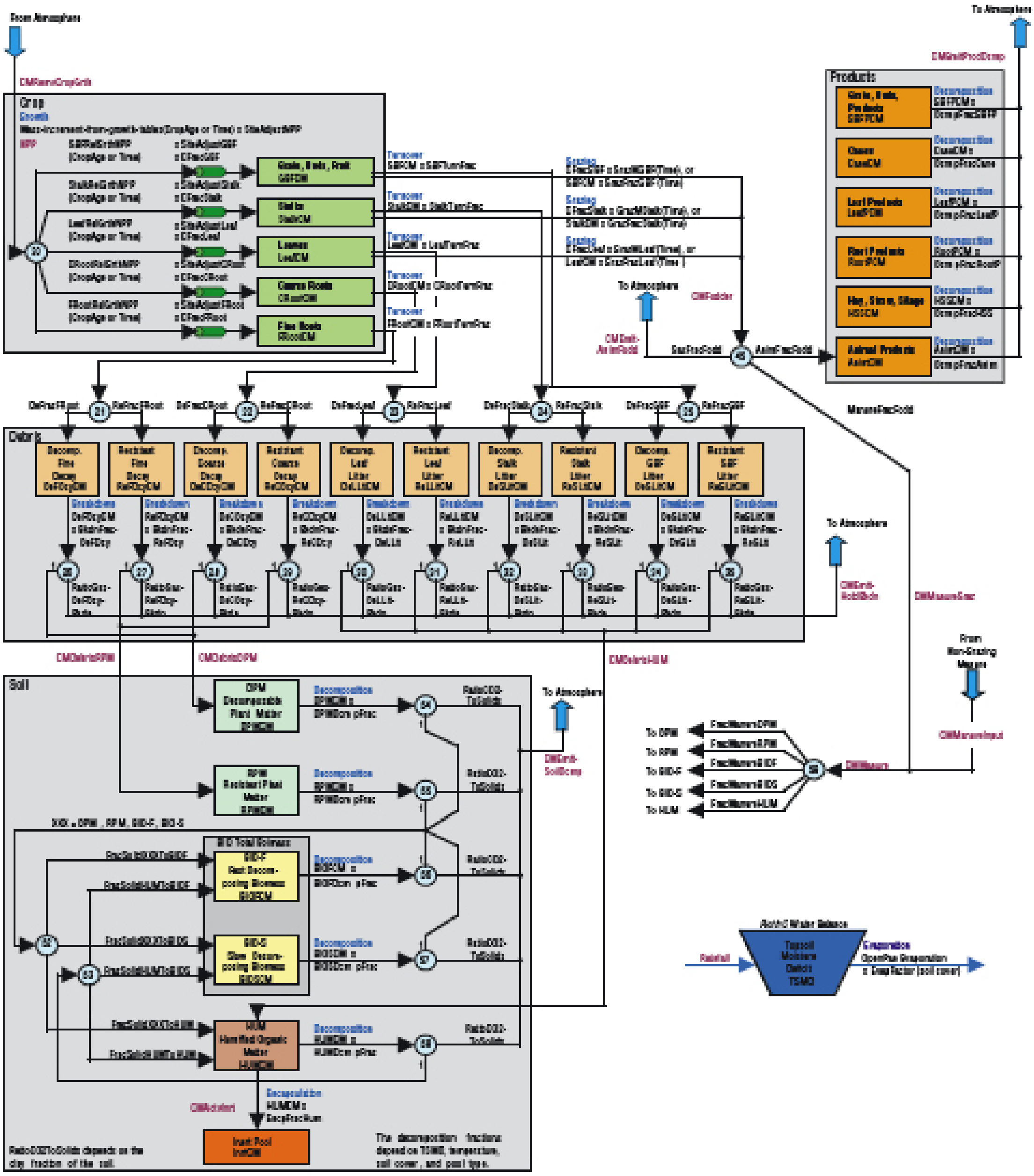
The *CAMAg* Model (b) Harvest



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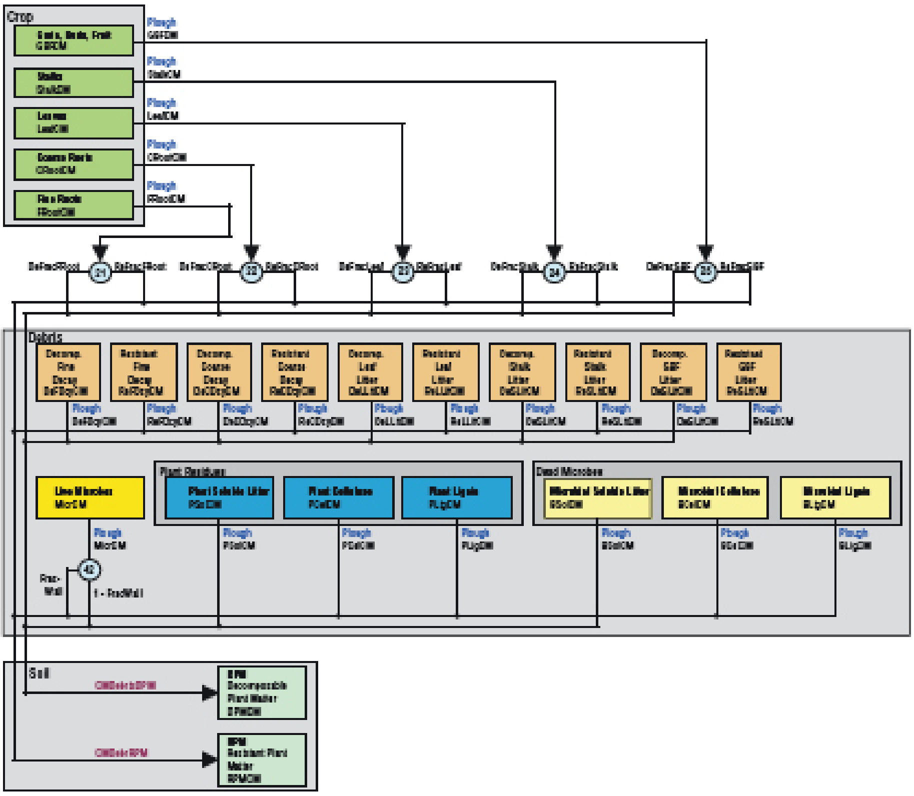
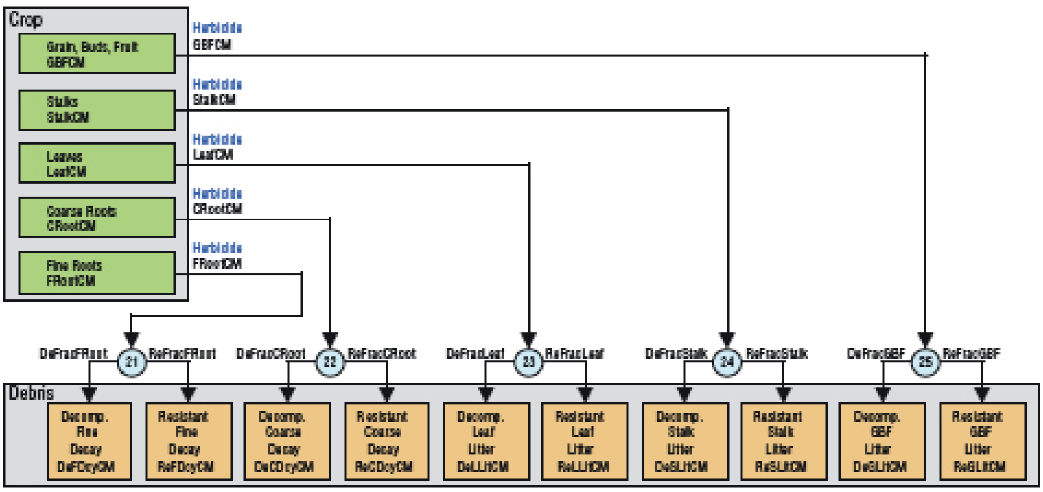
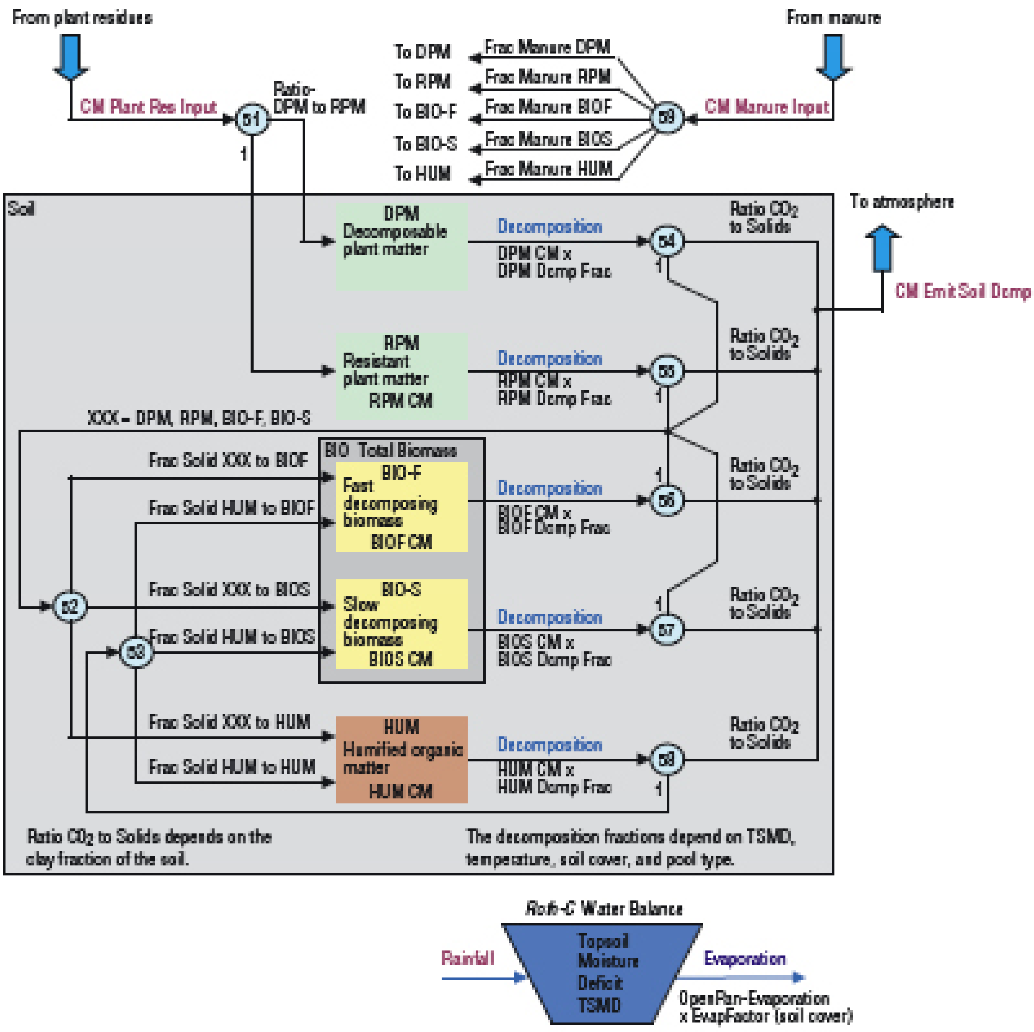
The *CAMAg* Model (d) Herbicide



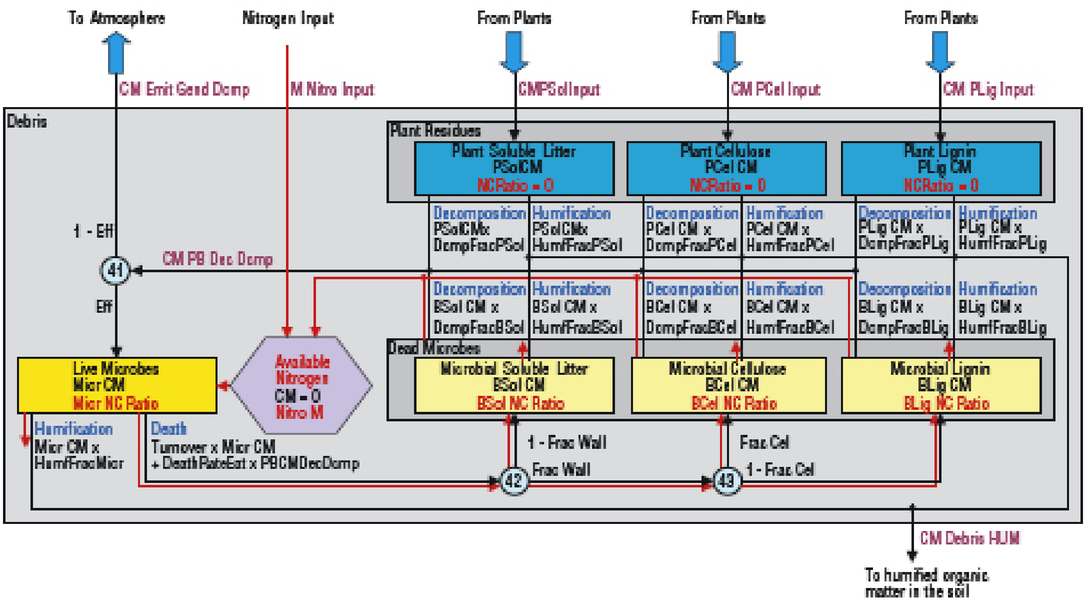
The *CAMAg* Model (c) Plough



The *GENDEC* Model



The *Roth-C* Model



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Appendix 7.B: Harvested Native Forests

Background

The model used for the reporting of carbon stock changes and CO_2 emissions from *Harvested Native Forests* currently only considers the above and belowground biomass and harvest slash. The areas and activities considered in the model are those associated with forest harvesting of Australia's native forests. Changes in dead organic matter, other than that generated as harvest slash, and soil carbon are considered to be in equilibrium. The areas of harvest and regrowth, and growth rate data are drawn from Australia's National Forest Inventory.

Australia's National Carbon Accounting System (NCAS) is developing the capacity to comprehensively report on *Forest land remaining Forest land*, the inventory category that incorporates harvested native forests, other native forests and plantations (that are not otherwise reported in the land converted to *Forest land* categories). NCAS reporting currently includes fully developed reporting for lands converted to *Forest land*, but the development of a Tier 3 fully spatially explicit estimation method for all native forests is yet to be completed. The spatially explicit methods when applied by the NCAS will ensure that there are no gaps or overlaps in reporting of either lands or emissions. In the interim, review of areas included in the *Forest lands converted to Cropland* and *Grassland*, and of forest *Plantations*, plus review of land tenure, ensures that these lands do not overlap other reporting categories.

Growth Modelling

The *Harvested Native Forest* growth model is implemented as an Excel spreadsheet.

Growth rates (in tC ha^{-1} yr^{-1}) are modelled by broad forest types and age classes (Table 7.B1). The total area of each forest type is divided into a series of age classes, each with different growth rates (Table 7.B2). A weighted average growth rate based on the area of forest in each age class is calculated to give an average per hectare growth rate for each forest type [1]. Total annual growth for each forest type is then calculated by multiplying the weighted average by the total forest type area [2], with all forest types summed to provide a total harvested native forest growth value [3]. Growth is then converted to CO_2 removals using a standard conversion rate based on the relative mass of C and CO_2 [4].

The total area of each forest type is the area of native forests that have been harvested at some time, and may still be available for harvest or may have been moved to a reserve or other land tenure unavailable for harvest. The forest areas within each forest type are assumed to not change with time and there is no movement between conservation and production areas. The model is constant for both area and growth rates for each forest type and forest age class. Hence the calculated CO_2 removals associated with forest growth remain constant through time.

Weighted average growth rate for forest type = ∑ (Area in age class * age class growth) / Total forest type area [1]

Forest type growth per year (tC yr^{-1}) = total area of forest type * weighted average of age class growth rates [2]

Total growth per year (tC yr^{-1}) = sum of annual growth for all forest types [3]

CO_2 removed by forest growth = total growth (tC yr^{-1}) * Fraction of carbon dioxide that is carbon (12/44) [4]

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Emission due to harvest slash

Harvested roundwood data is used to model the emissions from harvest slash. Total roundwood removals were summed from 8 sub-categories from 1971-94 (saw and veneer, sleepers, wood-based panels, paper and paperboard, fencing, mining, poles and piles, other). From 1995, the fencing, mining, pole and piles and other categories were no longer reported separately but included in the remaining categories (ABARE 2000, ABARE 2006b) (Table 7.B3). Hardwood slash is calculated as a direct proportion of roundwood removals [5] to account for roots and the non-merchantable components of trees felled and left to decay in-forest once merchantable products are removed.

$$\textit{Hardwood slash } (m^3) = \text{Roundwood removals } (m^3) * \text{Hardwood Slash Ratio } (0.9) \qquad [5]$$

Table 7.B1: Growth rates by forest type and age classes (tC ha^{-1} yr^{-1})

Forest Type	State Forests Whose Age Class is Unknown	Establishment 1-10 yrs	Juvenile 11-30 yrs	Immature 31-100 yrs	Mature 100-200 yrs	Senescent > 200 yrs	Two (mixed) Aged	Three or More Aged	Average Annual Increase, Weighted by Area
	t C ha^{-1} yr^{-1}								
Rainforests	0.56				0.86			0.25	0.576
Tall Dense Eucalypt Forests	3.24	6.44	4.41	2.23	0.74		2.99	2.64	2.403
Medium Dense Eucalypt Forests	1.62	4.24	2.80	0.99	0.18		1.19	0.33	0.948
Low Dense Eucalypt Forests									
Tall Sparse Eucalypt Forests									
Medium Sparse Eucalypt Forests	0.24							0.24	0.176
Low Sparse Eucalypt Forests									
Eucalypt Mallee									
Callitris Forests	0.25							0.25	0.254
Acacia Forests									
Other Forests	0.23							0.24	0.235

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Table 7.B2: Areas by forest type and age classes (ha)

Forest Type	State Forests Whose Age Class is Unknown	Establishment 1-10 yrs	Juvenile 11-30 yrs	Immature 31-100 yrs	Mature 100-200 yrs	Senescent >200 yrs	Two (mixed) Aged	Three or More Aged	Total for All Ages	Total for All Forests
	ha	ha	ha	ha	ha	ha	ha	ha	ha	ha
Rainforests	752,334				371,000	90,000		119,548	580,548	1,332,882
Tall Dense Eucalypt Forests	1,015,024	73,919	151,025	371,586	462,067	364,000	183,000	614,077	2,219,674	3,234,698
Medium Dense Eucalypt Forests	2,625,710	23,058	154,619	274,340	1,311,540	266,000	433,000	1,616,923	4,079,480	6,705,190
Low Dense Eucalypt Forests										
Tall Sparse Eucalypt Forests										
Medium Sparse Eucalypt Forests	433,869					546,000		1,049,383	1,595,383	2,029,252
Low Sparse Eucalypt Forests										
Eucalypt Mallee										
Callitris Forests	66,848							228,083	228,083	294,931
Acacia Forests										
Other Forests	1,064,653							224,134	224,134	1,288,787
Totals	**5,958,439**	**96,978**	**305,644**	**645,926**	**2,144,607**	**1,266,000**	**616,000**	**3,852,148**	**8,927,302**	**14,885,741**

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Table 7.B3: Annual roundwood removals from Harvested Native Forests

Year	Roundwood Removal 1,000 m^3
1990	10,535
1991	10,037
1992	9,512
1993	9,801
1994	9,793
1995	10,857
1996	9,920
1997	9,442
1998	9,793
1999	9,229
2000	10,942
2001	10,801
2002	9,831
2003	10,316
2004	10,092
2005	9,868
2006	8,577
2007	8503

Emissions from the decay of forest slash from harvested native forests is presumed as linear, with carbon moving to the atmosphere within a pre-defined number of years (Table 7.B4).

Model Parameterisation

Key parameters and the 'constraints' used in the model are shown in Table 7.B4. The parameters fall into grouping of similar types:

- carbon fraction of biomass;
- carbon to CO_2 conversion;
- partitioning of tree biomass to various components;
- carbon density of wood; and
- decay times of slash.

As with the growth rates and harvest areas, the data presented here has been contained in and reviewed during several national inventory submissions. Also, there is independent data for comparison with the data used in this model.

Table 7.B4: Parameters and default values used in the model

Description	Value	Units
Fraction of carbon dioxide that is carbon, by weight	0.27	
Ratio of hardwood slash to hardwood roundwood removal, by volume [(a)]	0.90	
Density of carbon in hardwood	0.325	t C / m^3
Time to total decay of hardwood slash (equal amount decays each year)	7	year

Source: a) Snowdon et al., 2000

Carbon to CO_2 Conversion

The conversion factor used is 44/12 (3.666) which is the IPCC recommended default.

Partitioning of Tree Biomass

The conversion factors used in the model is:

- ratio of hardwood slash (including roots) to hardwood roundwood removal – 0.9

This value can be compared to those found by Snowden et al., (2000). For commercial tree types of harvestable age Snowden et al., (2000) found that the slash ratio could vary from 0.25 to 5.0 for aboveground mass depending on forest type, harvesting method and available markets (primarily pulpwood) of 0.9 is considered to be a good overall estimate given the diversity of Australian forest types and silvicultural practices.

Density of Carbon (t C/m^3) for Hardwood

The value for the density of carbon (t C/m^3) used in this model for hardwood is 0.325. Independent studies by Jaakko Pöyry Consulting (1999 and 2000) derived a basic wood density value of 630 kg/m^3 for hardwood. Converted to an equivalent t C/m^3 using the carbon content of dry matter as 0.5 (Gifford 2000b), the Jaakko Pöyry Consulting results were equivalent to 0.315 t C/m^3 for hardwood. These independent values are similar, and confirm the appropriateness of the value used in the model.

Sources of Data, QA, QC and Verification

All data for the current model was derived from Australia's National Forest Inventory, and has been published as part of Australia's National Greenhouse Gas Inventory for several years. As such the growth and area data has been publicly available, and subject to domestic review through national review processes, and through international 'desk' and 'in-depth' review processes.

The estimates of both growth rates and areas extracted from Australia's National Forest Inventory can be verified against independent data published by the Resource Assessment Commission Forest and Timber Inquiry findings (Resource Assessment Commission 1991, Resource Assessment Commission 1992a, Resource Assessment Commission 1992b) and the growth rates reported by West and Mattay (1993), based on the data available to the Research Working Group of the Standing Committee on Fisheries and Forestry to Australian Government. Comparisons show that the estimates used are within the range of those described by the Resource Assessment Commissions (lower estimate) and West and Mattay (higher estimate).

Data on stem to whole tree conversions, carbon contents and wood densities are all cross-checked against independent estimates and are within the ranges published in the relevant technical reports (Snowdon et al., 2000; Ilic et al., 2000; Gifford 2000a,b). Data on harvest volumes are drawn from national statistics on forest products production consumption (ABARE). Decomposition estimates, such as for harvested wood products and forest slash are within ranges developed/used in independent studies.

Appendix 7.C: Plantations

Introduction

The Australian Government's capacity for carbon accounting in *Plantations* has been developed through Australia's National Carbon Accounting System (NCAS). The development of the NCAS includes four principal program areas; remote sensing of land cover change; biomass estimation; soil carbon estimation; and information system development. The capability developed for these programs is being progressively implemented for national reporting. The results presented in this report do not yet reflect an implementation of the full form of Tier 3 emissions estimation and Approach 3 land representation that will be used eventually.

Model Configuration

The approach to estimating emissions from *Plantations* will evolve and be refined as the NCAS develops.

While it has been shown that in the medium to long term, soil carbon contents do not change for most *Plantations* (Polglase et al., 2000), it has also been identified that there are frequently short term losses (later recovered in most situations) and some instances of long term losses or gains (Paul et al., 2002b). Work is currently underway to develop the capacity for soil carbon accounting for the range of plantation situations. Initial work (Paul et al., 2002b, 2003a and 2003b) shows the potential for the development of this capacity. However, as the ages of the plantations in this account are over an extended range, the initial losses will be counterbalanced by accumulation in older plantations in any one reporting year.

The model capability for the NCAS is also being extended to consider the non-CO_2 gas emissions, such as nitrous oxide and methane, which may arise from activities such as fertiliser application, burning and decomposition. These gases and their potential impact have not been considered in the current analyses, but are not expected to be significant.

Growth modelling and Management

For the *Plantation* sub category *FullCAM* uses the volume growth increment tables of Turner and James (2001), as developed from the National Forest Inventory (National Forest Inventory 1997a and 1997b) wood flow estimates (National Forest Inventory 2000). Areas of relevant *Plantation* types have been derived from Australia's National Plantation Inventory establishment estimates.

Within the *FullCAM* model, as implemented for the national plantation estate, *CAMFor* equivalent models for each of the *Plantation* types were developed. The development of these models is outlined in Richards and Brack (2004b). Additional information, beyond the growth tables and thinning regimes of Turner and James (2001) shown in Table 7.C1 and Attachment 7.C1, for each *Plantation* type included:

- wood density;
- stem to whole tree mass conversion;
- carbon contents;
- wood product destinations; and
- leaf and root turnover and decay rates.

Table 7.C1 and Attachment 7.C1 provide snapshots of the relevant inputs, and the resultant carbon balances on a per hectare basis from each of the *Plantation* types. These snapshots are incorporations of the information collated by the NCAS as individual model implementations for each *Plantation* type.

The 'Estate' module of *CAMFor* as contained within *FullCAM* is then used to calculate the results of the implementation of the individual *Plantation* type models on the basis of the new areas of each *Plantation* type established over time. To do this the model interrogates the carbon balance for each *Plantation* type at the relevant point in time to derive the overall account. The per hectare outcome, by the relevant age (as determined by the year of planting for each *Plantation* type), is multiplied by the number of hectares planted in the corresponding year to calculate the change for the whole of the estate in any one year. A fuller explanation of the operation of the 'Estate' module of *CAMFor* can be found in Richards and Evans (2000a).

Growth Tables and Thinning Regimes

Turner and James (2001) reinterpreted their previous work for the National Forest Inventory wood flow estimates (National Forest Inventory 1997b) to provide current annual increments (CAI) of stem volume for each Plantation Type represented. To determine the CAI, the estimates of total volume produced (from a per cent thin or clearfall) by age, region, species and *Plantation* type were fitted with growth curves that met the annual growth needed to meet the volume harvested (yield). The method of fitting growth curves to the known points of wood yield for each *Plantation* type is described in Turner and James (2001).

The empiricism of the estimates masks the influences of climate variability giving average performance over the time of measurement. It has been shown that a variable climate will cause variability in growth over time (Waterworth et al., 2005). While it is unlikely that the volume at maturity (reflecting the longer term climate average) would be much affected, performance over a shorter period, such as a single inventory year, may yield above or below the expected growth due to the prevailing climate conditions. The potential impact of prevailing climate conditions during the time of reporting is described in Brack and Richards (2002).

Wood Density Estimates

Wood density estimates were extracted from the compendium prepared by Ilic et al., (2000) for the NCAS. While many native forest species have few, and in some instances no, reported wood density estimates, plantation species are relatively well studied and reported. However, wood density is most commonly measured at the time of harvest, reflecting a mature state.

As it is commonly accepted that wood density increases with tree age, there is a potential that the adopted wood densities are over-estimates for the early stages of plantation growth. However, the overall effect is unlikely to be significant as lower densities occur when mass is least, that is, during early growth stages. Table 7.C1 and Attachment 7.C1 show the wood density values used for the major plantation species in the *Plantation* types.

Stem to Whole Tree Mass Conversions

Studies completed for the NCAS on the above and below ground partitioning of biomass (Keith et al., 2000, Eamus et al., 2000, Snowdon et al., 2000) have shown that both above and below ground variability reduces, as do non-stem allocations, as site biomass increases. Greatest uniformity, and therefore least variability, tends to occur in even-aged and productive stands. Attachment 7.C1 provides a synopsis of the non-stem allocations used in each *Plantation* type model.

The ratio of stem (merchantable) quantities to non-merchantable components is particularly important for the calculation of the amounts of forest slash generated by thinning and harvesting activity. The potential accumulation of slash can make a considerable contribution to increased carbon stock, particularly on former pasture sites.

Carbon Contents

The carbon contents of various tree components below and above ground were examined in Gifford (2000a) and Gifford (2000b) respectively in studies for the NCAS. Carbon contents were tested for various species and growing conditions, with recommended estimates given within the range of values yielded in test results. There was little variability in the results and more importantly no cause to suspect bias in any set of environmental conditions or plant groups. These results could be considered as robust and reliable estimates, providing little source of uncertainty in the carbon models.

Leaf and Root Turnover

The turnover rate of leaves affects both the amount of fine litter on the forest floor and subsequently most of the aboveground contribution to soil carbon. The turnover rate of fine roots is taken to be a direct input to soil carbon.

As this implementation of the model has not considered soil carbon, the rates of turnover of both leaves and fine roots are relatively unimportant. The key attributes of the assigned rates are that they are realistic and do not operate at rates high or low enough to either reduce below reasonable expectation, the mass of attached leaves and live roots, or to create unrealistically high or low levels of litter.

Table 7.C1: Wood densities and carbon contents

Region(s)	Species	Density	CC% Leaf	CC% Branch	CC% Wood	CC% Bark	CC% Fine Roots	CC% Coarse Roots	Regime Description
Green Triangle	Pinus radiata	440	52	51	52	53	46	49	Average Sites – 54% thinning @ 13 years, 25% @ 18, 28% @ 23, CF @ 30
Green Triangle	*Pinus* (other than radiata)	440	52	51	52	53	46	49	Average Sites – 54% thinning @ 13 years, 25% @ 18, 28% @ 23, CF @ 30
NSW Northern Tableland	Southern Pine (*P. elliotti, P. taeda, Araucaria cunninghamii*)	440	52	51	52	53	46	49	Average Sites – 27% thinning @ 14 years, 47% @ 20, CF @ 30
NSW	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites – 67% @ 20 years, 47% @ 35, CF @ 45
NSW	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites – CF @ 20
Qld	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites – 67% @ 20 years, 47% @ 35, CF @ 45
Qld	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites – CF @ 20
Qld	Southern Pine (*P. elliotti, P. taeda, Araucaria cunninghamii*)	440	52	51	52	53	46	49	All Sites – 35% @ 18 years, CF @ 35
SA	Eucalyptus planta ions	550	52	47	52	49	46	49	All Sites – CF @ 20
South Australia	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites – CF @ 15
South Australia	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites – CF @ 25
South Australia	*Pinus* (other than radiata)	440	52	51	52	53	46	49	Average Sites – 54% hinning @ 13 years, 25% @ 18, 28% @ 23, CF @ 30
Tasmania	Eucalyptus nitens	550	52	47	52	49	46	49	All Sites – CF @ 30
Tasmania	Eucalyptus nitens	550	52	47	52	49	46	49	All Sites – CF @ 15
Tasmania	Eucalyptus nitens	550	52	47	52	49	46	49	All Sites – CF @ 25
Tasmania	Pinus radiata	440	52	51	52	53	46	49	Average Sites – CF @ 35
Tasmania	*Pinus* (other than radiata)	440	52	51	52	53	46	49	All Sites – CF @ 35
Victoria (Central)	Pinus radiata	440	52	51	52	53	46	49	Average Sites – 34% thinning @ 15 years, 18% @ 22, 24% @ 28, CF @ 35
Victoria (Central)	Pinus radiata	440	52	51	52	53	46	49	Average Sites – CF @ 30
Victoria (Central Gippsland)	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites – CF @ 25
Victoria (Central Gippsland)	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites – CF @ 20
Victoria (Central Gippsland)	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites – CF @ 30
Victoria (Central Gippsland)	Eucalyptus plantations	550	52	47	52	49	46	49	All Sites – CF @ 35
Victoria (Central Gippsland)	Pinus radiata	440	52	51	52	53	46	49	Average Sites – 33% thinning @ 15 years, 37% @ 20, CF @ 30
Murray Valley	Pinus radiata	440	52	51	52	53	46	49	Average Sites – 47% thinning @ 14 years, 35% @ 22, 29% @ 29, CF @ 30
Murray Valley	Pinus radiata	440	52	51	52	53	46	49	Average Sites – 47% thinning @ 14 years, 35% @ 22, CF @ 30
Murray Valley	Pinus radiata	440	52	51	52	53	46	49	Very Good Sites – 44% thinning @ 14 years, 31% @ 18, 27% @ 23, CF @ 30
Victoria and NSW	Pinus radiata	440	52	51	52	53	46	49	Average Sites – CF @ 30 years
Victoria and NSW	Pinus radiata	440	52	51	52	53	46	49	Average Sites – 65% thinning @ 16 years, CF @ 30
Victoria and NSW	Pinus radiata	440	52	51	52	53	46	49	Average Sites – 65% thinning @ 16 years, 57% @ 24, CF @ 30
Victoria and NSW	Pinus radiata	440	52	51	52	53	46	49	Average Sites – 65% thinning @ 16 years, 57% @ 24, 27% @ 30, CF @ 35
Victoria and NSW	Pinus radiata	440	52	51	52	53	46	49	Poor Sites – 26% thinning @ 18 years, 32% @ 24, CF @ 30
Victoria and NSW	Pinus radiata	440	52	51	52	53	46	49	Poor Sites – CF @ 30 years
Western Australia	Eucalyptus globulus	550	52	47	52	49	46	49	Clear fall @ 10
Western Australia	Pinus pinaster	470	52	51	52	53	46	49	Average Sites – 65% thinning @ 18 years, 37% @ 25, CF @ 40
Western Australia	Pinus radiata	440	52	51	52	53	46	49	Average Sites – 51% thinning @ 12 years, 39% @ 18, 32% @ 24, CF @ 35

A simple reality check can be performed directly from observations of model results. While leaf turnover rates have been the subject of measurement and can be compared to observations, the difficulty in measuring root turnover means that there are very few reported measures against which to compare. However, as the stock of 'dead' fine root material is accounted for as soil organic matter, this becomes irrelevant until soil carbon modelling is implemented.

Table 7.C2: Tree component annual turnover rates

Tree Component	Turnover yr^{-1}
Branches	0.03
Bark	0.1
Leaves	0.5
Coarse Roots	0.05
Fine Roots	0.1

Slash Decomposition

Subsequent to harvest there are often large quantities of slash (stumpage, branches etc.) left on the forest floor to decompose. The rates of decomposition applied in the model have been guided by the work of Mackensen and Bauhus (1999) for the NCAS. Table 7.C3 shows the decomposition rates applied.

Table 7.C3: Slash decomposition rates

Litter Component	Breakdown Rate yr^{-1}
Deadwood	0.1
Bark Litter	0.5
Leaf Litter	1.0
Coarse Dead Roots	0.5
Fine Dead Roots	1.0

Activity data

Activity data for plantations is sourced from both the National Forest Inventory and the NCAS remote sensing programme.

Forest remaining Forest – Plantations

The plantation area data provided by Spencer et al., (2001) is reported on the basis of the 14 National Plantation Inventory regions (Figure 7.C1). Three broad classes of forest are defined – Short Rotation Hardwood (SRH), Long Rotation Hardwood (LRH) and Softwood (SW). This data is subsequently annualised (cumulative area divided by number of years) from within the blocks of years reported by Spencer et al., (2001).

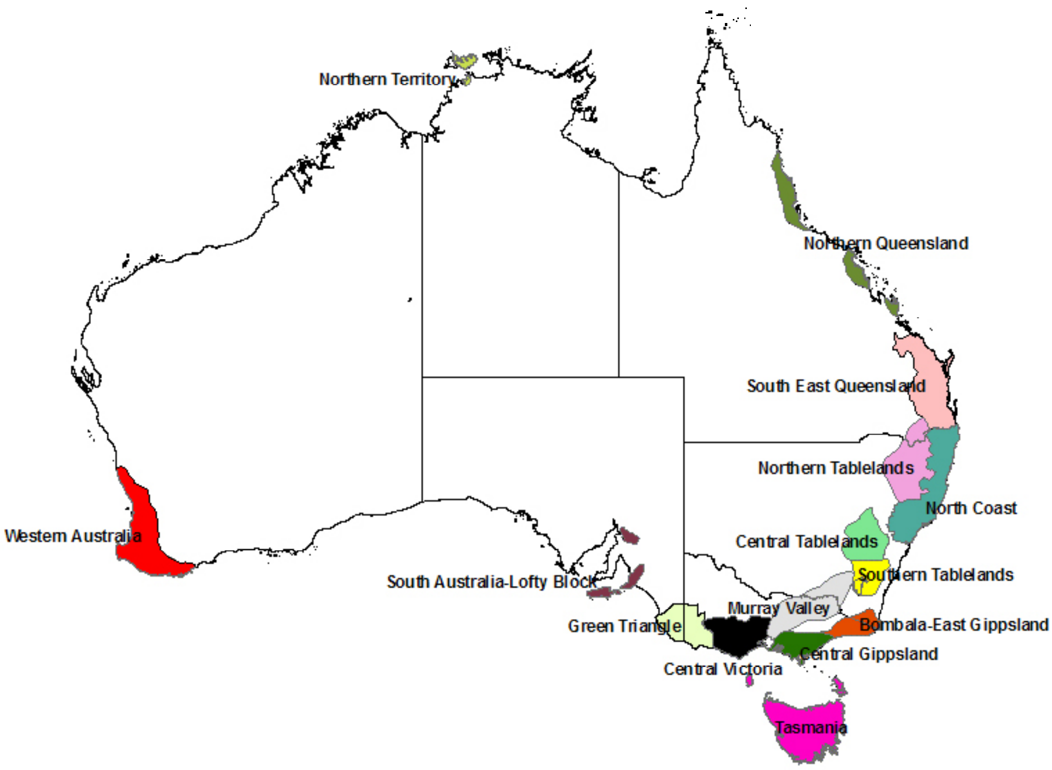
Lands Converted to Forest Land (post 1990 plantings)

Lands converted to Forest land can be identified and classified to *Plantation* type (native forest, hardwood and softwood) since 1990 using the Landsat TM and ETM data (see Appendix 7.A). Further analysis is planned to identify lands converted to plantation since the commencement of the Landsat archive in 1972. The time-series data is able to identify areas where *Plantations* have been established on land with a prior non-forest land use. The areas are shown in Table 7.C4.

Table 7.C4: Areas of land converted to forest

Year	Area (ha)
1990	85,269
1991	86,183
1992	77,105
1993	72,850
1994	71,976
1995	50,535
1996	50,535
1997	50,535
1998	64,420
1999	66,411
2000	86,856
2001	86,856
2002	87,764
2003	87,976
2004	77,275
2005	55,303
2006	48,833

Figure 7.C1: The national plantation inventory regions



Allocations of the Short Rotation Hardwood (SRH), Long Rotation Hardwood (LRH) and Softwood (SW) classes are made to the region and species specific Plantation Types as described by Turner and James (2001). Table 7.C5 shows the *Plantation* types for which growth increment (yield) tables are available. The yields, in terms of bole volume, are shown in Attachment 7.C1.

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Table 7.C5: Plantation types and management regimes

Species	Region	Regime
Pinus pinaster	Western Australia	Average sites – 65% thin @ 18yrs, 37% @ 25yrs and clearfall @ 40yrs
Pinus radiata	Western Australia	Average sites – 51% thin @ 12yrs, 39% @ 18yrs, 32% @ 24yrs, clearfall @ 35yrs
Pinus radiata	Victoria, NSW	Poor sites – clearfall @ 30yrs
Eucalyptus globulus	Western Australia	Clearfall @ 10yrs
Pinus radiata	Victoria, NSW	Average sites – 65% thin @ 16yrs,m 57% @ 24yrs, 27% @ 30yrs, clearfall @ 35yrs
Pinus radiata	Victoria, NSW	Poor sites – 26% thin @ 18yrs, 32% @ 24yrs, clearfall @ 30yrs
Pinus radiata	Victoria, NSW	Average sites – 65% thin @ 16yrs, clearfall @ 30yrs
Pinus radiata	Victoria, NSW	Average sites – 65% thin @ 16yrs, 57% @ 24yrs, clearfall @ 30 years
Pinus radiata	Murray Valley	Very Good sites – 44% thin @ 14yrs, 31% @ 18yrs, 27% @ 23yrs, clearfall @ 30yrs
Pinus radiata	Victoria, NSW	Average sites – clearfall @ 30yrs
Pinus radiata	Murray Valley	Average sites – 47% thin @ 14yrs, 35% @ 22yrs, 29% @ 29yrs, clearfall @ 30yrs
Pinus radiata	Murray Valley	Average sites – 47% thin @ 14yrs, 35% @ 22yrs, clearfall @ 30yrs
Eucalyptus spp	Vic(Central Gippsland)	All sites – clearfall @ 35yrs
Pinus radiata	Vic(Central Gippsland)	Average sites – 33% thin @ 15yrs, 37% @ 20 yrs, clearfall @ 30yrs
Eucalyptus spp	Vic(Central Gippsland)	All sites – clearfall @ 20 yrs
Eucalyptus spp	Vic(Central Gippsland)	All sites – clearfall @ 30yrs
Pinus radiata	Victoria (Central)	Average sites – clearfall @ 30yrs
Eucalyptus spp	Victoria (Central)	All sites – clearfall @ 25yrs
Pinus spp (not radiata)	Tasmania	All sites – clearfall @ 35yrs
Pinus radiata	Victoria (Central)	Average sites – 34% thin @ 15yrs, 18% @ 22yrs, 24% @ 28yrs, clearfall @ 35yrs
Eucalyptus nitens	Tasmania	All sites – clearfall @ 25yrs
Pinus radiata	Tasmania	Average sites – clearfall @ 35yrs
Eucalyptus nitens	Tasmania	All sites- clearfall @ 30yrs
Eucalyptus nitens	Tasmania	All sites – clearfall @ 15yrs
Eucalyptus spp	South Australia	All sites – clearfall @ 25yrs
Pinus spp (not radiata)	South Australia	Average sites – 54% thin @ 13yrs, 25% @ 18yrs, 28% @ 23yrs, clearfall @ 30yrs
Eucalypt spp	South Australia	All sites – clearfall @ 25yrs
Pinus spp (not radiata)	South Australia	Average sites – 54% thin @ 13yrs, 25% @ 18yrs, 28% @ 23yrs, clearfall @ 30yrs
Eucalypt spp	South Australia	All sites – clearfall @ 20yrs
Eucalypt spp	South Australia	All sites – clearfall @ 15yrs
Eucalypt spp	Queensland	All sites – clearfall @ 20yrs
Southern Pines	Queensland	All sites – 35% thin @ 18yrs, clearfall @ 35yrs
Eucalypt spp	NSW	All sites – clearfall @ 20yrs
Eucalypt spp	Queensland	All sites – 67% thin @ 20yrs, 47% @ 35yrs, clearfall @ 45yrs
Southern Pine	NSW Northern Tableland	Average sites – 27% thin @ 14yrs, 47% @ 20yrs, clearfall @ 30yrs
Eucalypt spp	NSW	All sites – 67% thin @ 20yrs, 47% @ 35yrs, clearfall @ 45yrs
Pinus radiata	Green Triangle	Average sites – 54% thin @ 13yrs, 25% @ 18yrs, 28% @ 23yrs, clearfall @ 30yrs
Pinus spp (not radiata)	Green Triangle	Average sites – 54% thin @ 13yrs, 25% @ 18yrs, 28% @ 23yrs, clearfall @ 30yrs

Uncertainty Analysis

Brack and Richards (2002) have provided the basis for the uncertainty analysis using the @Risk *Monte Carlo* capabilities attached to the *FullCAM* model. The analysis undertaken took advantage of the progression from treating all parameters as 'uncertain' with ranges of potential values, to describe the potential 'variance' within many parameters in terms of a probability distribution.

Dealing with quantified variance rather than constrained uncertainty within *Monte Carlo* analyses in *FullCAM* makes it possible to consider the correlation between variables and parameters and the likelihood of any single or interacting circumstance occurring. When the Monte Carlo analysis runs all statistical variants of possible inputs in combination, unrealistic biophysical scenarios may be induced. For example, under a high rainfall both growth rate and decomposition rates will likely increase. If the *Monte Carlo* analysis is not informed that these parameters are positively correlated, then the random selection of high growth values may be associated with decreased decomposition rates.

If correlations are not prescribed, combinations such as increased growth and decreased decomposition rates (a negative correlation) are as likely to be selected as a positive correlation, yet they are not likely in reality. This inclusion of unrealistic scenarios will considerably increase perceived uncertainty in model outcomes. The result is that a simple multiplicative array of potential (yet unrealistic) extreme results increases uncertainty ranges, as the generally ameliorating impacts of correlated inputs are not acknowledged.

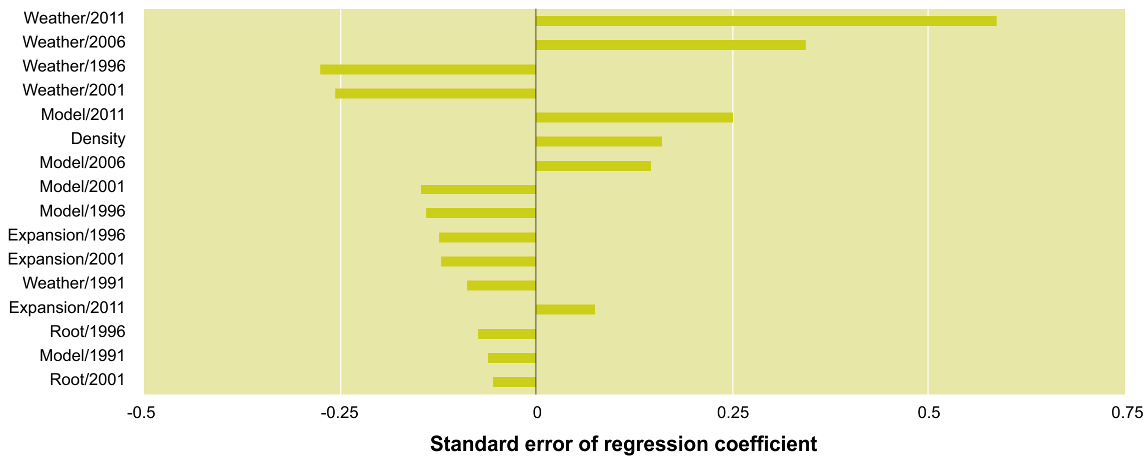
Brack and Richards (2002) modelled the performance of an individual stand using growth rates determined according to the observed growth variance around rainfall variability, error in allocating a growth index for the relevant growth model, and known variance or uncertainty in other key parameters. The key output for consideration is shown in Figure 7.C2.

The 'tornado' graph shows the sources of uncertainty of model parameters and variables in order of their importance to uncertainty in the model outcome. It is clear from the analysis that, on an individual stand basis and in this instance, predictions are more prone to climate based variation than any other influence.

Figure 7.C3 provides the mean and standard deviations for projected performance, providing the logical conclusion that stands aged around their maximum potential growth rate would be most affected (largest standard deviation) by variability largely driven by climate.

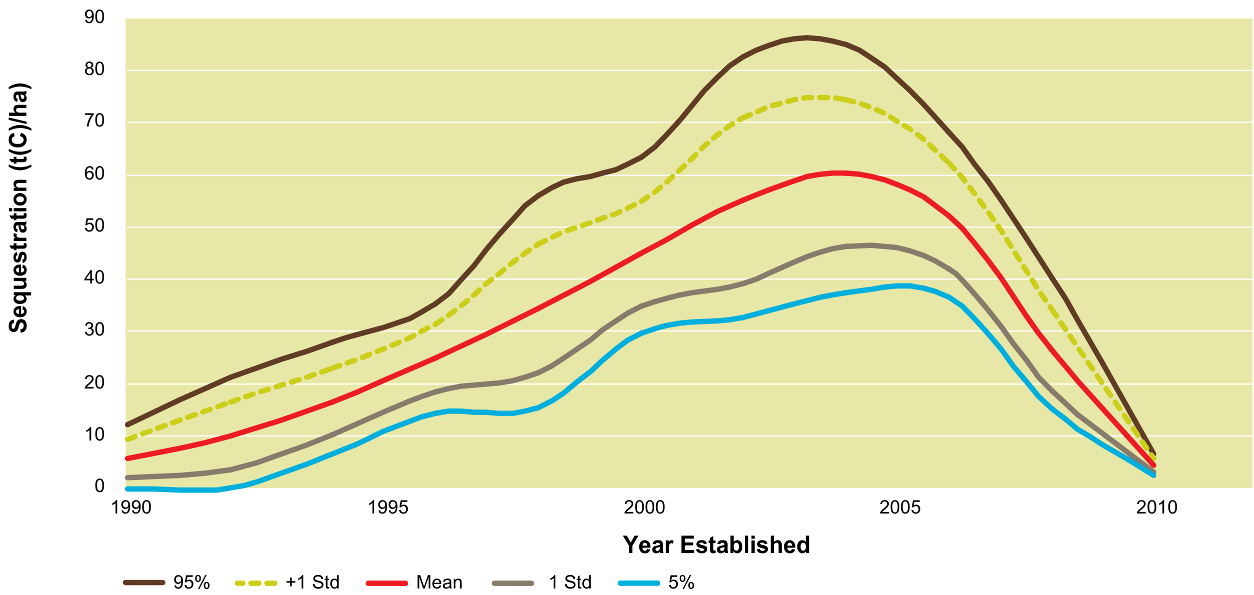
To take such individual stand-based uncertainty analyses to a national scale by simplistically extrapolating high and low outcomes would yield unrealistic results. The use of a 'low' base and the lower standard deviation is founded on the unlikely potential for below average rainfall for all plantation areas across the whole continent. Given the vast areas covered by *Plantations*, it is a reasonable expectation that across the continent, 'more average' conditions will be achieved at the national level.

Figure 7.C2: Tornado diagram derived from @ Risk simulations of the correlation between uncertainty of the inputs and distribution of sequestration estimates between 2008 and 2012 for a plantation established in 1990



Note: Weather/xxxx denotes the variation in weather during 5-year period commencing xxxx. Model/xxxx denotes the variation in the modelled site index during the 5-year period commencing xxxx. Expansion/xxxx denotes the variation in the expansion factors (caused as a result of he variation in increment of bark, branches, twigs and leaves) during the 5-year period commencing xxxx. Roots/xxxx denotes the variation in root increment and decay during the 5-year period commencing xxxx.

Figure 7.C3: Variability in stand performance by age of stand



Source: Brack and Richards 2002

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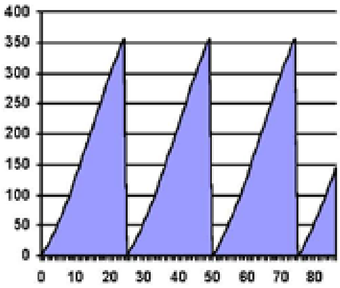
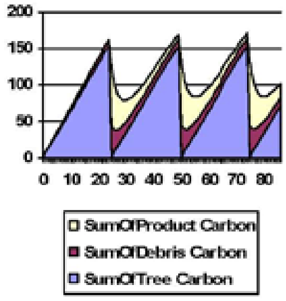
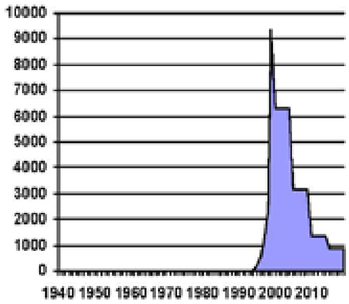
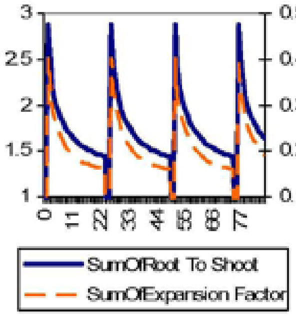
Attachment 7.C1: Plantation Type Model Parameters and Outcomes

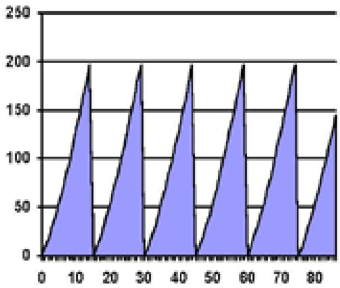


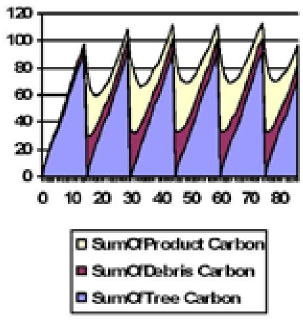


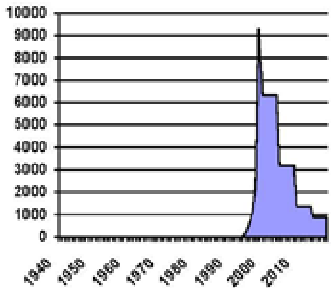


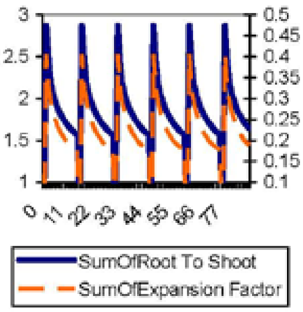


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
SA4 Euc 3	South Australia	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - CF @ 25









LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
SA4 Euc 2	South Australia	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - CF @ 15

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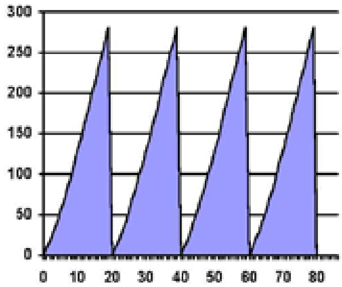
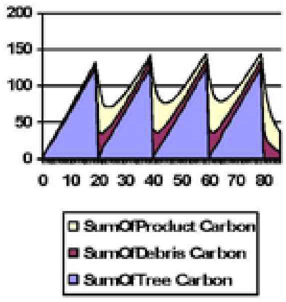
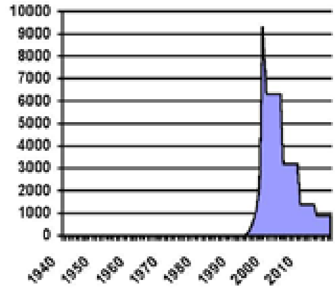
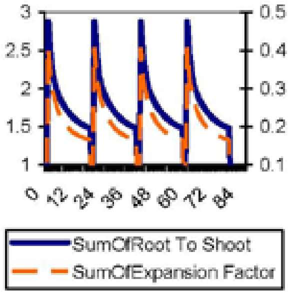
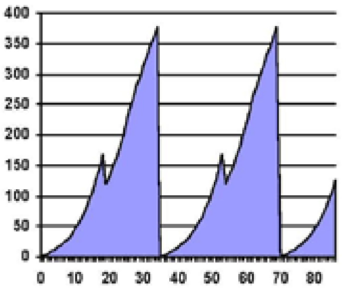


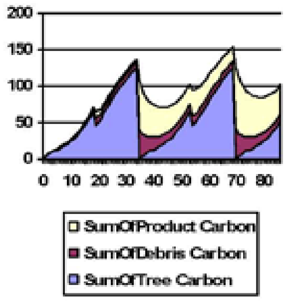


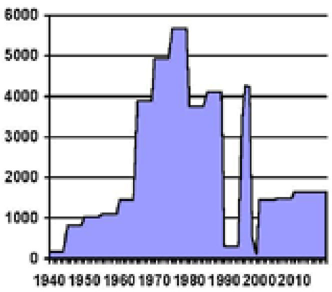


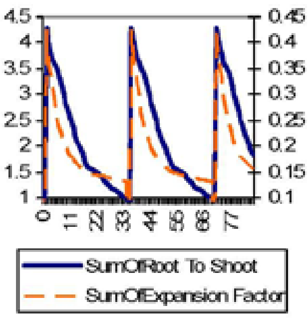


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
SA4 Euc 1	South Australia	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - CF @ 20

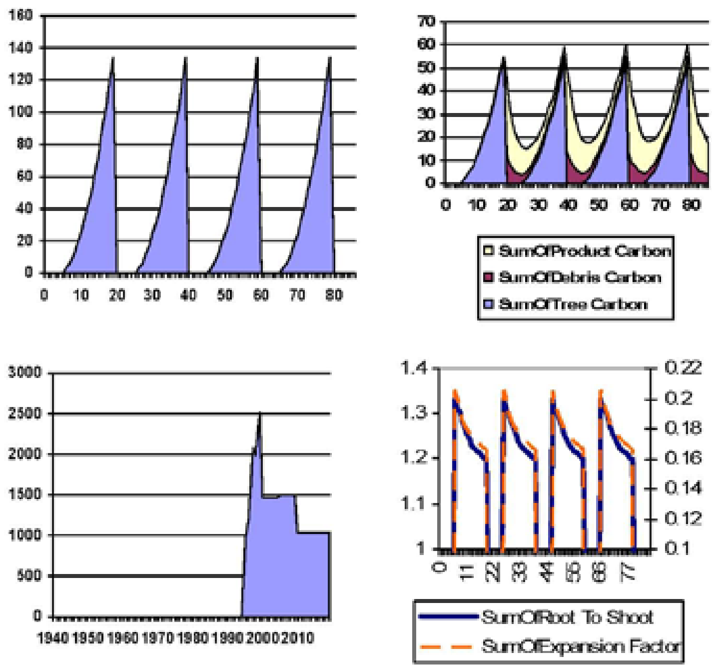




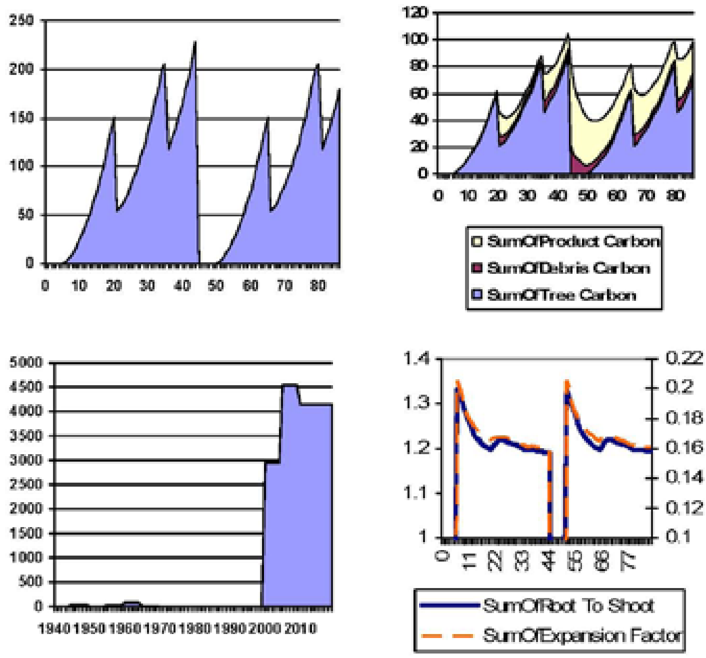




LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Qld1314 SthPine	Queensland	Southern Pine (*P. elliotti, P. taeda, Araucaria cunninghamii*)	440	52	52	51	51	52	53	All Sites - 35% @ 18 years, CF @ 35



LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Qld1314 Euc 2	Queensland	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - CF @ 20



LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Qld1314 Euc 1	Queensland	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - 67% @ 20 years, 47% @ 35, CF @ 45

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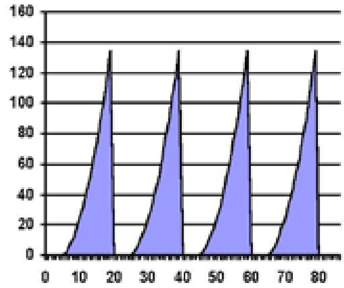
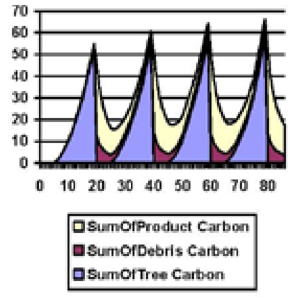
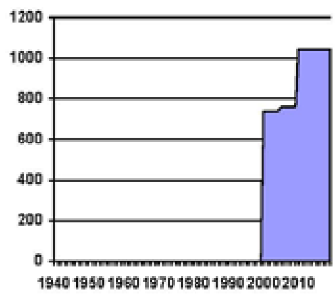
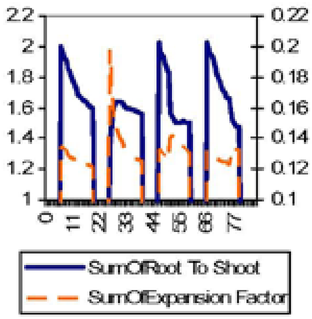
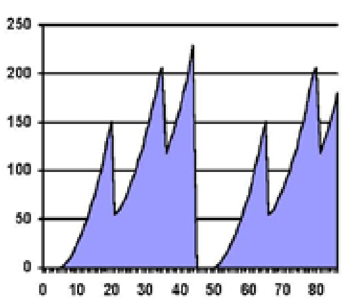


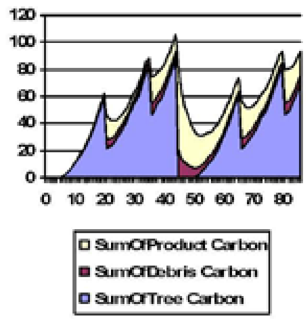


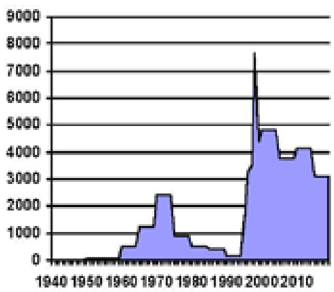


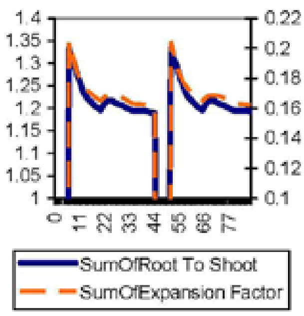


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
NSW9101112 Euc 2	NSW	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - CF @ 20



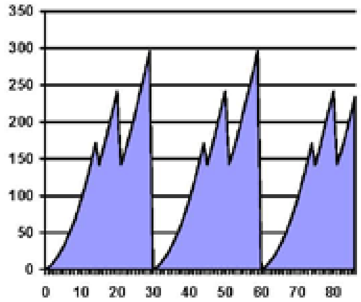


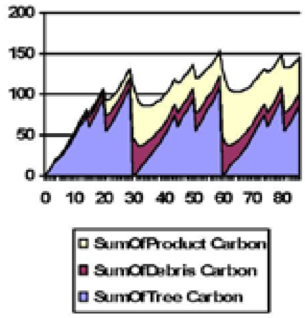


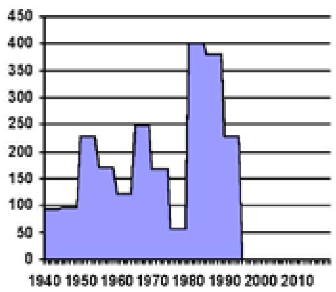


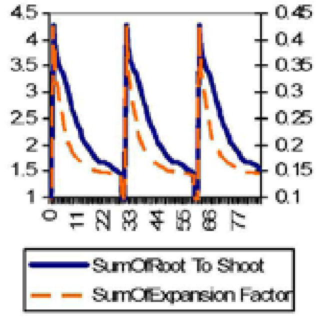
LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
NSW9101112 Euc 1	NSW	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - 67% @ 20 years, 47% @ 35, CF @ 45

APPENDICES

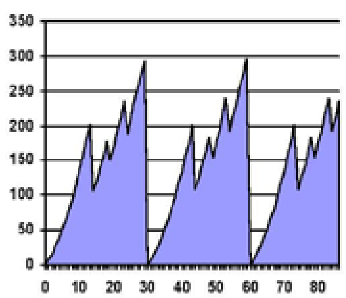


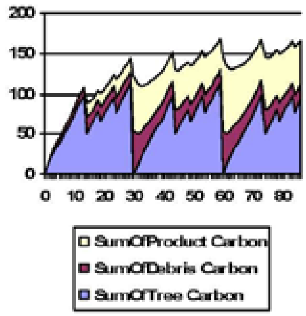


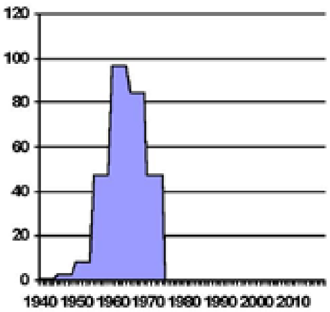


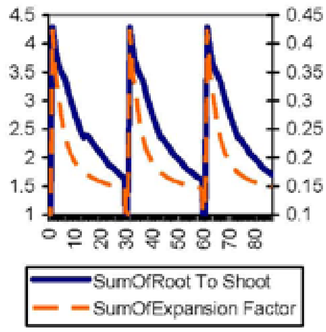


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
NSW11 SthPine 1	NSW Northern Tableland	Southern Pine (*P. elliotti, P. taeda, Araucaria cunninghamii*)	440	52	52	51	51	52	53	Average Sites - 27% thinning @ 14 years, 47% @ 20, CF @ 30









LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
GrnTri3 Pinus 1	Green Triangle	Pinus (other than radiata)	440	52	52	51	51	52	53	Average Sites - 54% thinning @ 13 years, 25% @ 18, 28% @ 23, CF @ 30

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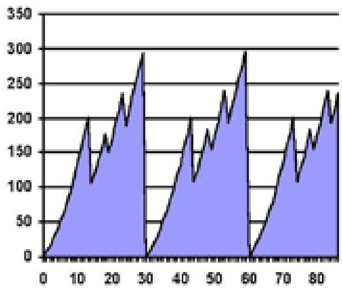
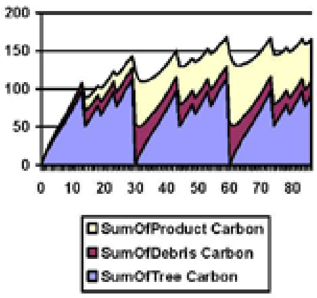
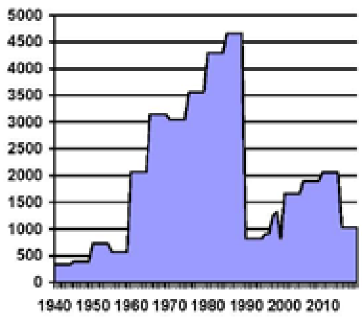
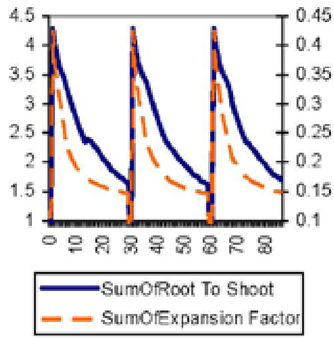
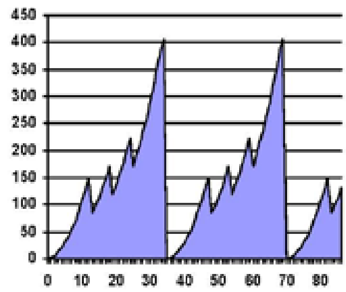


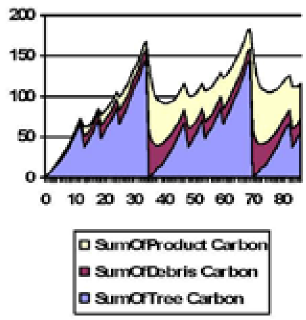


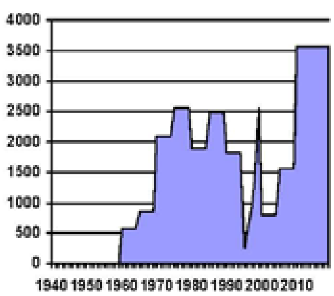


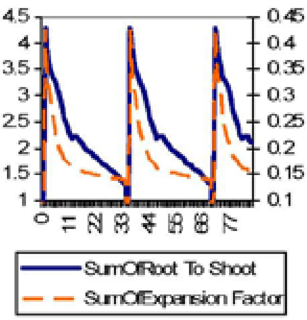


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
GrnTri3 P.rad 1	Green Triangle	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - 54% thinning @ 13 years, 25% @ 18, 28% @ 23, CF @ 30

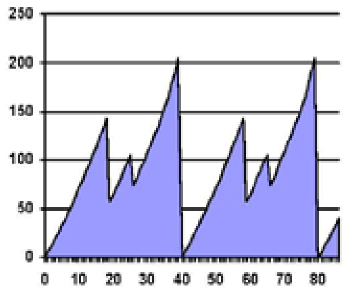


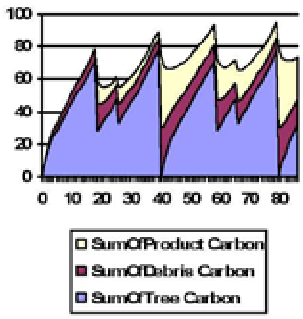


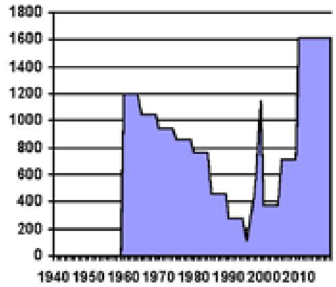


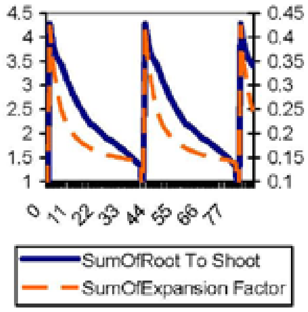


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
WA1 P.rad 1	Wester Australia	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - 51% thinning @ 12 years, 39% @ 18, 32% @ 24, CF @ 35

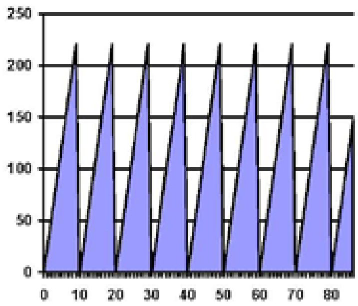


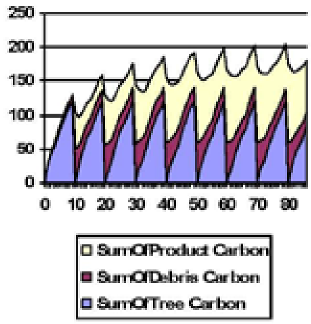


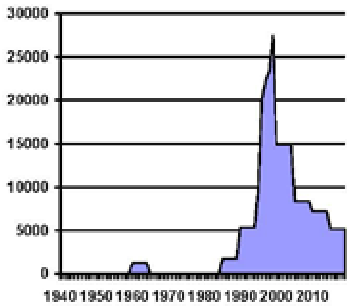


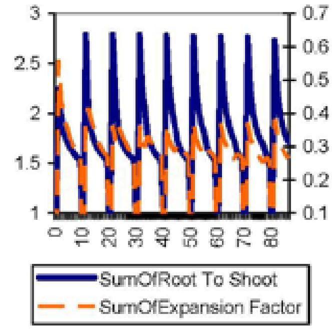


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
WA1 P.pin 1	Wester Australia	*Pinus pinaster*	470	52	52	51	51	52	53	Average Sites - 65% thinning @ 18 years, 37% @ 25, CF @ 40









LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
WA1 E.glob 1	Wester Australia	*Eucalyptus globulus*	550	52.8	49.8	47	48.7	50.7	49	Clear fall @ 10

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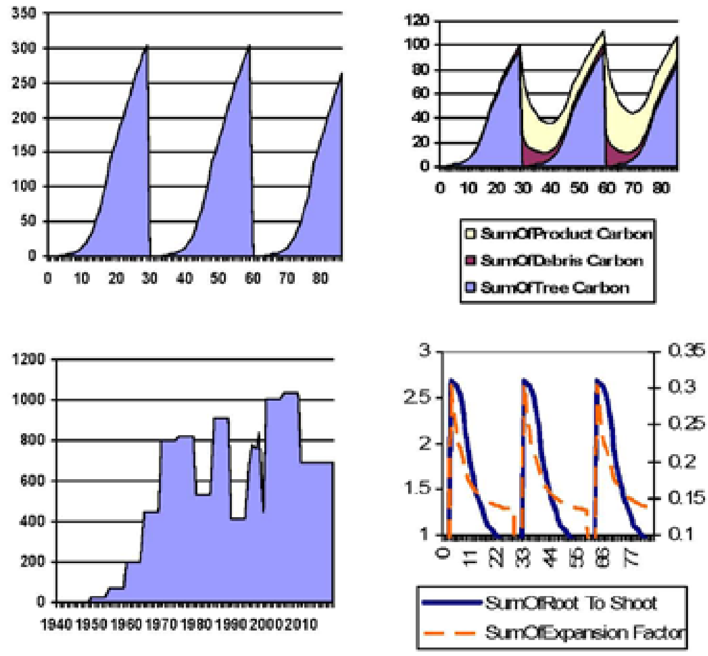
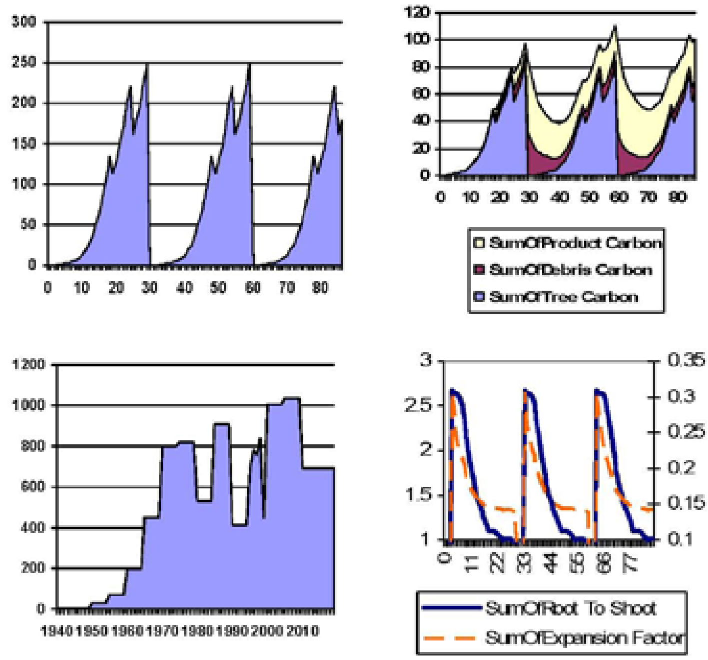


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
VicNSW891011 P.rad 6	Victoria and NSW	*Pinus radiata*	440	52	52	51	51	52	53	Poor Sites - CF @ 30 years



LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
VicNSW891011 P.rad 5	Victoria and NSW	*Pinus radiata*	440	52	52	51	51	52	53	Poor Sites - 26% thinning @ 18 years, 32% @ 24, CF @ 30

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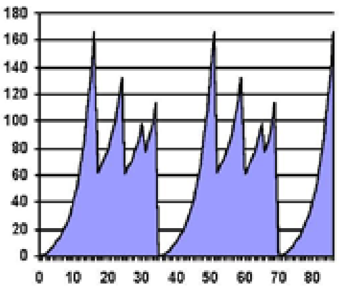
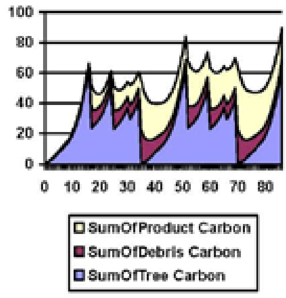
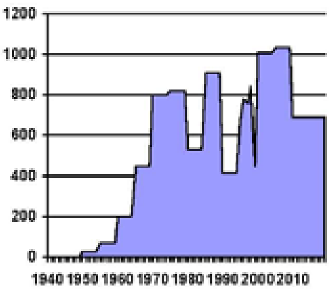
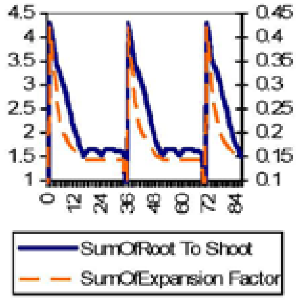
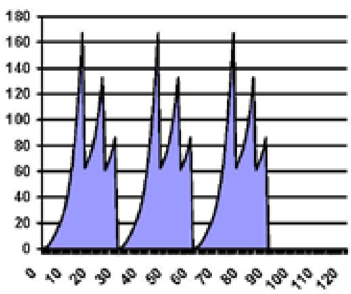


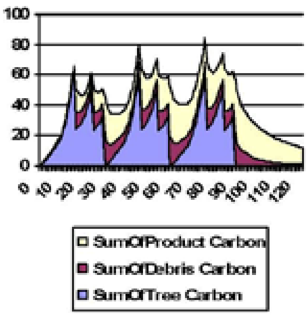


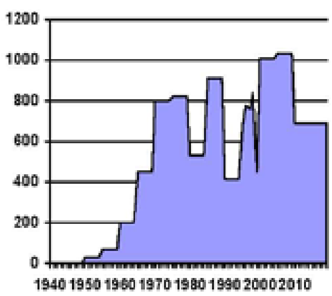


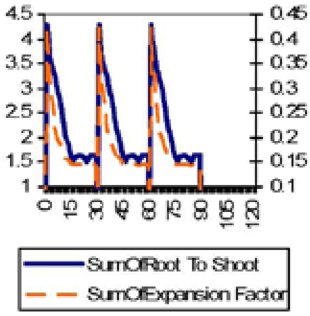


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
VicNSW891011 P.rad 4	Victoria and NSW	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - 65% thinning @ 16 years, 57% @ 24, 27% @ 30, CF @ 35

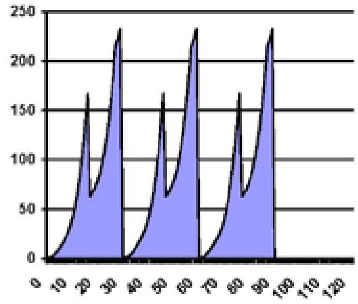


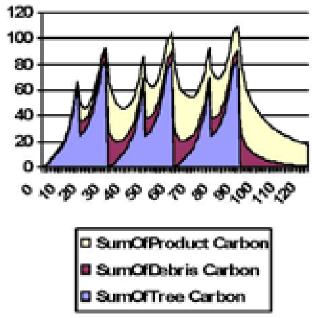


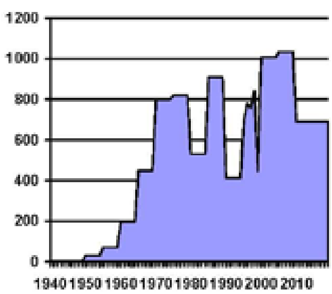


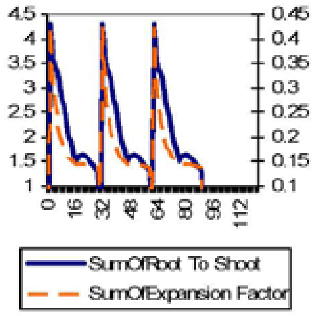


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
VicNSW891011 P.rad 3	Victoria and NSW	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - 65% thinning @ 16 years, 57% @ 24, CF @ 30

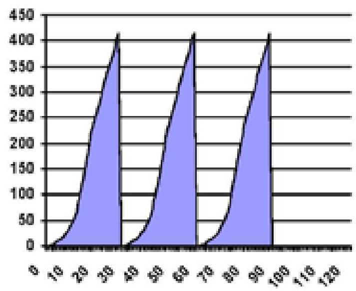


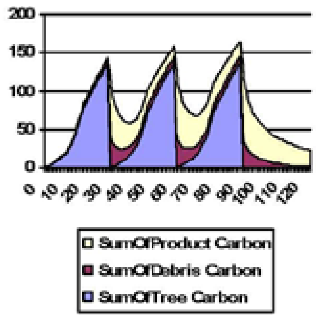


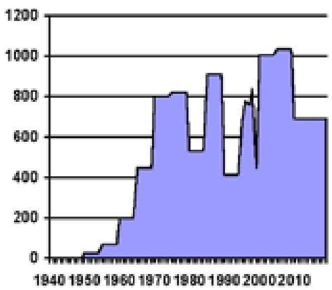


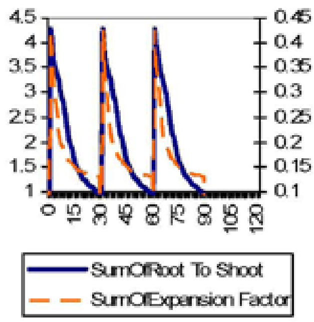


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
VicNSW891011 P.rad 2	Victoria and NSW	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - 65% thinning @ 16 years, CF @ 30









LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
VicNSW891011 P.rad 1	Victoria and NSW	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - CF @ 30 years

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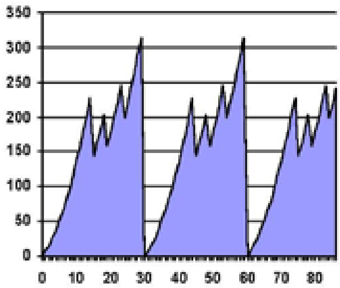
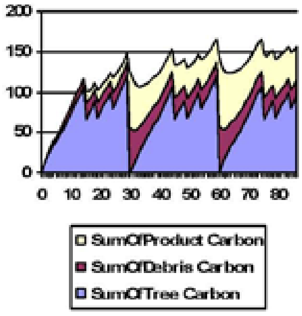
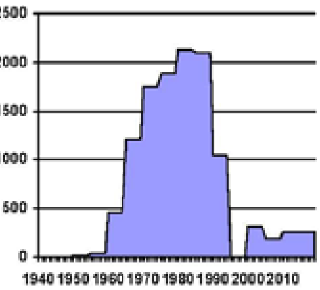
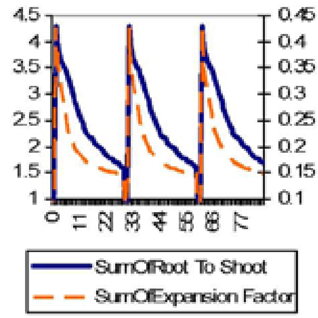
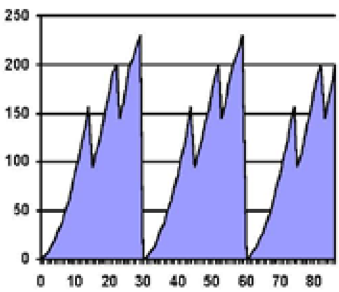


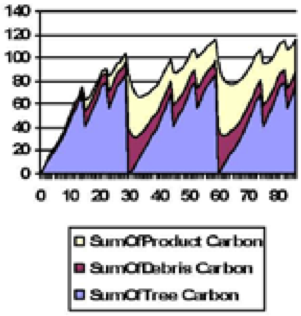


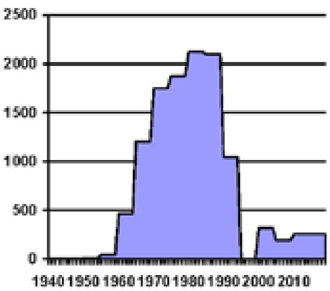


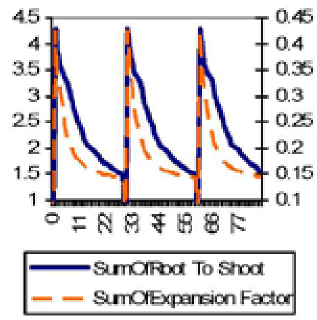


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
VicNSW6 P.rad 3	Murray Valley	*Pinus radiata*	440	52	52	51	51	52	53	Very Good Sites - 44% thinning @ 14 years, 31% @ 18, 27% @ 23, CF @ 30









LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
VicNSW6 P.rad 2	Murray Valley	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - 47% thinning @ 14 years, 35% @ 22, CF @ 30

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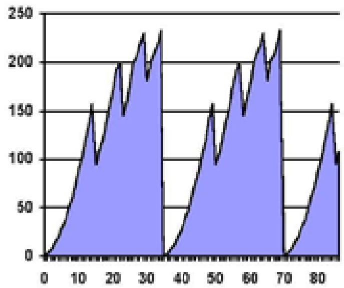
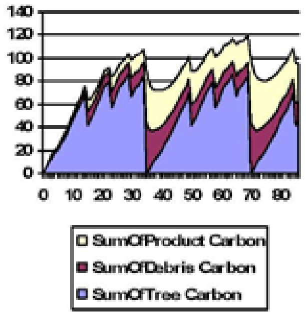
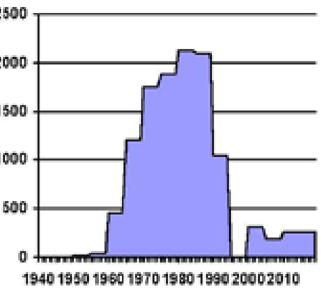
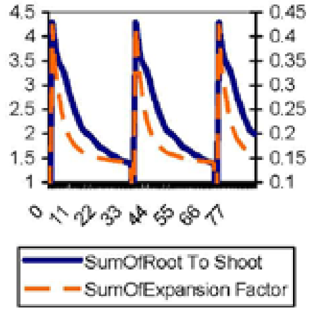
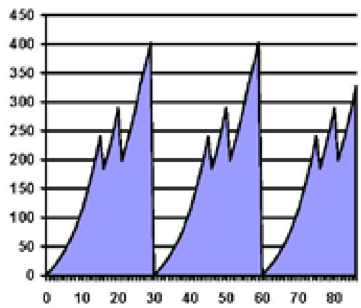


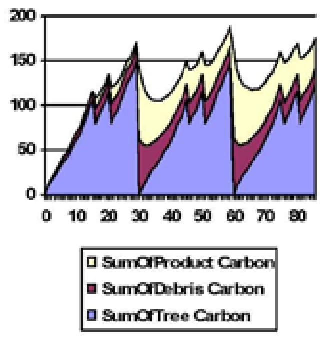


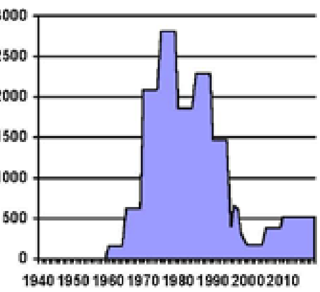


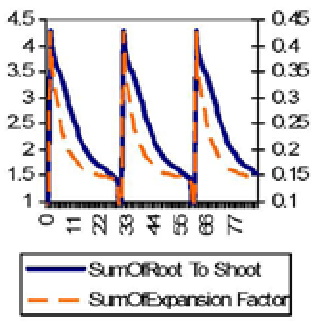


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
VicNSW6 P.rad 2	Murray Valley	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - 47% thinning @ 14 years, 35% @ 22, CF @ 30



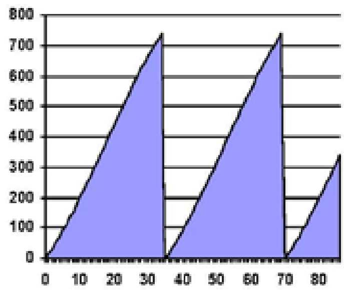


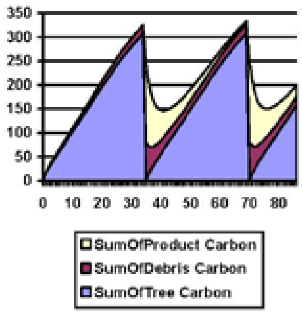


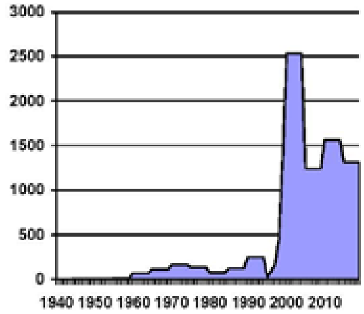


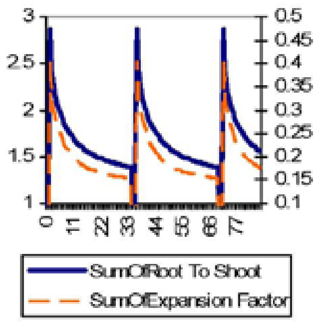
LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Vic7 P.rad 1	Victoria (Central Gippsland)	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - 33% thinning @ 15 years, 37% @ 20, CF @ 30

APPENDICES









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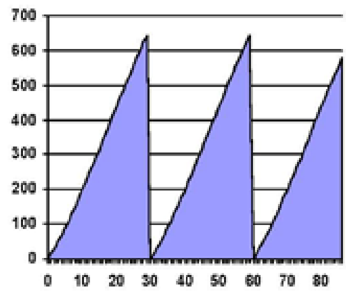
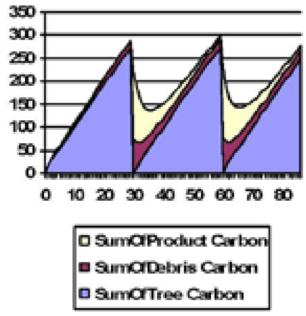
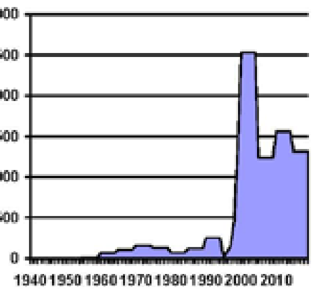
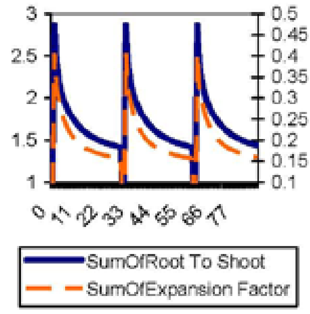
Vic7 Euc 4	Victoria (Central Gippsland)	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - CF @ 35



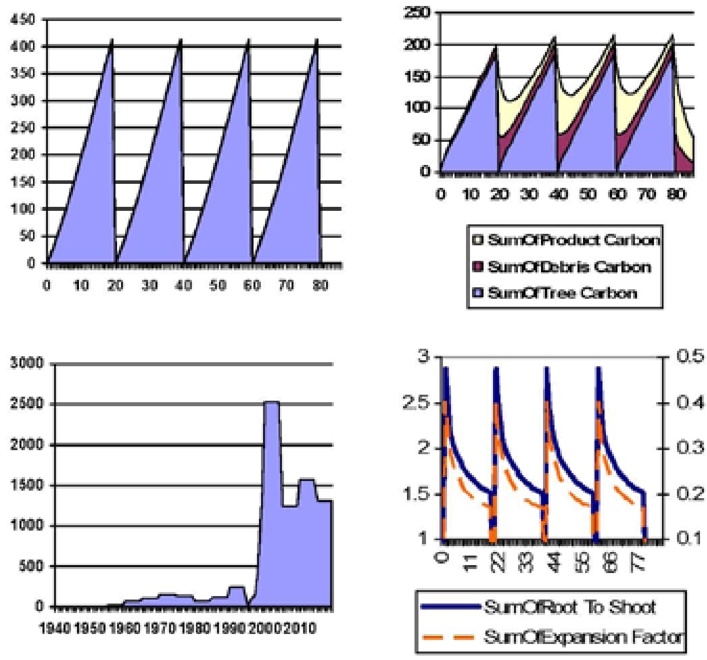






LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Vic7 Euc 3	Victoria (Central Gippsland)	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - CF @ 30

APPENDICES



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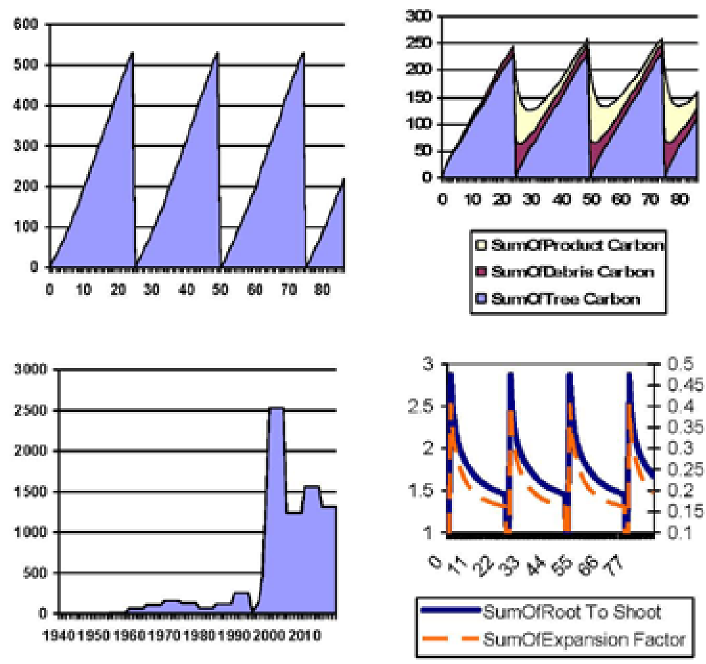
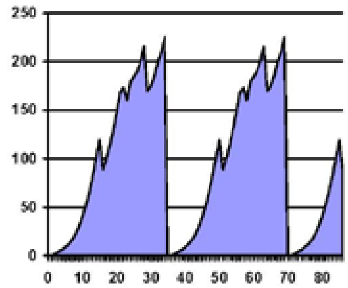
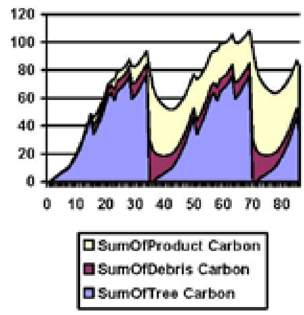
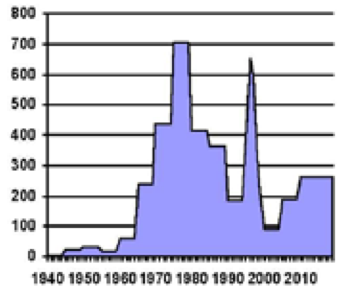
Vic7 Euc 2	Victoria (Central Gippsland)	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - CF @ 20

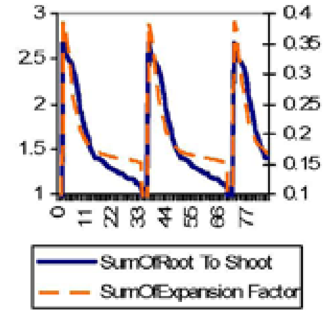


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Vic7 Euc 1	Victoria (Central Gippsland)	Eucalyptus plantations	550	52	52	47	52	52	49	All Sites - CF @ 25

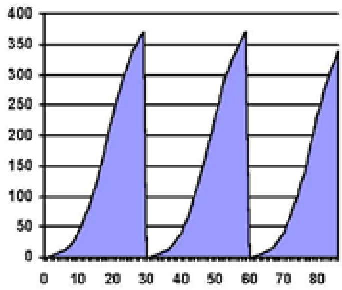


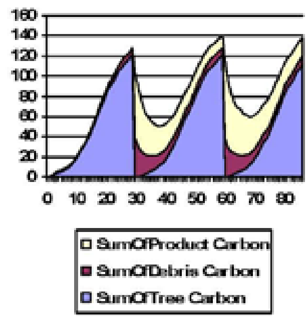


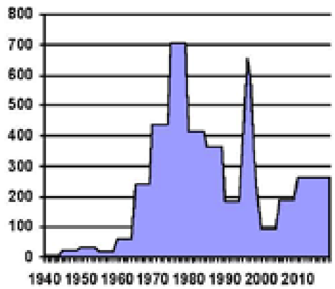


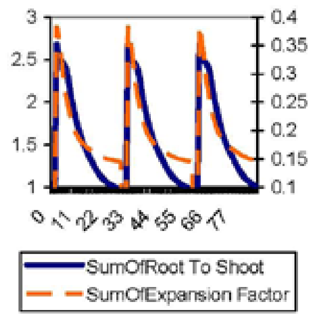


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Vic5 P.rad 2	Victoria (Central)	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - CF @ 30









LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Vic5 P.rad 1	Victoria (Central)	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - 34% thinning @ 15 years, 18% @ 22, 24% @ 28, CF @ 35

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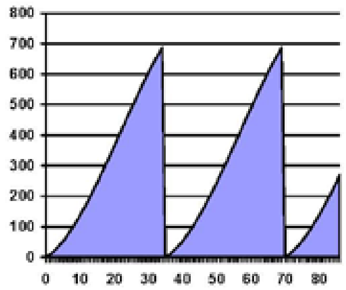
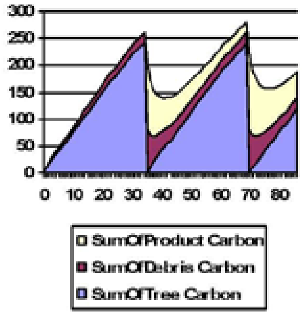
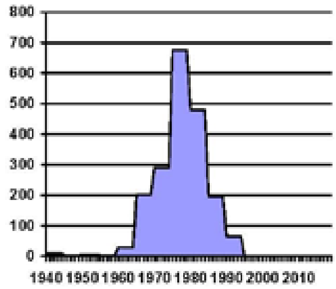
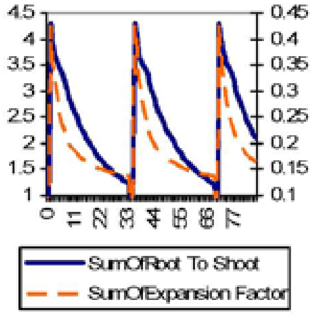
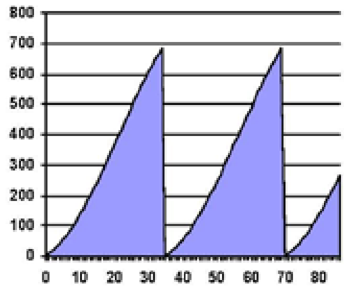


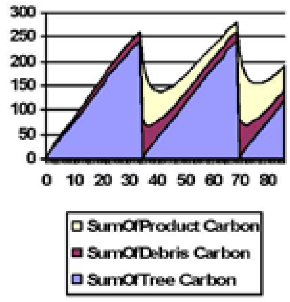


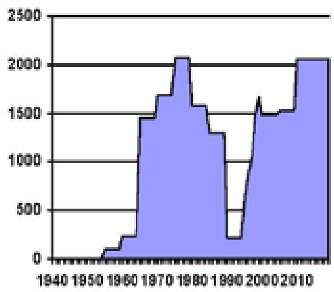


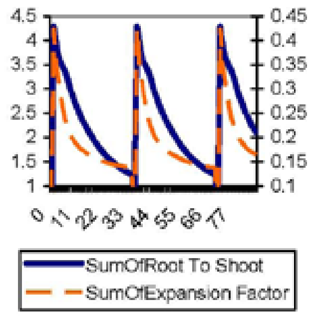


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Tas2 Pinus 1	Tasmania	Pinus (other than radiata)	440	52	52	51	51	52	53	All Sites - CF @ 35



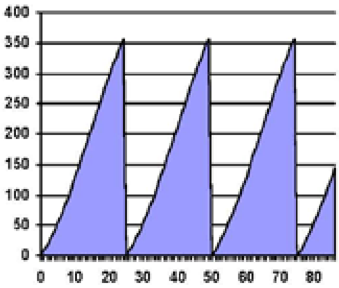


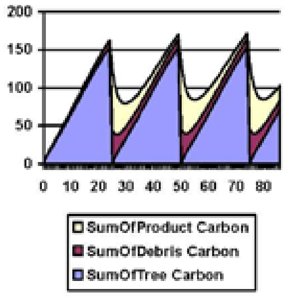


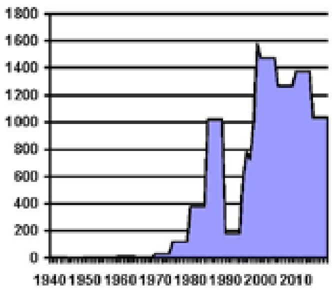


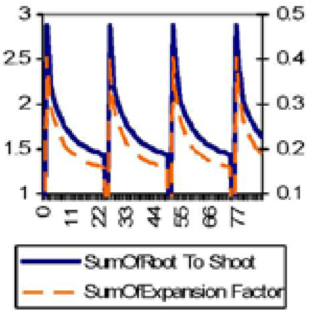
LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Tas2 P.rad 1	Tasmania	*Pinus radiata*	440	52	52	51	51	52	53	Average Sites - CF @ 35

APPENDICES

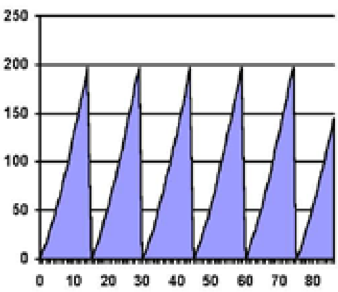


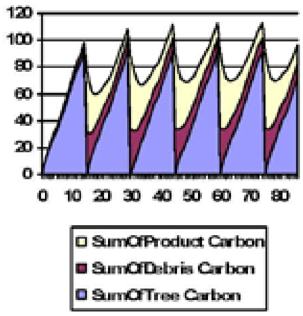


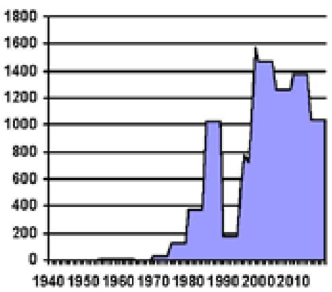


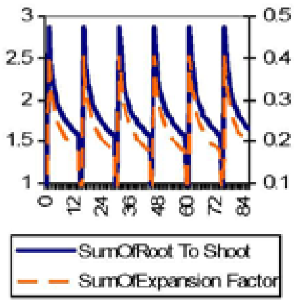


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Tas2 E.nit 3	Tasmania	*Eucalyptus nitens*	550	52	52	47	52	52	49	All Sites - CF @ 25









LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Tas2 E.nit 2	Tasmania	*Eucalyptus nitens*	550	52	52	47	52	52	49	All Sites - CF @ 15

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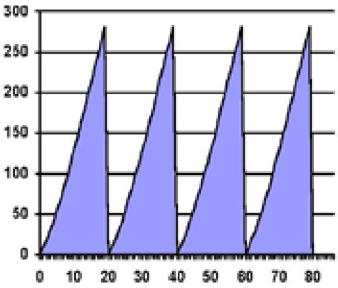
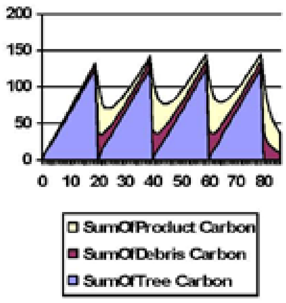
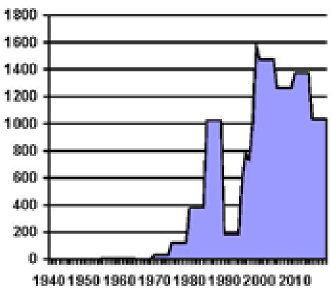
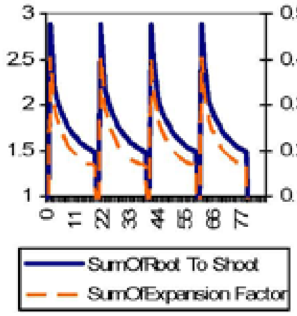
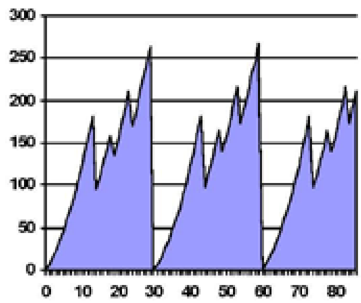


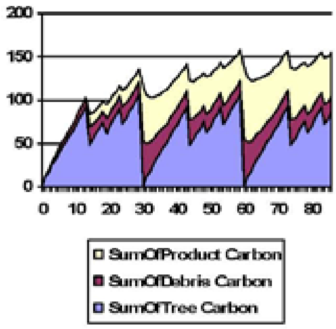


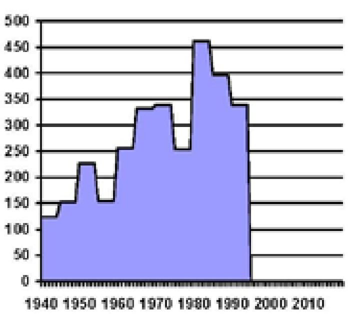


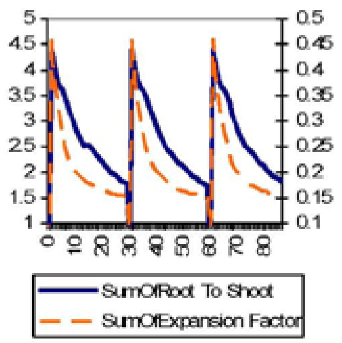


LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
Tas2 E.nit 1	Tasmania	*Eucalyptus nitens*	550	52	52	47	52	52	49	All Sites - CF @ 30









LookUp	Region(s)	Species	Density	CC% Leaf	CC% Twig	CC% Branch	CC% Sapwood	CC% Wood	CC% Bark	Regime Description
SA4 Pinus 1	South Australia	Pinus (other than radiata)	440	52	52	51	51	52	53	Average Sites - 54% thinning @ 13 years, 25% @ 18, 28% @ 23, CF @ 30

APPENDICES

Attachment 7.B2: Quality Assurance

Forestry and Forest Products

Banks Street, Yarralumla, ACT 2600, Australia
Postal Address: PO Box E4008, Kingston ACT 2604, Australia
Telephone: (02) 6281 8211 (International + 61 2 6281 8211)
Facsimile: (02) 6281 8312 (International + 61 2 6281 8312)
E-mail: enquiries@ffp.csiro.au
http://www.ffp.csiro.au/

30 November 2001

Mr Ian Carruthers
Senior Executive Manager
Greenhouse Policy Group
Australian Greenhouse Office
GPO Box 621
CANBERRA ACT 2601

Dear Ian

National Article 3.3 Model

I am pleased to be able to provide the following report of the review of the National Carbon Accounting System National Article 3.3 Model performed by a team of four scientists from CSIRO Forestry and Forest Products. The CSIRO team have not been directly involved in development of the CamFor model or its calibration for this particular application. However, CSIRO are very aware of the work that has supported it.

Based on some fundamental presumptions (such as the area statements and growth and yield estimates) the CSIRO team undertook a quality control/assurance review of the modelling framework, assumptions and results. During the review, future refinements of the models were agreed with the NCAS developers.

Findings:

1. Areas and Forest Types

The modelling was based upon some prescribed inputs that were not the subject of quality assurance. These were provided by the BRS and included:

1) Area statements and plantation expansion scenarios
2) Forest types, modified from the NPI
3) Average growth and yield forecasts for each of those forest types

The assignment of areas to forest types, and the entry of growth and yield data to the model, appears to be correct.

A u s t r a l i a n S c i e n c e , A u s t r a l i a ' s F u t u r e

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2. *Model Framework*

The CAMFor/CAMForEstate models are appropriate for this task. The alternative of using a processes-based modelling approach is considered premature, due to inadequate validation at the national scale. The capability for risk analysis, which is part of the model, is an important tool for analysing uncertainty.

3. *Density, Carbon Contents and Allocations*

Data for a range of tree characteristics have been drawn from a range of published sources and transferred to the models. Wood density is drawn from the NCAS Technical Report No. 18, Carbon Contents from NCAS Technical Reports 7 and 22, and expansion factors and root:shoot ratios from NCAS Technical Reports 5a, 5b and 17. The reports summarise the extent of readily available knowledge. This information has been summarised and correctly incorporated into CAMFor.

4. *Turnover Rates*

In this model application, rates of change were specified for :

(i) Turnover of tree components, and (ii) decomposition of wood products.

The turnover rates of tree components applied in the model provide realistic results. They should be revised to ensure more consistent model performance, but this is unlikely to have a major impact on forecasts of C sequestration.

The wood product decomposition rates are those derived from the NCAS Technical Reports 8 and 24, and whilst representing the state-of-knowledge in this area, are very uncertain. Getting better estimates is very important to improving future predictions.

5. *Model Results*

Model predictions are consistent with site level changes in carbon pools for the range of forest types examined.

6. *Transparency*

The model and data underpinning its calibration have been published in a range of NCAS reports, and peer-reviewed literature. Thus the assumptions can be readily reviewed, and feedback at several levels has been used to refine the model.

2

7. Future Developments

While the National Article 3.3 model represents good practice there are a range of areas where additional development would be beneficial.

1) Area Statements – a desirable objective would be to derive a plantation map from the NCAS satellite data. This will provide a more robust and spatial estimation of Kyoto-compliant forests. Projected rates of plantation establishment are the greatest source of uncertainty in estimating future carbon sequestration.

2) Growth and Yield –growth and yield curves should be progressively updated based on research and industry data so as to account for change in the plantation land base and management methods.

3) Forest Litter and Soils – while forests soils tend to stabilise around small net change in carbon stock in the medium to long term, the short term changes combined with highly skewed age class distributions have the potential to impact on the national account over the first Commitment period. Continued development of the NCAS capacity to operationalise a spatial soil carbon model should be pursued.

4) Data – the information used for model calibration, such as partitioning and turnover are the best available, but requires improvement. Further collection and synthesis of such data are required.

Yours sincerely

John Raison

John Raison
Chief Research Scientist

APPENDICES

Appendix 7 D: Other Native Forests

Background

The *Other Native Forests* sub-category includes all areas of forest that are not *Plantations* (see Appendix 7.C), not *Harvested Native Forests* (see Appendix 7.B) and have not been subject to deforestation (*Forest land converted to Cropland* and *Grassland*; Appendix 7.E). The *Other Native Forests* subcategory includes protected areas (such as Wilderness areas and National Parks) and areas of extensive forests and woodlands. Australian vegetation is adapted to frequent disturbances, such as recurrent fires, and the effects of extreme climate variability (in particular, droughts). The influences on annual emissions and removals that are likely to affect *Other Native Forests* include:

- fire;
- thickening and dieback;
- annual climate variability;
- selective extraction of forest products;
- grazing; and
- recovery from pre 1972 land use change.

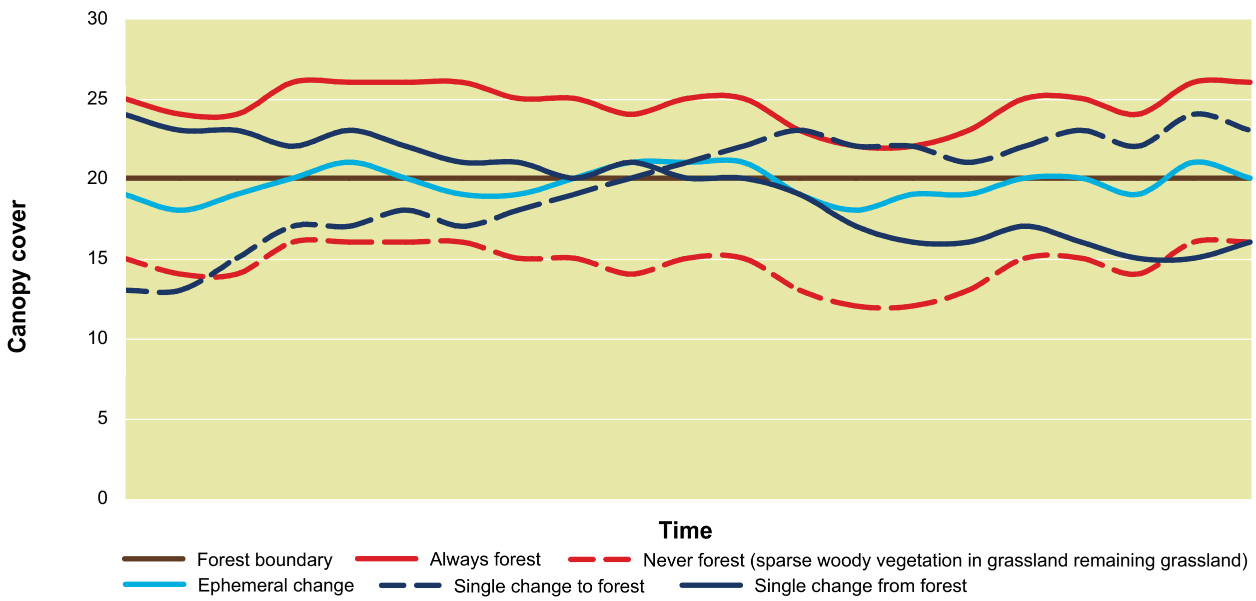
As most of the emissions and removals from these activities are driven by natural variability and natural disturbance, the effects are generally:

- cyclic in terms of disturbance and recovery patterns over time;
- typically regionally specific because differences in climate and ecosystem type imply different stages of disturbances and recovery at different times; and
- not expected to exhibit consistent trends toward either emissions or removals over longer term, but will be highly variable over time.

Trends in Forest Vegetation Cover in Other Native Forests

The mixture of climate effects, grazing, fire and recovery from land use change, and the regional differences in these processes gives rise to variability in forest cover over time. Figure 7.D1 shows the typical fluctuations in forest cover that occur around the prescribed canopy cover definition of a forest (20% in Australia).

Figure 7.D1: Patterns of change in forest cover in areas not subject to deforestation or afforestation and reforestation



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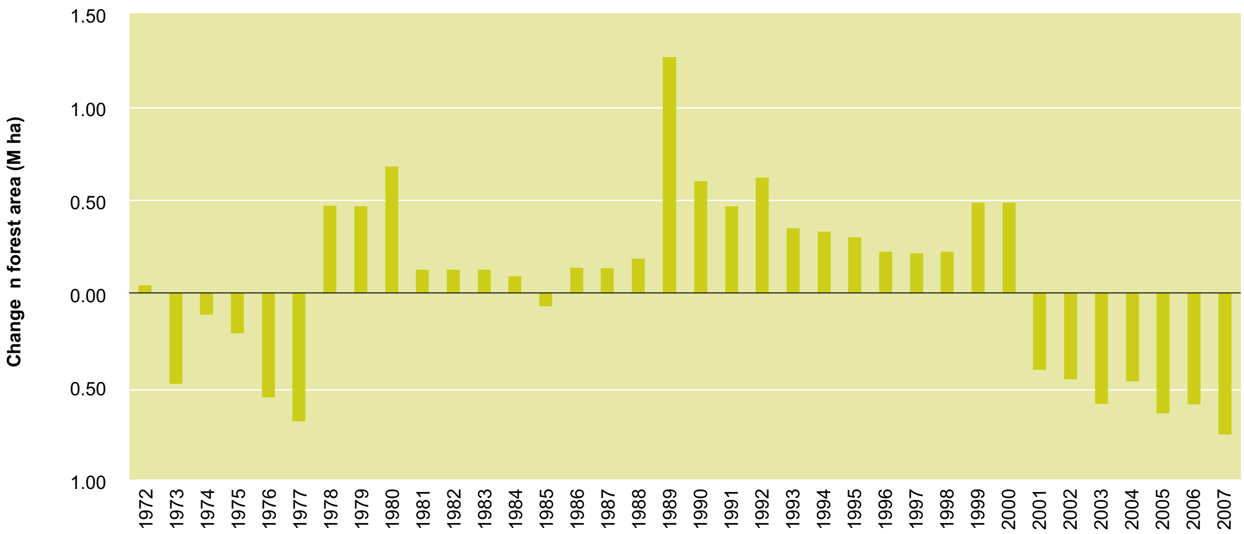
For the areas that exhibit a loss or gain in the area of forest, it is possible to extract this data from the time-series of remotely sensed data. Figure 7.D2 below shows the net national gains and losses in forest cover in *Other Native Forests* since 1972. This represents the areas of forest cover change not assessed as being a land use change.

Figure 7.D2: Change in forest area (millions of hectares) not attributable to land use change and included in Other Native Forests, since 1972



One of the first ways to contemplate attribution to a 'cause' for loss or gain is to look at the correlation of change with climate variation. This can be done at a national scale by comparing the gains and losses of forest area not attributable to anthropogenic land use change with a key climate variable of tree stress, such as vapour pressure deficit. Notably, at this coarse national scale there is a statistically significant ($p<0.01$, $r2=0.67$) association between vapour pressure deficit and change in forest cover (Figure 7.D3).

Figure 7.D3: (a) Change in forest area

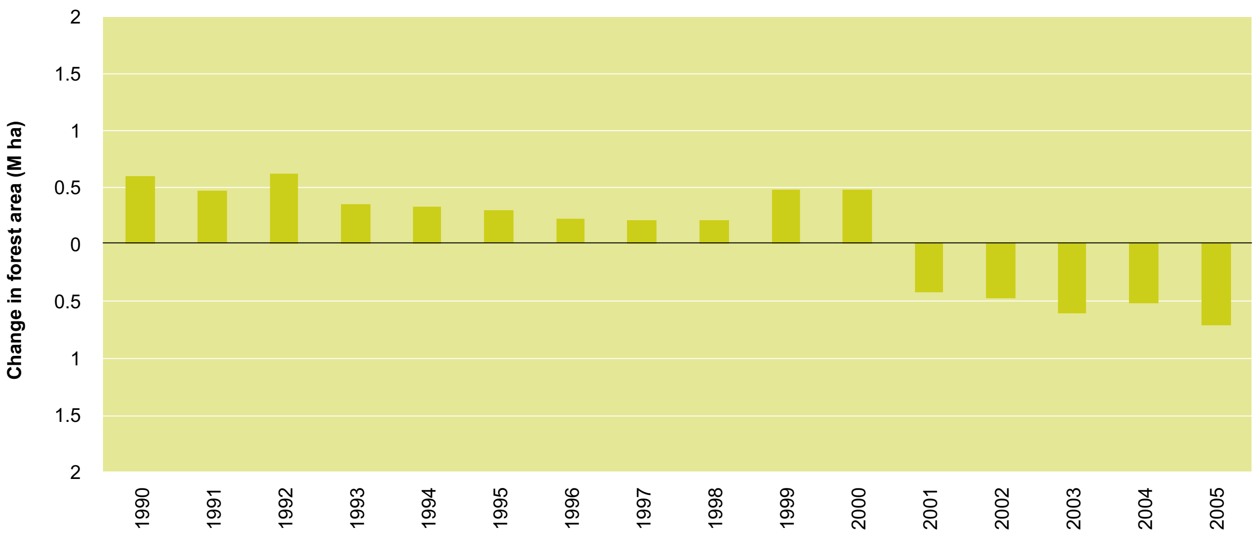


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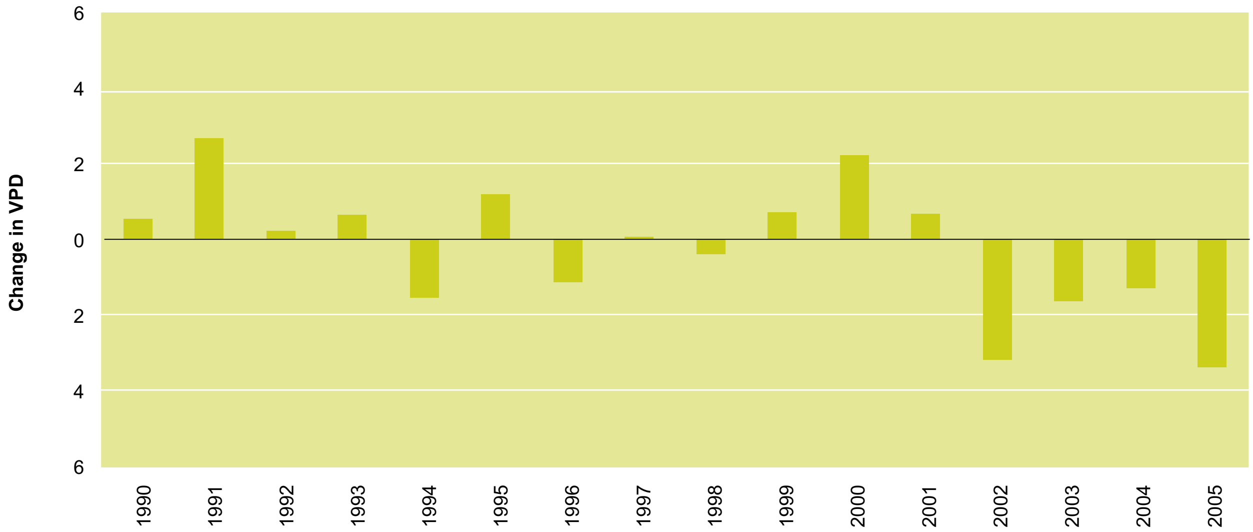
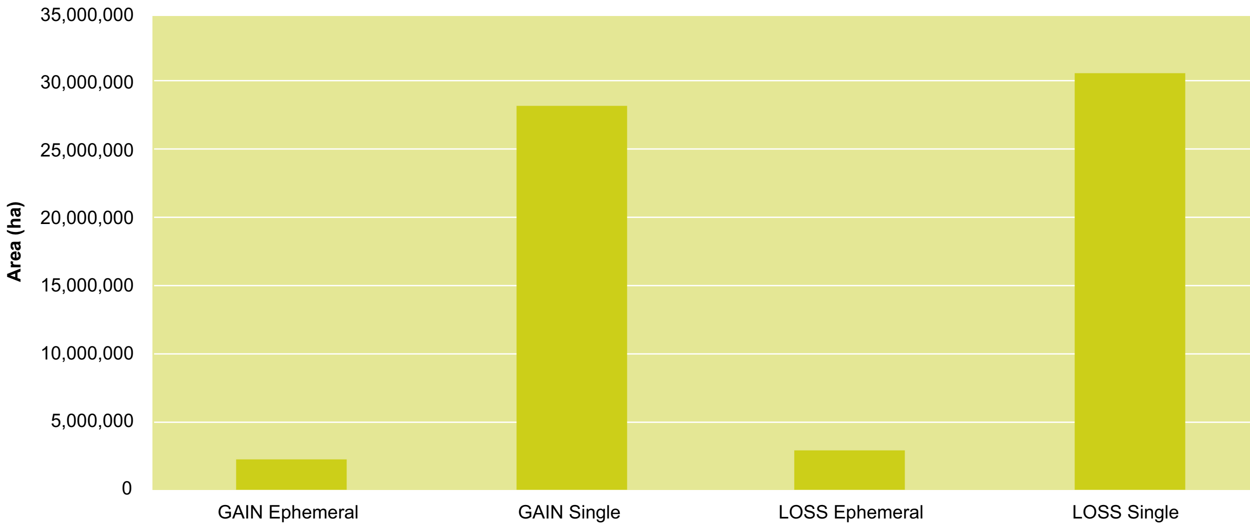
Figure 7.D3: (b) Variation from average of VPD



To estimate emissions, it is of significance whether these are persistent changes on different areas of land, or whether they are intermittent and ephemeral changes on the same areas of land. To resolve this question, the areas affected by non-anthropogenic change in forest area were analysed to determine the proportion that were impacted by a single observed change in the remote sensing time series, or intermittent change. The process used to separate the human caused land use change areas from natural cycles in forest cover change is described in Appendix 7.A. Figure 7.D4 shows that the proportion of areas affected by a single change (a single transition in either direction) compared to intermittent and ephemeral change (more than on transition) is around 8%.

Figure 7.D4: Areas of forest to non-forest transitions that are single (one transition only) and ephemeral (more than one transition) at some time in the time series of remotely sensed data



The importance of the information on the number of transitions to the estimation of emissions is that:

- a single transition (loss or gain) usually indicates the long-term (e.g., not seasonal) loss or establishment of a long-term forest system unless it occurs at the end of the time series; and,

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- multiple transitions are indicative of ephemeral changes, likely affecting only leaf mass and with negligible emissions or removal consequences.

For the second component of *Other Native Forest*, (those that have continuously been forest since 1972) the process of emissions and removals is determined by the combination of variation in patterns of densification and degradation. This must be accounted for using both the temporal and spatial approaches.

Methodology

The estimates of emissions and removals in Other Native Forests consist of several sub models. The five components of the estimate of emissions and removals are:

1. ephemeral, intermittent changes in forest cover (i.e., forest and non-forest transitions) due to changes in leaf area;
2. changes in leaf area in areas of continuous forest cover (i.e., no change in forest status);
3. single changes in forest cover (i.e., forest and non-forest transitions) through dieback and regrowth;
4. woody thickening; and
5. emissions and removals of CO_2 through wildfire and prescribed burning.

Annual changes in foliage mass

The thinning and flushing of tree crown cover with climate fluctuation is a common feature of Australian forests. As the change is not persistent, it is presumed that there is no significant tree mortality or seedling recruitment beyond normal levels. With extensive areas of forest just at the lower crown cover threshold, annual climate variability can move substantial areas of forest under and over the forest threshold (2 metres height and 20% crown cover density) value, with only a small loss or gain of leaf mass. In areas of thicker forest, changes in leaf mass will not lead to changes in forest cover, but will still lead to small amounts of emissions and removals. These two processes, although driven by the same factors, are modelled separately as ephemeral, intermittent changes in forest cover, and changes in leaf area of continuous forest cover.

Ephemeral, Intermittent Change in Forest Cover

The proportion of forest cover that is ephemeral and intermittent is around 8% of the total non-anthropogenic change identified using the forest extent data obtained from the Landsat analysis (Appendix 7.A). For these lands a Tier 2 model is used to estimate emissions and removals due to changes in forest cover. The method assumes a total change of 0.15 tDM ha^{-1} yr^{-1} for both losses and gains, and a carbon content of 50%. The estimate of 0.15 tDM per hectare is based on an estimated aboveground biomass of 30 tDM for dry forests at the edge of the forest/non-forest boundary (based on Raison et al., 2003), with 2% of the aboveground mass being leaf, and a total potential loss or gain of 25% with climate variability.

Changes in Leaf Area of Continuous Forest Cover

In many areas of *Other Native Forests* there are intermittent changes in forest cover, largely attributed to changes in leaf area with climate variability. Despite the change, the forest crown cover may not move to a level below the lower threshold used to define a forest condition, i.e., the area remains a forest.

As the change is due to fluctuations in leaf area (and leaf mass) but not the woody component of trees, the effect on emissions and removals are short-lived and sporadic, as the carbon stock losses are small and recovery rapid. For this class of change in forest cover, both losses and gains are considered to take place within the one year. The parameters used in the Tier 2 model developed are shown in Table 7.D1. This method assumes a maximum change in leaf mass of 0.2 tC ha^{-1} between the maximum and minimum LAI values. When the average LAI declines, leaf mass is lost and when LAI increases leaf mass also increases. The amount of loss or gain depends on the change in LAI.

Table 7.D1: Parameters used to estimate emissions and removals from changes in leaf mass in areas of forest cover

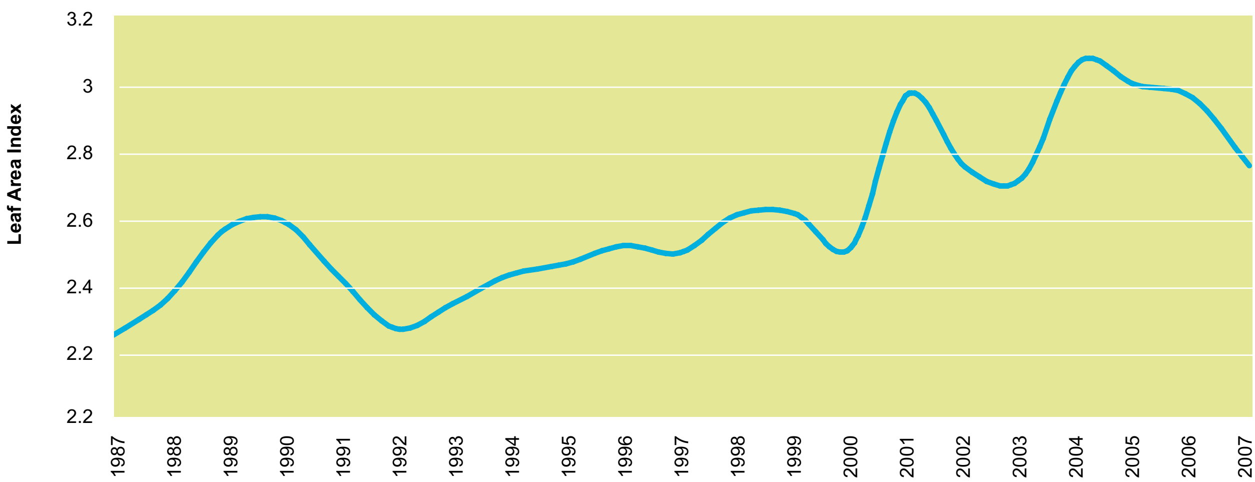
Parameter	
Max LAI	3.05
Min LAI	2.23
LAI range	0.82
Leaf mass range (tC/ha)	0.20

Australia is working on the development of methods for the time-series mapping of forest crown cover density that can be extracted from the existing Landsat data archives. However, until the development of the methods is complete, the best estimate of changes in forest crown cover through time can be obtained by:

- calculating Leaf Area Index (LAI) from the time-series of Normalised Difference Vegetation Index of the AVHRR, NOAA satellite sensor using equation (10) presented in Kesteven et al., (2004);
- intersecting the LAI data with forest extent (that is, only include areas of continuous forest cover as determined from the 25m Landsat data); and
- summing and averaging the monthly LAI values to give annual, national LAI value.

The time-series trend in LAI for areas of continuous forest cover is shown for the period where the LAI data series is available (i.e., since 1987) (Figure 7.D5).

Figure 7.D5: Time-series national annual leaf area index



Permanent loss and gain of forest cover

This category is for areas where there is a single change in forest extent, as either a loss or a gain throughout the observed time-series. This represents either a gain or loss of forest cover in independent areas. The emissions and removals for these areas reflect a change in forest cover, even in the absence of a land use change. A long term effect is more likely to result from changes in woody biomass than the ephemeral changes that affect only leaf mass as reported in the following section. The Tier 2 model developed for the estimation of emissions of change from these sustained effects uses the parameters shown in Table 7.D2. A carbon increment value of 0.5 tC ha^{-1} $year^{-1}$ (Lucas et al., 1997) is used, as most of these changes are occurring in drier, degraded woodland systems. The model assumes that carbon is lost or gained for 20 years following inclusion or removal of the forest from the national forest area. This reflects both the slow uptake of carbon in regrowing systems and continuing decline and emissions from areas which fall below the forest threshold.

Table 7.D2: Parameters used in the model of single change in forest cover

Parameter	
Total C loss/gain from single change	10
Years over which C is lost	20
Years over which C is gained	20
Effective growth rate (tC ha^{-1} yr^{-1})	0.5
Effective loss rate (tC ha^{-1} yr^{-1})	0.5

Woody thickening

Some studies in Australia have indicated a trend towards 'woody thickening' in Australian forests (e.g. Burrows et al., 2002; Gifford and Howden 2001). Where this thickening is occurring it is likely to lead to carbon uptake. Conversely, other studies have found evidence of widescale dieback and degradation (Fensham 2009), which would lead to decreasing carbon stocks and increase emissions.

An estimate of the area subject to woody thickening was derived based on the results of both Burrows et al., (2002) and Fensham et al., (2009). The regional coverage of the Burrows et al., (2002) study is limited and is only considered representative for the 71% of the 27 Mha of SE Queensland woodlands (19.1 Mha). Based on the work of Fensham et al., (2008; 2009), this area estimate was reduced by 50% to account for dieback and degradation. The total area used in the woody thickening model is therefore 9.55 Mha.

Burrows et al., (2002) estimated an average aboveground biomass increment of 0.25 tC/ha for areas subject to woody thickening. This was adjusted to include belowground biomass by applying a root:shoot ratio of 0.4 based on Snowdon et al., (2000). This results in a total growth of 0.35 tC/ha per year, which is equivalent to 1.28 tCO_2/ha/year.

The calculation for the woody component of Other Native Forests (that have always been forest) is therefore 9.55 Mha * 1.28 tCO_2/ha/yr = 12.2 Mt CO_2 per year. This value is applied for each year in the inventory.

Fire

The *Other Native Forests* category includes CO_2 emissions from both prescribed burning and wildfire. Prescribed burning includes managed fires that aim to reduce debris loads in *Other Native Forests* and are typically low intensity, only removing fine litter from the forest. Wildfires are uncontrolled fires and can range from low intensity burns which remove fine litter through to high intensity wildfire which can remove most debris as well as foliage and small branches. While it is rare in native systems for a fire to be 'stand-replacing', even in instances where this occurs, carbon from live biomass is typically transferred to coarse woody debris. High levels of combustion are typically confined to 'fines' such as grasses, leaves and twigs. Even under the most intense fire, most stems will remain.

The emissions due to fire are affected by the areas burnt, the combustion efficiency of fires and micro-scale climate condition (e.g., wind, local temperatures and topography). The rates of recovery (removals) after fire vary with climate, ecosystem type, previous fire history and site conditions. As fires often remove only fine debris and leaves from live biomass, the recovery can be quite rapid. The estimation of CO_2 emissions from forest fires and CO_2 removals from recovery in *Other Native Forests* is based on the areas burnt (Figure 7.D6), parameters and input data developed for the estimation of non-CO_2 emissions from forest lands in section 7.A13.1.1. The debris mass recovers within 5 years, with a typical rapid input of scorched leaf and bark material.

For forest fires the total mass of fuel burnt is calculated as:

$$M_{jk} = A_{jk} * FL_{jk} * Z_{jk} * 10\text{-}3 \qquad (1)$$

Where: A_{jk} = area of category burnt annually (ha),
M_{jk} = mass of fuel burnt annually (Gg),
FL_{jk} = fuel loading (dry weight) (Mg ha^{-1}) (Table 7.A8 and 7.A9),
Z_{jk} = burning efficiency (Table 7.A10).

Annual CO_2 emissions are calculated as:

$$E_{ijk} = M_{jk} * CC_{jk} * C_i \qquad (2)$$

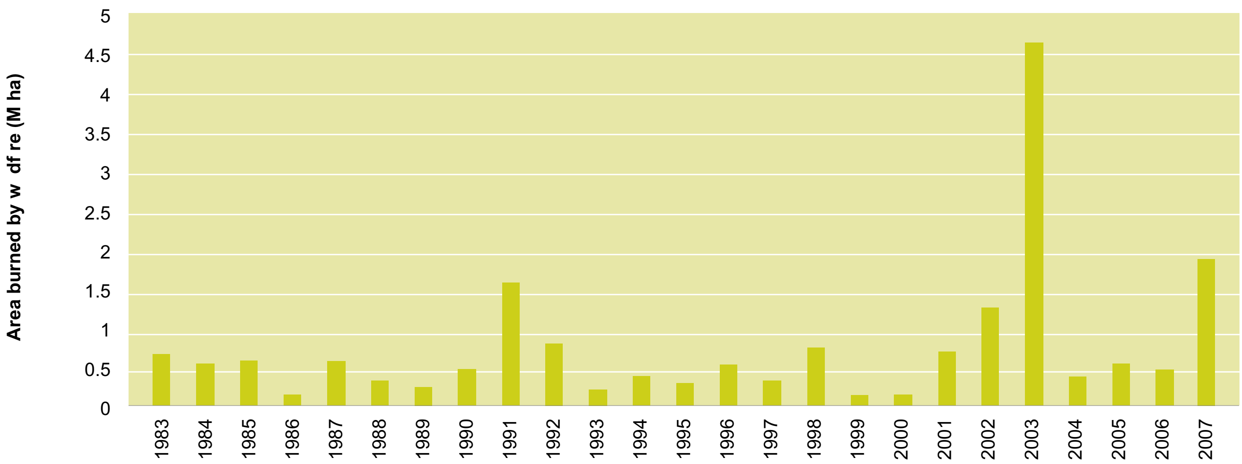
Where: E_{ijk} = annual emission of gas *i* from biomass burning (Gg),
M_{jk} = mass of fuel burnt annually (Gg yr^{-1}),
CC_{jk} = carbon mass fraction in vegetation (Table 7.A11),
C_i = 3.67 factor to convert from elemental mass of gas species *i* to molecular mass.

Annual CO_2 removals are calculated as:

$$R_{ijk} = \sum(M_{jk} * CC_{jk}) / t * C_i \qquad (3)$$

Where: R_{ijk} = annual removals of CO_2 following biomass burning *(Gg),*
$\sum M_{jk}$ = mass of fuel burnt over period t,
t = time required for carbon lost due to fire to be recovered (assumed to be 5 years),
CC_{jk} = carbon mass fraction in vegetation (Table 7.A11),
C_i = 3.67 factor to convert from elemental mass of gas species *i* to molecular mass.

Figure 7.D6: Areas burned by wildfire 1983-2007



Results

The annual emissions and removals from *Other Native Forests* are highly variable due to the effects of natural variability and disturbance (Table 7.D3). Emissions and removals from the change in leaf area (leaf mass) of continuous forests are highly variable, responding on annual timescales to climate variability. For the period 1990 to 2007 emissions estimation for the single change in forest cover the model indicates a net removal (sink) due to the increase in new forest area from the late 1970's until 2000 (Figure 7.D2). The decrease in forest area since 2000 is yet to offset the area gains of the previous 20 years. Emissions from fire are highly variable and contribute the majority of variation in emissions and removals for the *Other Native Forests* category.

Table 7.D3: Results of the estimates of annual emissions and removals in Other Native Forests

Year	Emissions (Mt CO_2)					
	Ephemeral change in forest	Leaf mass change in continuous forest	Single change in forest	Woody Thickening	Fire	Total
1990	-0.01	-2.10	-4.01	12.20	4.20	6.08
1991	-0.01	13.74	-4.72	12.20	54.05	21.21
1992	-0.01	12.84	-5.69	12.20	4.97	19.34
1993	-0.01	-6.21	-7.10	12.20	-21.71	-1.11
1994	-0.01	-6.95	-7.85	12.20	-9.67	-2.60
1995	-0.01	-2.59	-8.72	12.20	-16.80	0.88
1996	0.00	-4.49	-10.02	12.20	-4.48	-2.31
1997	0.00	1.73	-11.53	12.20	-2.80	2.40
1998	0.00	-9.16	-11.10	12.20	13.29	-8.06
1999	-0.01	-0.28	-11.13	12.20	-14.73	0.78
2000	-0.01	8.12	-10.79	12.20	-10.26	9.52
2001	0.01	-36.32	-9.88	12.20	12.38	-33.98
2002	0.01	17.27	-8.87	12.20	36.21	20.62
2003	0.01	2.50	-7.63	12.20	173.50	7.08
2004	0.01	-27.10	-6.62	12.20	-43.15	-21.51
2005	0.02	5.20	-5.55	12.20	-37.47	11.86
2006	0.00	0.00	-5.32	12.20	-45.24	6.88
2007	0.00	0.00	-5.08	12.20	22.87	7.12

Appendix 7.E: Forest Conversion to Croplands and Grasslands

Introduction

Emissions estimates from forest land converted to a non-forest land use apply the full capability of Australia's National Carbon Accounting System (NCAS). This capability uses a mass balance, process-based ecosystem model (Tier 3) in a fully spatially explicit land representation (Approach 3). The areas and timing of forest conversion are identified through a national time-series of Landsat satellite data.

The data used for *Forest land converted to Grassland* and *Forest land converted to Cropland* are reported below. The descriptions are framed around the program areas of the NCAS that provide the required input data. A full description of the methods used are provided in Appendix 7.A

Model configuration

The *FullCAM* model is used for estimating emissions from the *Forest land converted to Grassland* and *Cropland* sub-categories. For these sub-categories *FullCAM* operates in its fully spatially explicit (Approach 3) manner using Tier 3, mass balance modelling. The model runs in a mixed configuration (i.e., both forest and agricultural systems) using the *CAMFor, CAMAg* and *Roth-C* sub-models as shown in Table 7.E1. Initial biomass and tree growth is established using the approaches outlined in Appendix 7.A. A description of the sub-models, how they are linked to ensure mass balance, and their performance is also provided in Appendix 7.A.

Consistent with the treatments of *Forest land* conversion under the IPCC Good Practice Guidance (IPCC 2003), only areas that have been affected by a relevant land cover change are accounted for. This includes land cover change in previous years (since 1972) which can have a 'lagged' impact on carbon stock. Once an area of land is identified as subject to conversion its status is subsequently tracked through time.

To support this form of *FullCAM* model implementation, a series of tabular and spatial databases are used, including:

Maps

- fifteen sequences of both clearing and regrowth 1972-2007 (25 m);
- an initial 1972 forest/non-forest mask (25 m);
- monthly rainfall maps of Australia since 1968 (1 km);
- monthly average temperature maps of Australia since 1968 (1 km);
- annual top-soil moisture deficit maps of Australia since 1970 (1 km);
- a long-term average productivity (index) map of Australia (250 m);
- annual productivity maps of Australia since 1970 (1 km);
- a soil clay content map of Australia (250 m);
- a pre-disturbance soil carbon content map of Australia (250 m);
- a maximum forest biomass (biomass at maturity) map of Australia (250 m); and
- a forest type (MVG) map of Australia (200 m).

Tabular Data (from the FullCAM relational database)

- forest type attributes (partitioning, density etc.);
- forest litter amounts and characterisation;
- land use allocations (to allocate cleared land to an agricultural land use based on the time of clearing, soil type and region);
- soil fractionation scheme for each soil type;
- crop type attributes (harvest index, yield etc.); and
- crop management (activities, sequencing and timing for land use systems etc.).

Table 7.E1: *FullCAM* configuration used for the Forest to Cropland and Grassland categories

Component	Forest	Agriculture
Living biomass	CAMFor – Forest Productivity Index and Tree Yield Formula	CAMAg – Crop yield tables
Dead organic matter	CAMFor	CAMAg
Soil carbon	RothC	RothC
Offsite products	NA	NA

Data used

Land Cover Change

The area of land that is converted from forest to crop and grassland is obtained from the NCAS remote sensing programme described in Appendix 7.A. This data provides both the timing and location of change since 1972. The spatially explicit nature of this data allows for the pixel by pixel (Approach 3) modelling of *Forest land converted to Cropland* and *Grassland* across the landscape. The long time series of data also allows for the identification of cyclic clearing/regrowth cycles that are common across much of Australia's drier inland regions (Australian Greenhouse Office, 2000).

Climate and Soil Inputs

Climate variation has a significant effect on emissions in the short term, and as many management and reporting issues also relate to short term changes, it is important to be able to account for this variability. The process-based models used in *FullCAM* (e.g., *Roth-C*) use the climate data described in Appendix 7.A to reflect this variability. The methods used to develop the climate surfaces are detailed in Kesteven et al., (2004). Soil inputs to the model are soil type (for fractionation), clay content and the initial top soil moisture deficit. These affect the amount of carbon in each soil fraction (e.g., RPM, DPM) and the subsequent rates of loss or gain in soil.

Crop Growth and Plant Parameters

Crop Yield and Residue (CAMAg)

The amount of plant residue input to litter and soil carbon pools is a significant determinant of total site carbon and trends in soil carbon over time (Janik et al., 2002). Therefore, reliable crop growth information (supported by management practice information as management practice affects residue generation and management) is important for robust soil carbon estimation. The crop growth data used in the model is based on crop yield statistics where available, as detailed in Swift and Skjemstad (2002) and Skjemstad and Spouncer (2002). The available crop data is usually expressed in terms of the mass of the saleable product component of growth (e.g., tonnes of grain, cane, leaf yield per hectare or tonnes of total aboveground yield per hectare). Available data has been reviewed to develop the appropriate corrections for each plant type to enable conversion from mass of saleable product to total plant mass. The crop types and plant partitioning used in the modelling are shown in Table 7.E2. Where crop yield data is not readily available the crop yield data is estimated using plant growth model outputs.

The crop yield data is updated annually by CSIRO and provided to the NCAS. The data is then incorporated into the *FullCAM* relational database so that it can be accessed during modelling for each cropping system at the relevant time, IBRA region, and soil type.

Figure 7.E1: Overview of the Crop Growth and Plant Parameters Program

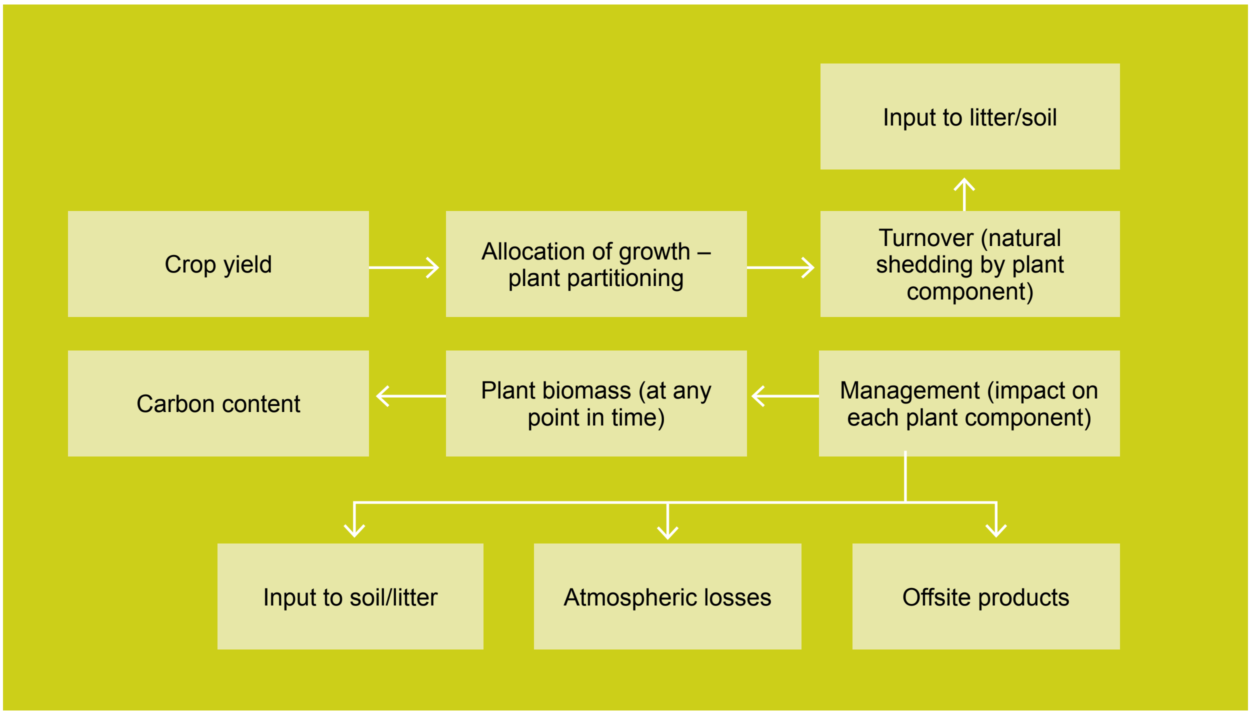


Table 7.E2: Plant partitioning by crop type

Name	Yield Allocation to Grains, Buds or Fruit (fraction)	Yield Allocation to Stalks (fraction)	Yield Allocation to Leaves (fraction)	Yield Allocation to Coarse Roots (fraction)	Yield Allocation to Fine Roots (fraction)
Agricultural crops	0.28	0.00	0.42	0.00	0.30
Annual pasture	0.00	0.00	0.50	0.00	0.50
Annual pastures	0.00	0.00	0.50	0.00	0.50
Barley	0.30	0.00	0.40	0.00	0.30
Canola	0.27	0.00	0.51	0.00	0.22
Cereal	0.27	0.00	0.43	0.00	0.30
Cereal forage	0.00	0.00	0.60	0.00	0.40
Cereals	0.26	0.00	0.43	0.00	0.31
Cleared improved pasture	0.00	0.00	0.50	0.00	0.50
Continuous pasture	0.00	0.00	0.50	0.00	0.50
Crop	0.27	0.00	0.43	0.00	0.30
Cropping (e.g. barley)	0.24	0.00	0.46	0.00	0.30
Fallow	0.20	0.20	0.20	0.20	0.20
Grain sorghum	0.29	0.00	0.41	0.00	0.30
Grass pasture	0.00	0.00	0.50	0.00	0.50
Horticulture	0.00	0.00	0.30	0.60	0.10
Improved pasture	0.00	0.00	0.50	0.00	0.50
Irrigated cotton	0.25	0.25	0.30	0.10	0.10
Legume	0.00	0.00	0.50	0.00	0.50
Legume crop	0.30	0.00	0.48	0.00	0.22
Lucerne	0.00	0.00	0.50	0.00	0.50
Lupins	0.23	0.00	0.55	0.00	0.22
Maize	0.34	0.32	0.09	0.00	0.25
Pasture	0.00	0.00	0.50	0.00	0.50
Pasture permanent	0.00	0.00	0.50	0.00	0.50
Peanut	0.35	0.00	0.35	0.00	0.30
Poppies	0.25	0.20	0.35	0.00	0.20
Pulse	0.30	0.00	0.48	0.00	0.22
Root vegetables	0.00	0.00	0.30	0.60	0.10
Roughly cleared pasture	0.00	0.00	0.50	0.00	0.50
Sugar cane	0.00	0.75	0.15	0.00	0.10
Sugarcane	0.00	0.75	0.15	0.00	0.10
Sunflower	0.32	0.39	0.20	0.00	0.10
Unimproved or native pasture	0.00	0.00	0.50	0.00	0.50
Wheat	0.26	0.00	0.44	0.00	0.30
Winter grain (wheat)	0.28	0.00	0.42	0.00	0.30

The amount of plant residue generated by a crop or grass is dependent on both the crop growth and management practice. As well as containing the crop growth and species data, the relational database describes the agricultural management practices, (e.g., use of fire and harvesting methods) applied to each crop. This data is used to determine how much of the crop mass becomes residue for incorporation and decomposition to litter and soil carbon models, how much is taken offsite and how much is burnt.

Carbon Contents of Crop and Grass Species

Little data was available on the carbon content of various components of each crop type. To determine a robust general value, various plant materials were obtained from around the country and, using a dry combustion method, the materials were analysed for carbon content. This analysis established an average crop carbon content value of 0.45 (expressed as a fraction of dry matter).

Initial Crop Litter Mass and Decomposition Rates

Given both the rapid rates of decomposition of onsite crop material (compared to woody material) and the active management of litter in most agricultural systems, only small initial litter pools have been used in the model initialisation. The decomposition rates applied acknowledge that the crop residues that form the litter generally decompose within 12 months. The initial mass of litter assigned and their decomposition rates are shown in Table 7.E3.

Table 7.E3: Initial litter mass and decomposition rates for crop systems

Plant Component	Initial Mass t ha^{-1}	Decomposition Rate yr^{-1}
Grains, Buds, Fruit (Resistant)	0.10	1
Grains, Buds, Fruit (Decomposable)	0.00	1
Stalks (Resistant)	0.01	1
Stalks (Decomposable)	0.01	1
Leaves (Resistant)	0.01	1
Leaves (Decomposable)	0.01	1
Coarse Roots (Resistant)	0.01	1
Coarse Roots (Decomposable)	0.01	1
Fine Roots (Decomposable)	0.01	1

Crop Turnover Rates

Turnover (natural shedding of material) rates for crop and pasture species are generally high given that they are primarily annual by nature. Within this annual constraint, the litter and soil carbon modelling is relatively insensitive to turnover rate. For continuous (perennial) systems such as grazed pastures, root sloughing in response to grazing is included in the model which maintains the relative ratio of aboveground to belowground plant mass with grazing. The turnover rates used are shown in Table 7.E4.

Table 7.E4: Turnover rates applied to the crop systems

Plant Component	Turnover Rates yr^{-1}
Grains, Buds, Fruit	0.8
Stalks	0.8
Leaves	0.8
Coarse Roots	0.8
Fine Roots	0.8

Quality Assurance and Quality Control

There was a surprising scarcity of available data on crop characteristics and likeness of similar crop types was often presumed for plant partitioning, decomposition rate and turnover rate model settings. These conform to published values, but limited empirical data constrains the extent of external quality assurance. Crop yields of saleable commodities were the most readily available data, for obvious reasons, and were generally accessed via published statistics. Beyond quality control of the transfer of data into the model, statements of yield were presumed correct. Additional parameters were independently analysed (e.g., carbon contents) or taken from existing literature.

Forest growth and tree parameters

Forest growth in the *Forest land* to Cropland and Grassland category is modelled using the fully spatial, hybrid process-empirical method described in Appendix 7.A and detailed in Richards and Brack (2004a) and Waterworth et al., (2007). To parameterise the model a program of consolidation and synthesis of available national data on relevant forest and tree parameters was conducted. This data was then supplemented with additional research where required. The results of this work are provided in the NCAS Technical Report series (www.climatechange.gov.au/ncas/publications) and only a brief summary is provided here.

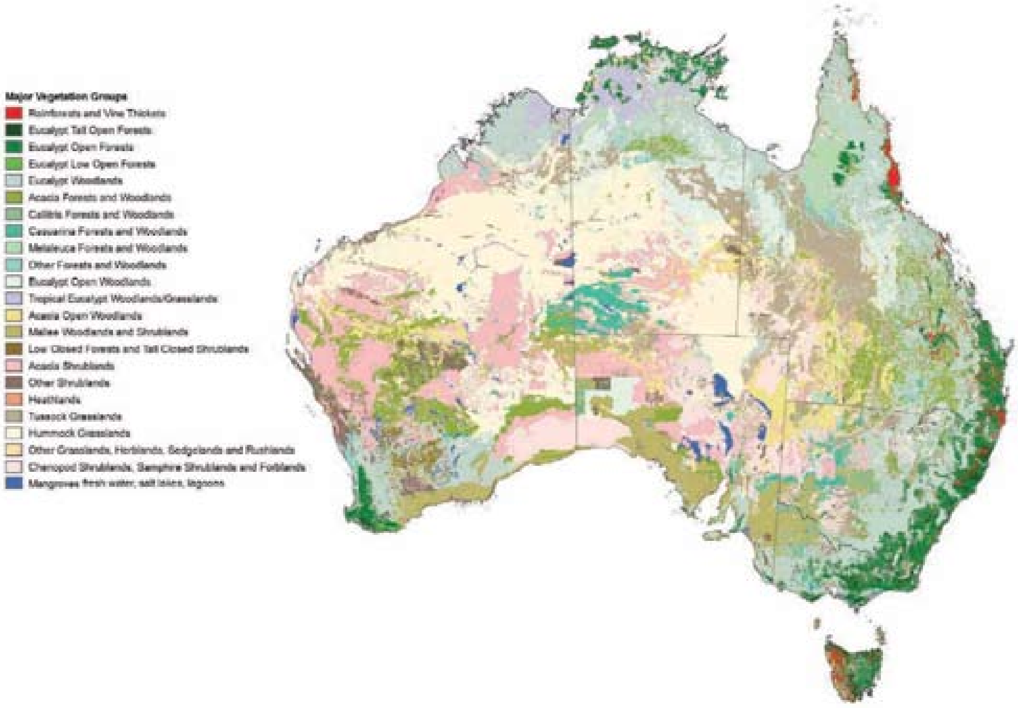
Forest Type Mapping

The National Vegetation Information System (NVIS, see NLWRA 2001) provides a composite of the best available vegetation mapping in Australia. For the *Forest land converted to Cropland* and *Grassland* category various forest characteristics (e.g., forest floor coarse woody debris and litter) are associated with the forest types extracted from the NVIS. The NVIS collates and provides, in a consistent taxonomy and classification, the best available vegetation maps from all available sources. Six levels of information are available (Table 7.E5). For the purposes of carbon accounting the Level III Major Vegetation Grouping (MVG) categories were applied. These vegetation types are described in Attachment 7.E1.

Table 7.E5: National Vegetation Information System (NVIS) hierarchical classifications

Hierarchical level	Description	National Vegetation Information System structural/floristic components required
I	Class	Dominant growth form for the ecologically dominant stratum
II	Structural Formation	Dominant growth form, cover and height for the ecologically dominant stratum.
III	Broad Floristic Formation	Dominant growth form, cover, height and broad floristic code usually dominant land cover Genus for the upper most or dominant stratum.
IV	Sub-Formation	Dominant growth form, cover, height and broad floristic code usually dominant Genus and Family, for the three traditional strata.(i.e. Upper, Mid and Ground)
V	Association	Dominant growth form, height, cover and species (3 species) for the three traditional strata. (i.e. Upper, Mid and Ground)
VI	Sub-Association	Dominant growth form, height, cover and species (5 species) for all strata.

Figure 7.E2: Major vegetation groups (MVG)



In addition to the ‘current’ vegetation mapping which represents a composite of recently collected data, the NVIS also modelled forest distributions to infer a pre-European settlement (i.e. pre-1770) vegetation map. Some of the land clearing identified by the NCAS land cover change program pre-dated the current vegetation mapping (which was generally based on data from 1990 onwards). This meant that areas identified as cleared land in the NVIS could have been forested between 1972 and the date used in the NVIS mapping. In these instances, the vegetation type allocation was drawn from the 1770 modelled (inferred) vegetation map.

While the forest potential maximum (at maturity) biomass and growth rates are largely independent of forest type, other tree characteristics are specific to forest type. Wood density, partitioning of mass to different tree components, the belowground to aboveground biomass ratios and the initial debris stocks are forest type dependent. These are described in the sections below.

Wood Density

One of the key benefits of the direct biomass (rather than volume) modelling approach used in the *Forest land converted* to *Cropland* and *Grassland* categories, is that the considerable uncertainty in wood density values for various forest types and species does not affect the model results, as would be the case for volume based inventories. Although volume, and hence basic density, is not used in the carbon modelling, it is back calculated during the analysis to assist in comparisons between modelled estimates and measured plot data for verification purposes.

The wood density information used for the back calculation of wood volume has been drawn from Ilic et al., (2000), a national compendium of wood density information prepared for the NCAS. The data of Ilic et al., (2000) is presented on a species basis. The wood density assigned to each forest type is an approximate average of the values for species typically represented in each class. The wood density values used are shown in Table 7.E6.

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Table 7.E6: Wood density values for the major vegetation group (MVG) classes

MVG Class	Wood Density (Basic) (kg dry matter/m^3)
Rainforest and Vine Thickets	500
Eucalypt Tall Open Forests	550
Eucalypt Open Forest	625
Eucalypt Low Open Forest	550
Eucalypt Woodland	890
Acacia Forest and Woodland	940
Callitris Forest and Woodland	650
Casuarina Forest and Woodland	860
Melaleuca Forest and Woodland	660
Other Forests and Woodland	800
Tropical Eucalypt Woodland/Grassland	830
Eucalypt Open Woodland	890
Acacia Open Woodland	940
Mallee Woodland and Shrubland	1,060
Low Closed Forest and Closed Shrubland	1,000
Acacia Shrubland	940
Other Shrublands	940
Heath	900
Chenopod Shrub, Samphire Shrub and Forbland	900
Unclassified Native Vegetation	780

Age of maximum biomass increment

Where an area that has previously been cleared begins to regrow to forest, the forest biomass increment is modeled using the simple empirical growth model described in Appendix 7.A and Richards and Brack (2004a), Brack et al., (2006) and Waterworth et al., (2007). One of the key parameters in this model is the age of maximum aboveground biomass increment (BI_a)

Available national data and literature sources were analysed to estimate BI_a for regrowth forests (i.e., those identified by remote sensing as recovering from clearing since 1972). This work was conducted by the Australian National University and was based largely on the work of West and Mattay (1993). This was a challenging task due to the lack of growth data for Australia's native forests, in particular for the drier woodlands. This was noted by Richards and Brack (2004a) who suggest that understanding *"… growth patterns in lower productivity (generally non-commercial forest types….)."* could be enhanced by further sampling as *"… Few yield tables are available for these types of forests*".

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Available data, such as that reported by West and Mattay (1993), suggests the age of maximum current annual increment (CAI) for stem volume is within a small range (12-20 years) for most species and is largely independent of site productivity. For the *Forest land* converted to Cropland and Grassland category the age of maximum aboveground biomass increment is set to 10 for all species based on the following:

- available data for production native forests which yields a central estimate of 14 years for maximum volume increment (range 12-20);
- the age of maximum volume increment is reduced by 1-2 years to account for increased allocation of biomass growth to non-stem (wood volume) components as trees are establishing, in particular just before canopy closure;
- the age of maximum volume increment is further reduced by 1-2 years to allow for the lag in detection of regrowth by remote sensing data (i.e., accounting for the time until detection of trees becomes possible); and,
- a final reduction is applied to account for the rapid site occupancy of woodland species which regenerate from root stock left after clearing, allowing more rapid growth following the removal of grazing pressures.

The effect of these adjustments is that a BIa of 10 is equivalent to an effective age of maximum current annual increment in stemwood volume of around 14 years. A BIa of 10 is higher than that found in most eucalypt plantations, which reach this peak between 2-7 years. Plantation management aims to achieve maximum growth rates as quickly as possible and probably represent the best achievable early age growth rates when compared to natural forests.

Tree Partitioning

The partitioning of mass to different tree components has limited effect on the carbon modelling for forest conversion, but robust data is required for model accuracy. The NCAS initiated a number of studies to collect data relevant to partitioning (Keith et al., 2000, Eamus et al., 2000, Grierson et al., 2000 and Burrows et al., 2001). Snowdon et al., (2000) provides a synthesis of the available data. While in harvested forests, tree components will likely be treated independently (e.g., stemwood being removed from the site as wood product and crowns burnt or left to decay onsite); such differential management does not occur in land clearing activity to any degree of significance, except for some removal of firewood. A national study on firewood collection indicated that limited activity is associated with forest conversion (Driscoll et al., 2000).

The most important attribute in partitioning is the ratio of belowground biomass to aboveground biomass (the root:shoot ratio), which is estimated using available data (Snowdon et al., 2000). There is also a need to apportion materials to different decomposition pools from above–ground components. As land cover change is frequently cyclic (including removal of regrowth), any over- or under-estimates in growth due to the root-to-shoot ratio applied will be largely compensated for by an equivalent over – or under-estimate in amounts of regrowth removed. The partitioning ratios used are drawn from the best available data, largely taken from the synthesis of data compiled by Snowdon et al., (2000) for the NCAS. The partitioning used for each forest type is shown in Table 7.E7.

Table 7.E7: Partitioning of biomass by major vegetation group (MVG) class

Name	Yield Allocation to Stems (fraction)	Yield Allocation to Branches (fraction)	Yield Allocation to Bark (fraction)	Yield Allocation to Leaves (fraction)	Yield Allocation to Coarse Roots (fraction)	Yield Allocation to Fine Roots (fraction)
Rainforest and vine thickets	0.78	0.06	0.06	0.01	0.06	0.03
Eucalyptus Tall Open Forest	0.67	0.09	0.10	0.02	0.08	0.04
Eucalyptus Open Forest	0.45	0.12	0.10	0.02	0.25	0.06
Eucalyptus Low Open Forest	0.45	0.12	0.10	0.02	0.25	0.06
Eucalyptus Woodland	0.44	0.15	0.10	0.02	0.23	0.06
Acacia Forest and Woodlands	0.42	0.15	0.10	0.02	0.25	0.06
Callitris Forest and Woodlands	0.42	0.15	0.10	0.02	0.16	0.15
Casuarina Forest and Woodland	0.42	0.15	0.10	0.02	0.25	0.06
Melaleuca Forest and Woodland	0.42	0.15	0.10	0.02	0.25	0.06
Other Forests and Woodlands	0.42	0.15	0.10	0.02	0.25	0.06
Eucalyptus Open Woodland	0.41	0.18	0.10	0.02	0.23	0.06
Tropical Eucalyptus woodlands/grasslands	0.41	0.18	0.10	0.02	0.23	0.06
Acacia Open Woodland	0.22	0.165	0.10	0.025	0.42	0.07
Mallee Woodland and Shrubland	0.22	0.165	0.10	0.025	0.42	0.07
Low Closed Forest and Closed Shrublands	0.22	0.165	0.10	0.025	0.42	0.07
Acacia Shrubland	0.22	0.165	0.10	0.025	0.25	0.24
Other Shrublands	0.22	0.165	0.10	0.025	0.25	0.24
Heath	0.00	0.3	0.18	0.03	0.25	0.24
Chenopod Shrub, Samphire Shrub and Forbland	0.00	0.3	0.18	0.03	0.25	0.24
Mangrove, tidal mudflat, samphire and bare areas, claypan, sand, rock, salt lakes, lagoons, freshwater lakes	0.167	0.167	0.167	0.167	0.167	0.167
Unclassified Native vegetation	0.39	0.14	0.09	0.02	0.25	0.11

Tree Carbon Contents

The carbon content of the estimated biomass (dry matter) is needed to derive a carbon mass equivalent from the biomass modelling. Studies by Gifford (2000a) and Gifford (2000b) for the NCAS considered the carbon content of various tree components, for a range of species and across a range of environments. Drawing on this work, the carbon contents used in this analysis are shown in Table 7.E8.

Table 7.E8: Carbon contents of tree components

Tree Component	Carbon Content (fraction of dry matter)
Stems	0.50
Branches	0.47
Bark	0.49
Leaves and Twigs	0.52
Coarse Roots	0.50
Fine Roots	0.48

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Tree Component Turnover Rates

Tree component turnover rates determine the inputs to litter, while soil organic matter is largely derived from root turnover (the balance coming from litter decomposition). The tree component turnover rates have little effect on the *Forest land converted to Cropland* or *Grassland* category except for areas under trees that are part of the cyclic regrowth cycle. Litterfall (leaf), branch and bark shed and root turnover have been determined from available literature. The rates applied are in Table 7.E9. These draw heavily on the rates determined by Paul et al., (2002b) in a model calibration study for the NCAS.

Table 7.E9: Tree component turnover rates

Tree Component	Turnover rate yr^{-1}
Leaf	0.0470
Branch	0.0056
Bark	0.0083
Coarse Roots	0.0560
Fine Roots	0.1042

Forest Litter

Initialisation of the forest litter stock in the model (coarse woody debris and fine litter) draws upon assessments carried out for the NCAS in conjunction with the soils measurement program (Murphy et al., 2002, Griffin et al., 2002, Harms and Dalal 2002 and Harms et al., 2005) and a separate study by Mackensen and Bauhus (1999). Sites used in these studies were widespread throughout the areas primarily cleared for agricultural purposes. Additional data was drawn from literature where available. The values used are shown in Table 7.E10. Debris mass is converted to carbon assuming a carbon fraction of 0.45.

Forest Residue Management

The principal methods of land cover change for forest conversion involve the extraction of root material (tree-pulling etc.) to allow for subsequent cultivation for pasture and cropping. Limited use of tree poisons, with subsequent standing decomposition (by microbial and invertebrate activity) also occurs.

Table 7.E10: Initial forest litter values (t dry matter ha^{-1})

Major VegetationGroup (MVG) Class	Decomp-osable Fine Decay	Resistant Fine Decay	Decomp-osable Coarse Decay	Resistant Coarse Decay	Decomp-osable Leaf Decay	Resistant Leaf decay	Decomp-osable Bark Decay	Resistant Bark Decay	Decomposable Deadwood Decay	Resistant Deadwood Decay
Rainforest and Vine Thickets	30	18	14	10	5	2	0.5	2	18	100
Eucalypt Tall Open Forests	30	18	14	10	12	5	1	5	18	100
Eucalypt Open Forest	20	9	7	5	10	4	1	5	9	56
Eucalypt Low Open Forest	10	5	4	3	7	3	0.75	3	5	30
Eucalypt Woodland	5	2	1	1	4.5	2	0.5	2	2	12
Acacia Forest and Woodland	5	2	1	1	4.5	2	0.5	2	2	12
Callitris Forest and Woodland	5	2	1	1	4.5	2	0.5	2	2	12
Casuarina Forest and Woodland	5	2	1	1	4,5	2	0.5	2	2	12
Melaleuca Forest and Woodland	5	2	1	1	4.5	2	0.5	2	2	12
Other Forests and Woodland	5	2	1	1	4.5	2	0.5	2	2	12
Tropical Eucalypt Woodland/Grassland	6	3	2	1.5	4	2	0.5	2	2	15
Eucalypt Open Woodland	5	2	1	1	4.5	2	0.5	2	2	12
Acacia Open Woodland	1	0.2	0.1	0.1	3	1	0.2	1	1	2.5
Mallee Woodlandand Shrubland	1	0.2	0.1	0.1	3	1	0.2	1	1	2.5
Low Closed Foresand Closed Shrubland	1	0.2	0.1	0.1	3	1	0.2	1	1	2.5
Acacia Shrubland	1	0.2	0.1	0.1	3	1	0.2	1	1	2.5
Other Shrublands	1	0.2	0.1	0.1	3	1	0.2	1	1	2.5
Heath	1	0.2	0.10.	3.1	1	0.2	1	1	2.5	
Chenopod Shrub, Samphire Shruband Forbland	1	0.2	0.1	0.1	3	1	0.2	1	1	2.5
Unclassified Native Vegetation	8	4	3	2	5	2	0.5	2	2	25

Tree pulling usually involves forming 'wind rows' for subsequent burning. Burning of wind rows follows a period of curing (drying), but combustion is still not always complete. The *FullCAM* model has been developed to accommodate these processes by implementing a delayed burning, with subsequent decomposition of residual material. The residual decomposing pool also includes 'standing dead' material from treatments such as poisoning. The proportion of biomass potentially affected by burning is set at 98 per cent, leaving 2 per cent of all biomass unaffected by burning. Further residue is left to decompose following incomplete combustion, due to combustion efficiencies of 90 per cent for stems, 95 per cent for bark, 95 per cent for leaf litter, 80 per cent for coarse dead roots and 70 per cent for fine roots.

Litter decomposition rates have been extracted from available information including the study undertaken by Mackensen and Bauhus (1999) for the NCAS. The rates applied are shown in Table 7.E11. There are few studies in Australia of litter decomposition rates with most work being focused on wood product longevity trials. The data was supplemented with some limited chronosequence work on paired sites.

However, the main focus of this work was on modelling rates that coincided with measures of litter mass when the models were run over extended periods so that a reasonable balance between turnover (input to litter pools) and decomposition of litter pools was achieved.

Table 7.E11: Litter decomposition rates for tree components

Plant Component	Decomposition Rate (yr^{-1})
Decomposable Leaf	1.0
Resistant Leaf	1.0
Decomposable Deadwood	0.1
Resistant Deadwood	0.1
Decomposable Bark	0.5
Resistant Bark	0.5
Decomposable Coarse Root	0.4
Resistant Coarse Root	0.1
Decomposable Fine Root	0.3
Resistant Fine Root	0.4

Soil Carbon parameters

The soil carbon model (*Roth-C*) parameters were not varied from those developed as part of the NCAS development programme. A full description of the programme and the parameterisation of the model is provided in Appendix 7.A.

Quality Assurance and Quality Control

The combination of spatial outputs and intermittent generation of long-term point-based models allows for verification of results over both space and time. The carbon outputs can be evaluated alongside relevant data on land cover change, climate, vegetation, management and soil type for verification. The point-based models can be used to ensure that the correct spatial data has been used in the model. The ability to perform spatial overlays (e.g., carbon change over time against land cover change over time) provides strong visual verification of the carbon outputs. This can be enhanced by the creation of animations that show progress of change in both over time.

The vegetation mapping provided by the NVIS has been compiled under a major national program with contributions made by relevant data holding groups, in particular State and Territory Governments. Quality Assurance on this product is conducted by both State and Federal Government agencies.

Forest floor litter (coarse and fine) has been estimated using standardised methods as published in the NCAS Technical Reports 14 (McKenzie et al., 2000b) and 31 (Snowdon et al., 2002). Available data conforms to these methods and has been checked for plausibility on entry into the NCAS system and subsequently to the *FullCAM* model.

Wood density information was compiled for the NCAS and has been published and made available via website distribution (http://www.climatechange. gov.au/ncas/files/publications.html). Reliability scales were applied to each source of data subsequent to review of methods used. Carbon contents were analysed for a range of species, tree components and site types and have been published for some time. These values generally concur with the range of values published in independent literature, but frequently the source method is not specified. Partitioning of biomass to different tree components has been largely de-sensitised by direct modelling of total aboveground biomass and consistent management treatment of residues irrespective of tree component. Available literature and data, published for the NCAS, have been used to provide a “best” estimate of belowground allocation.

The results of the Tier 3 Approach 3 model have also been compared to those developed using a Tier 2, Approach 2 method. The results of the two methods were largely consistent, with the primary difference being the greater variability in emissions and removals in the Tier 3 model due to the effects of climate.

Uncertainty

Uncertainty and sensitivity analyses have been an important part of the development of the NCAS programs. Method development, data compilation, remote sensing and field measurement programs have all been undertaken using sensitivity testing as an integral component. The sensitivity analysis has been targeted at providing an understanding of the key factors in carbon stock change estimation. Priorities in program development have been established around improvement in the specific inputs identified though sensitivity testing. Sensitivity analyses have mostly been undertaken in the context of *Monte Carlo* type analyses. This has been carried through the @Risk (Palisade Corporation 1997) software which was applied to both the Excel-based developmental and test models and in direct application in the *FullCAM* model. The various results of the uncertainty and sensitivity analyses are reported in Brack and Richards (2002), Brack (2001a), Paul et al., (2002a), Paul et al., (2003) and Janik et al., (2002).

The development of the NCAS was initiated with a clear understanding that there would be imperfect data available, but that the significance of data limitations (and, therefore, priority supplementation) could be fully assessed only in a functional integrated system. It was also recognised that no matter what quality of biophysical data is available, there will almost certainly be an inherent variable quality in that data. This tacit acceptance of variability allowed for a proper focus on matters of accuracy and bias, rather than on potentially unachievable precision. Following from this comes recognition that over a large sample, such as a national inventory derived from an aggregation of fine-scale events, a robust central estimate can be achieved provided that error propagation via biased or 'skewed' inputs is avoided. Over the large sample (several hundred million 25 m model applications for the *Forest land converted* to *Cropland* and *Grassland* categories), a bias away from a central estimate is a key item for attention.

The focus of the land cover change program was to identify any potential bias that may be caused by errors of omission or commission (bias toward inclusion of false change or only including change where this is absolutely certain). With the extensive QA/QC, verification and continuous improvement programs built into the overall programs, the potential for such bias is insignificant. Ongoing accuracy assessment is built into continuous improvement programs and will provide for ongoing refinement and incremental identification of potential improvements. The biomass estimation program sensitivity analyses were applied in a variety of ways including tests of variability in growth (Brack and Richards 2002; Brack 2001b) and of mass at maturity (Richards and Brack 2004a).

Variability in growth over time and wood density were shown to be the most sensitive factors in biomass estimation. Inter-annual variability in growth has been included via the multi-temporal productivity mapping which is used to adjust growth according to the prevailing climate (as is reflected in the temporal variability in the productivity mapping). The method used in this application of *FullCAM* to estimate biomass and biomass increment provides a direct measure of aboveground mass, so no measure of wood density is required to convert volume into mass. This approach is described in Richards and Brack (2004a). As shown in Snowdon et al., (2000) there is limited information available on root-to-shoot ratios for tree species. The adopted ratios represent the best estimates from the variable data available. There is no cause, from the data available, to presume that there is any bias introduced, despite the evident lack of precision (variability) in the data. The low sensitivity of model results to the root-to-shoot ratio is largely due to the compensatory effects of regrowth. As regrowth is accounted for in the modelling, over- or under-estimates in losses due to forest conversion will be compensated for by a symmetrical over- or under-estimate in regrowth.

The mass estimation of the initial (1972) biomass has been constrained to the available known mass measures as reported in Richards and Brack (2004a). The approach provides a 'measured' or empirical constraint derived from field measurements to the process-based modelling. While the data available is variable (imprecise), the method used to develop a best fit mathematical model of the available data was reviewed for potential to derive biased error estimates. Unbiased error estimates provide reassurance that bias is not occurring in the mathematical model and should therefore not be expressed or propagated in model application.

The sensitivity of the model to changes in BI_a was tested by Richards and Brack (2004a). The sensitivity testing showed the value of BI_a=10 years produced yield curves that moderated the patterns to a similar shape to those produced if a higher value of 15 was used. To test the sensitivity of the *Forest land converted* to *Cropland* and *Grassland* accounts to BI_a the model was rerun applying a value of BI_a=15 for all forests. The increase in BI_a from 10 to 15 caused little change in the results (1.0 Mt increase in CO_2–e in 1990, less than 1% of emissions). The minimal effect of this parameter on the model results is due to the balancing of reduced emissions from cyclic regrowth clearing by the slower growth rate of regrowth areas that were not cleared in 1990.

Both the multi-temporal productivity mapping and climate mapping were subject to independent quality assurance, providing confidence that the use of these data products does not provide a potential source of bias in the modelling. The spatial and temporal resolution provided by these products reduces the significant potential for bias in soil carbon models that has been shown to arise from spatially or temporally averaged data inputs (Janik et al., 2002). Extensive sensitivity testing of the soil carbon modelling, as reported in Janik et al., (2002) and Paul et al., (2002a), showed that input data is required to be at a fine temporal and spatial resolution, as regionally and temporally averaged data provided uncertain, and frequently spurious, results. The use of input data at the appropriate scale, and verification against relevant field measurements, were the main forms of uncertainty reduction.

The most extensive sensitivity testing was undertaken for the soil carbon model calibration and verification program. The multi-faceted testing included reviews of model performance against measured chronosequence soil pairs and long-term trial data. The model calibration and verification as reported in Skjemstad and Spouncer (2002) gives no cause to suspect that there is any bias from model over- or under-estimation. Under the spatially and temporally disaggregated approaches taken, variance in input data for each grid (25 m) of the model run (presuming it is without skew in the variability in inputs) will, over a large sample, provide a robust and stable central estimate. In terms of uncertainty and potentially biased estimates, this is a significant advance on the default approaches which use constants (emissions factors) to define the change in stock as suggested under Tier 1 and Tier 2 accounting as described in the IPCC Inventory Guidelines.

Attachment 7.E1: Major Vegetation Groupings Classified by the National Vegetation Information System

Group 1. Rainforest and Vine Thickets

Rainforest communities in Australia are mostly confined to the wet and cooler areas or climatic refuges in eastern Australia, apart from the semi-evergreen vine thickets of the Brigalow Belt and the monsoonal vine thickets that are found in the tropics in Western Australia and the Northern Territory. Community types include cool temperate rainforest, sub-tropical rainforest, tropical rainforest, vine thickets, and semi-deciduous and deciduous vine thickets. Rainforests were cleared extensively in the late 19th or early 20th centuries for high value timbers, dairying, tobacco/sugar cane or other agricultural production. The best known examples of this are the "Big Scrubs" of Illawarra and northern New South Wales and the Atherton Tableland in north Queensland.

Group 2. Eucalyptus Tall Open Forests

These communities are restricted to all but the wetter areas of eastern Australia from the margins of the wet tropical rainforests of north Queensland to Tasmania, and the south west of Western Australia, often in rugged mountainous areas. At their maximum development in Tasmania and parts of Victoria, they contain the world's tallest flowering plants, with some trees rising to heights in excess of 100 m. These communities are typified by a well-developed often broad-leaved shrubby understorey or sometimes tree ferns and are mostly found adjacent to, or in association with, rainforest communities. Extensive areas of these communities were cleared for agriculture and grazing early in the 20th century, particularly where they occurred in association with rainforests. Major areas remain today in crown reserves as State Forests or National Parks.

Group 3. Eucalyptus Open Forests

Widespread along the sub-coastal plains and foothills and ranges of the Great Dividing Range in eastern Australia and the sub-coastal ranges of the south west of Western Australia. Generally this group has a shrubby understorey which is low to moderate in height, but in drier sites they may have a grassy understorey with scattered shrubs and/or cycads. There has been widespread clearing of these communities for grazing and agriculture in the major agricultural zones of eastern Australia and the south west of Western Australia. The rate of clearing in these communities by the early 20th century saw the development of crown reserves for the protection of forests, either as national parks or as production forests, and the establishment of Forestry departments within several jurisdictions.

Group 4. Eucalyptus Low Open Forest

This group contains a series of montane communities of the Great Dividing Range such as Snow Gum, Red Stringybark and Scribbly Gum, and the drier Jarrah communities in the south west of Western Australia. Extensive areas of these communities have been cleared principally for grazing.

Group 5. Eucalyptus Woodlands

Widespread throughout the mountain ranges and plains west of the divide in Eastern Australia and east of the sub-coastal ranges of south west Western Australia. This group includes a series of communities, which have come to typify inland Australia. For example the box (poplar box, white box, yellow box etc.) and ironbark woodlands of eastern Australia are included in this group. The Eucalyptus woodlands have been extensively cleared and modified, particularly in the agricultural zones of eastern Australia and in south west Western Australia. In many regions only small isolated fragments remain today, in many instances found only along creeks and road verges.

Group 6. Acacia Forests and Woodlands

Brigalow (*Acacia harpohylla*) and Mulga (*A. aneura*) dominate this group with mulga covering large parts of the arid interior of the continent. A series of other acacias such as Lancewood (*A. shirelyii*) and Myall (*A. pendula*) are also included. Mulga is one of the most widespread species on the continent, occurring on a series of forest, woodland and shrubland communities. The Mulga and Brigalow communities of eastern Australia have been extensively cleared for grazing and agriculture and in many regions only scattered remnants are found today. Mulga communities in the arid interior have not been subject to clearing to the same degree but many areas have been subject to modification by grazing pressures from cattle/sheep and feral animals, and increased macropod populations supported by the increased availability of water from bores.

Group 7.A Callitris Forests and Woodlands

Cypress Pine forests are found mostly in a series of discrete regions, notably in the Brigalow Belt, but also in the arid areas in South Australia and in association with mallee communities near the South Australia – Victoria border. Extensive areas have been cleared for grazing in the Brigalow Belt and in the Mallee bio regions in particular, but major areas are included in State Forests and other crown reserves in Queensland and New South Wales.

Group 8. Casuarina Forest and Woodland

Containing both Casuarina and Allocasuarina genera, these occur in a series of quite distinct communities, notably foredune (*C. equisetifolia*) communities, swamp (*C. glauca*) communities, riverine (*C. cunninghamiana*) and desert (*C. cristata*) communities. These communities have been extensively cleared in many coastal areas for agriculture, or for industrial uses or urban developments. Areas in the arid zone are subject to modification by grazing of domestic stock and from feral herbivores.

Group 9. Melaleuca Forest and Woodland

These cover substantial areas in the tropical north, but are also found in temperate climates most often in or adjoining coastal or montane wetlands. These communities have been extensively cleared in many coastal areas for agriculture or housing near major cities. Extensive areas remain in the tropical north, in particular southern Cape York Peninsula.

Group 10. Other Forests and Woodlands

This is a diverse group of communities, some of which such as Banksia woodland are comparatively restricted in their extent, but may be locally abundant. It also includes a series of mixed communities of the arid zone, which are not dominated by any particular species. These communities have been extensively cleared in many coastal areas for agriculture or urban uses. Extensive areas remain in the arid zone but are subject to modification by grazing of domestic stock and from feral herbivores.

Group 11. Eucalyptus Open Woodland

These cover extensive areas of the arid zone or drier tropical north mostly with a shrubby or grassy ground layer. Little of this group has been cleared. Many areas have been subject to modification by grazing of domestic stock and from feral herbivores.

Group 12. Tropical Eucalyptus Woodlands/Grasslands

This group contains the so-called tall bunch-grass savannas of north Western Australia and related Eucalyptus woodland and Eucalyptus open woodland communities in the Northern Territory and in far north Queensland, including Cape York Peninsula. They are typified by the presence of a suite of tall annual grasses, notably Sorghum spp, but does not include communities in more arid sites where *Triodia spp* becomes more dominant. The fundamental difference between how Western Australia and the Northern Territory and Queensland describe these vegetation communities, necessitated their separation into a separate MVG.

Group 13. Acacia Open Woodland

These also cover extensive areas of the arid zone or drier tropical north mostly with a shrubby or grassy ground layer such as Blue Grass (*Dicanthium sericeum*). Eucalyptus species such as the Yapunyah (*E. thozetiana*) may also be present. Little of this group has been cleared but many areas have been subject to modification by grazing of domestic stock and from feral herbivores.

Group 14. Mallee Woodland and Shrublands

Multi-stemmed eucalyptus trees in association with a broad range of other shrubs or grasses cover extensive areas of the southern arid zone from Victoria to the south west of Western Australia. The mallee communities in Victoria and parts of South Australia have been extensively cleared, with only isolated remnants remaining in some areas, but these communities are still widespread in the arid zone of South Australia and Western Australia. These are subject to modification by grazing of domestic stock and from feral herbivores.

Group 15. Low Closed Forests and Closed Shrublands

These dense communities are found mostly in coastal environments, for example Kunzea and Leptospermum scrubs, or sub-coastal plains e.g., Banksia scrubs, and can cover significant areas. They also occur in rugged mountainous areas, such as sub-alpine areas in Tasmania. They have been extensively cleared in many coastal areas for agriculture or urban development.

Group 16. Acacia Shrublands

Mulga, Gidgee and mixed species communities of the central Australian deserts dominate this group, but it also includes a series of other desert acacia communities. Little of this group has been cleared outside of the major agricultural zones, but they have been subject to modification by grazing from domestic stock and from feral herbivores.

Group 17.A Other Shrublands

This is a diverse group containing a series of communities dominated mainly by genera from the Mrytaceae family. Kunzea, Leptospermum and Melaleuca shrublands are important component of this group, but it also includes a suite of mixed arid zone communities and other communities dominated by typical inland genera such as Eremophila and Senna. This group has been extensively cleared in the agricultural regions and in coastal areas adjoining major cities. In the arid zone, little of this group has been cleared but many areas have been subject to modification by grazing of domestic stock and from feral herbivores.

Group 18. Heath

This group includes the stunted (< 1 m tall) vegetation of the coastal sand masses, typified by the family Epacridaceae and also other dense low shrublands in sub-coastal or inland environments, mostly on drainage impeded soils or natural hollows or depressions. The communities have been cleared for sand mining, agriculture and urban development.

Group 19. Tussock Grassland

This group contains a broad range of native grasslands from the Blue Grass and Mitchell Grass communities in the far north to the temperate grasslands of Southern New South Wales, Victoria and Tasmania. The group contains many widespread genera including Aristida, Astrebla, Austrodanthonia, Austrostipa, Crysopogon, Dichanthium, Enneapogon, Eragrostis, Eriachne, Heteropogon, Poa, Themeda, Sorghum and Zygochloa and many mixed species communities. Extensive areas of this group have been cleared and replaced by exotic pasture species and most other areas have been subject to modification by grazing, weed invasion and land management practices associated with grazing domestic stock, such as frequent fire and the application of fertilisers.

Group 20. Hummock Grassland

The spinifex (*Triodia spp*. and *Plechrachne spp*.) communities of the arid lands are quintessential to the Australian outback. These cover extensive areas of the continent either as the dominant growth form with the occasional emergent shrub or small tree (either acacia or eucalypt). They are also a conspicuous element of other communities such as open woodlands. Little of this group has been cleared but many areas have been subject to modification by grazing of domestic stock and from feral herbivores.

Group 21. Other Grasslands, Herbland, Sedgeland and Rushland

This diverse group contains a series of communities, some of which are restricted within the landscape, some of which occur as mosaics and others that are otherwise too small or diffuse across the landscape to be easily discerned at a continental scale.

Group 22. Chenopod Shrub, Samphire Shrub and Forbland

The chenopods such as Saltbush (*Atriplex spp*.) and Bluebush (*Maireana spp*.), cover extensive areas of the arid interior on saline soils. They are also associated with the ephemeral salt lakes of these arid areas, often in association with samphires such as Halosarcia species. Similarly, some forbland communities contain a mix of species including samphires and chenopods. Other forblands containing Asteraceae species are found in Queensland.

Group 23. Mangrove, Tidal Mudflat, Samphire, Claypan, Salt Lakes, Bare Areas, Sand, Rock, Lagoons and Freshwater Lakes

Mangroves vary from extensive tall closed forest communities on Cape York Peninsula to low closed forests or shrublands in southern regions. Samphires are found in the coastal mudflats and marine plains, adjoining mangrove areas in many instances, but they also cover extensive marine plains inland from the southern Gulf of Carpentaria and other parts of the tropical north. In the harsh environments of the arid interior extensive areas devoid of vegetation can be found as bare ground, either sand dune, claypan or salt lakes. Similarly, the coastal sand masses can often contain extensive areas of bare sands, mostly as active dunes. In mountainous areas, large areas of bare rock, or scree may be a feature of the landscape. This is particularly the case where large rocky outcrops dominant the landscape, such as Uluru and the Olgas in central Australia, Bald Rock in northern New South Wales and many examples of large monadnocks in the south west of Western Australia. Widespread clearing or infilling of mangroves and tidal mudflats in coastal areas near urban major centres for industrial uses or urban developments.

Appendix 7 F:
Grassland Remaining Grassland

Background

The *Grassland remaining Grassland* category covers around 440 million hectares of land. The vast majority of this area occurs in inland Australia and is used for extensive grazing of both sheep and cattle. In Australia grazing occurs across very diverse climate, ecosystem and management systems. The pasture types and associated management intensities range from highly improved and sometimes irrigated pastures to extensive rangeland systems in the semi-arid and arid regions of Australia. Native or naturalised pastures are the major pasture type, grown on about 17% of Australia with sown and fertilised pastures occupying only 4% of the land mass. Sown pastures are represented by mixed annual grasses and legumes as well as mixed perennial grasses and legume species depending upon rainfall and regional location. A proportion of both pastures and crops are either cut for hay or harvested for grain and used to support the intensive livestock industry. Irrigated pastures represent about 1% of all pastures and are generally confined to the dairy and feedlot industries.

Pasture productivity determines the amount of live biomass that is produced, while the effects of grazing and fire determine transition of the living biomass into carbon stock pools over a reporting period. In addition, both the dead organic matter and soil carbon pools will be influenced by pasture utilisation (grazing management), and interventions such as burning. The introduction of an improved pasture system may lead to a moderate increase or decrease in soil carbon, and this may vary (increase or decrease) on an annual basis according to annual climate variability.

Methodology

The *Grassland remaining Grassland* category includes emissions and removals in both shrub (non-forest forms of perennial woody vegetation) and grass systems, including the effects of grazing, grass and shrub transitions and the effects of fire. This comprehensive approach therefore also captures the losses and uptake of carbon associated with savanna burning, both anthropogenic and natural. The key drivers of the emissions and removal in *Grassland remaining Grassland* are:

- grazing intensity;
- annual variability in biomass due to climate variability;
- land management (in particular burning practice);
- natural disturbances (wildfire); and
- shrub and grass transitions (due to both natural effects and anthropogenic cause).

The distribution and area of land in *Grassland remaining Grassland* was taken from the mapping of the National Land and Water Resources Audit (www.nlwra.gov.au) prepared by the Bureau of Rural Sciences. The subset of areas of *Grassland remaining Grassland* that were shrub vegetation was established by the methods described below. The area that was only grasses was established by removing the areas of shrubland from the total *Grassland remaining Grasland* area.

‘Grasses’ component

The reporting for the ‘grasses’ component includes all on-site carbon pools (living biomass, dead organic matter and soil). Emissions and removals are estimated using the Tier 3, Approach 3 NCAS mass balance, process-based ecosystem model *FullCAM*, as described in Appendix 7.A. The calibration and verification of this model, along with the associated quality assurance and quality control program are described in Appendix 7.A. The data used in the model runs includes plant growth rates, grazing intensity and pasture management practices such as burning. These data are described in Appendices 7.A and 7.E.

For *Grassland remaining Grassland*, no land use changes (deforestation) took place after 1972, so to initialise the model, it was presumed that land in the *Grassland remaining Grassland* area entered this category following deforestation between 1924 and 1971. The exact date of deforestation of each pixel is randomly allocated in the period between these two years with the amount of clearing approximately evenly distributed in each year. The model then uses a 'run-in' period from 1972 to 1989 for the initial reporting year of 1990. The run-in period is used to stabilise the soil carbon stocks to reflect soils under long term management, i.e., not significantly affected by the initial pasture establishment or former land use. This run in allows the model to represent both areas which have always been grassland and those cleared for grazing prior to 1972.

For the current *Grassland remaining Grassland* grass component estimates, management data is not varied as comprehensive data for all of Australia's *Grassland*s is not yet available (as opposed to the *Forest land converted to Grassland* category where data is available). Hence variation in the live biomass, dead organic matter and soil pools are largely driven by variations in the climate.

Grass and Shrub Transitions

There are many processes that lead to transitions between 'shrubs' and 'grasses' in Australian ecosystems. These processes are driven by factors that include how palatable the shrubs are to herbivores, and whether they are resistant or susceptible to fire, drought and waterlogging. The species concerned may be endemic, native (but not endemic), or introduced.

The direct anthropogenic transitions between shrub and grass systems, such as land clearing and establishment of shrub plantations (e.g., saltbush for grazing, tea-tree for oils etc.), are readily associated with a 'cause' for the transition. Equally, losses due to natural and managed fires, are similarly straight forward to interpret. Another natural phenomenon that impacts carbon stocks and transitions between grasses and shrubs, is climate driven changes in the shrub condition. While the climate driven process is well understood, quantifying its effects is not straight forward. Figure 7.F1 highlights how the presence of shrubs can be affected by climate variability with 'flushing' in standing plants following a rainfall event.

Figure 7.F1: The impact of climate variability on woody shrubs

Photos on the left are drought affected shrublands, while the photos on the right are the same shrublands following a rainfall event.

APPENDICES

Transitions that are not in response to a direct human intervention are difficult to assign a cause to, although they may occur in response to the combination of past or current land management and climate. These transitions, are predominately a shift from grass to shrubs in a process often described as 'woody weed invasion'. Woody weed invasion has been reported in many areas of Australian rangelands and savannas. Woody weed invasion is often associated with changed fire regimes (lower frequency and less intensive) that have accompanied the introduction of grazing.

A range of land management practices are used to treat woody weed invasion and include:

- prescribed burning;
- mechanical control (e.g., ploughing); and
- chemical control.

Mapping of Extent and Change in Shrubs

The mapping of the extent, and change in extent in forest systems (as reported in other forest related emissions categories) is now relatively straight forward using data from the Landsat satellite data archives (see Appendix 7.A). To supplement the forest mapping a national mapping program is currently underway to assess both the extent, and changes in extent, of sub-forest forms of woody vegetation. The results of the program to date are that:

- reliable extent and change mapping is possible (Caccetta and Furby 2004) by supplementing the techniques applied to forest mapping to deal with the impact of low signal (proportion of woody vegetation of interest) to noise (other vegetation) ratio;
- the low signal to noise ratio leads to a variable lower detection limit. 'False change' (i.e., change only in the lower detection limit threshold) can occur and this must be addressed by enforcing a constant lower limit, which is in the order of 5-7% woody cover; and
- the analysis can only be applied to the more recent (since 1988) Landsat TM and ETM^{+} data. Data from the earlier Landsat MSS sensors is not able to deal with the low signal to noise ratio in these systems.

Currently there is only partial national coverage of shrubland extent 'base' maps (see Figure 7.F2) for a single point in time. A further subset of areas (see Figure 7.F3) includes change analysis which has been applied and verified for the period 1991 to 2004.

Figure 7.F2: Areas (in grey) where sub-forest woody vegetation maps were available for the 2007 inventory

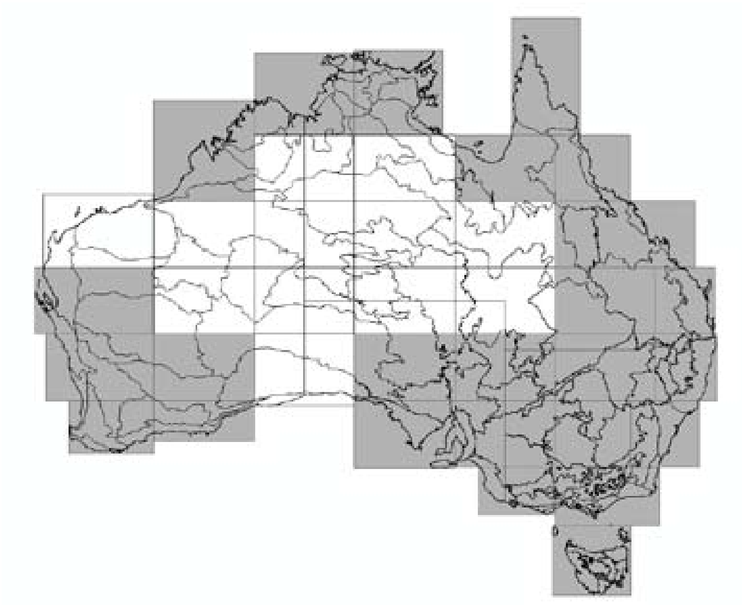
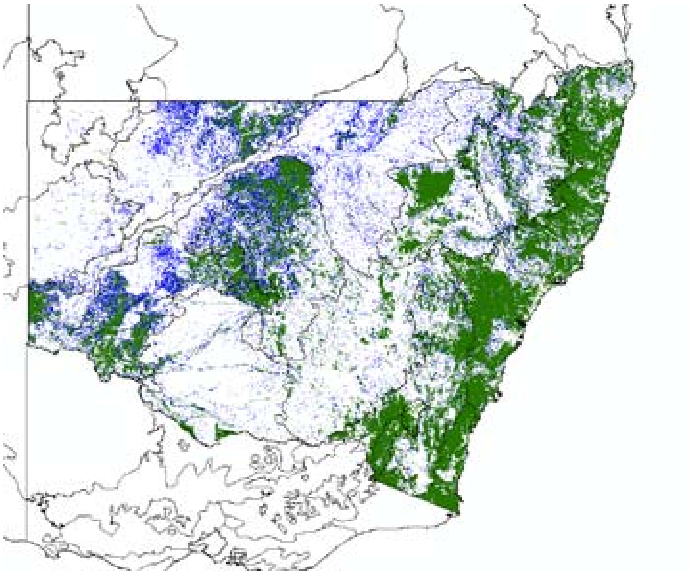


Figure 7.F3: Map of forest (green) and sub-forest woody vegetation (blue) for the area where the sparse change analysis has been verified



To use this preliminary data to derive an estimate of the emissions from grass to shrub transitions Australia has:

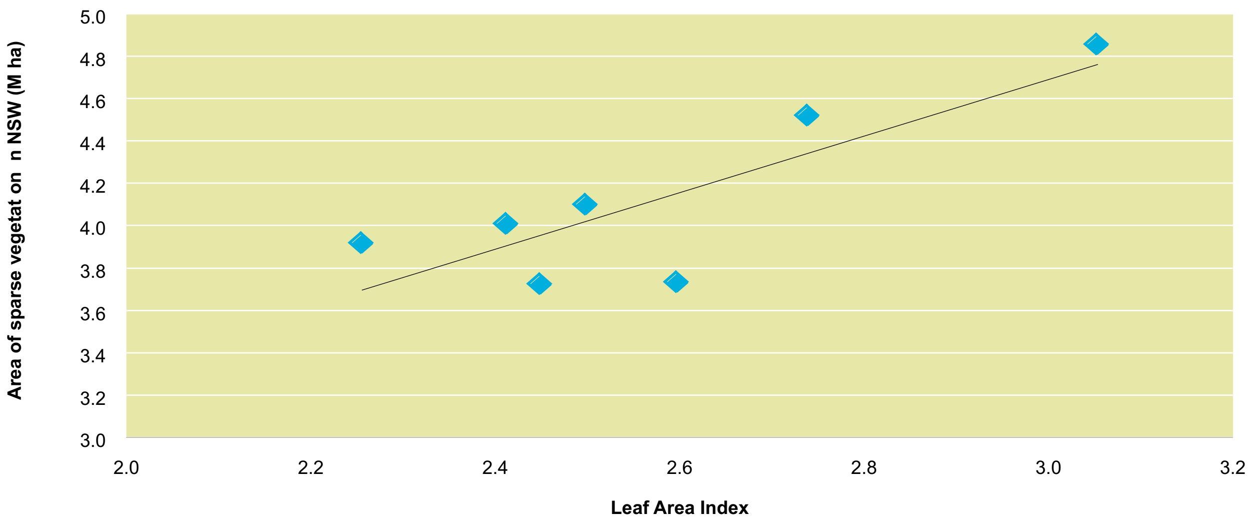
- used the proportion of shrubland in each bio-geographic region (IBRA Thackway & Creswell 1995) for the available sub-forest woody vegetation data and applied this to areas where data is not yet available; and
- used the time-series trends for change in areas where change is available (see Figure 7.F3) and applied this to the national extent.

As the data on the transitions between shrubs and grasses was only available for a sample of the country since 1991, it was necessary to extrapolate the data so that an emissions estimate for 1990 could be derived. To do this, a relationship between the observed transitions (change) in the sample area and the national trends in leaf area index (derived from satellite data) was developed (Figure 7.F4; $r^2 = 0.65$). The robustness of this relationship allows for extrapolation of the observed shrub and grass transitions to the date of the first leaf area index (LAI) data in 1987. Prior to 1987 no net change in extent of shrub vegetation is assumed.

Estimation of emissions and removals

To estimate the change in shrub biomass due to the change in shrub area, the net annual change in area was placed in a simple Tier 2 model. The model uses an average woody biomass of 10 t DM/ha (Raison et al., 2003) and presumes a loss of that amount in the years of net area loss. Where the area of shrubland increases it is assumed that these will regrow to 10 t DM ha^{-1} over 5 years (i.e., a growth rate of 2 t DM ha^{-1} yr^{-1}). The results of this analysis are shown in Table 7.F2.

Figure 7.F4: The relationship between leaf area index and trends in woody vegetation change



Fires

Fires are the major natural disturbance in grasslands, and area burned varies from year-to-year. Fire in grass areas of the *Grassland remaining Grassland* category are modelled as part of the Tier 3 *FullCAM* analysis. Fires in the shrubland component of the *Grassland remaining Grassland* category are modelled using a Tier 2 method. The fire activity data and model parameters (see Table 7.F1) applied in the Tier 2 model are the same as those used for the estimation of non-CO_2 gases from the *Prescribed Burning of Savannas* (4.E). Following burning shrub biomass is presumed to recover over a four year period.

For some states (Victoria, NSW, Tasmania) the area burnt data used for the *Prescribed Burning of Savannas* (4.E) does not include a differentiation between shrubland and grassland. For these states it was assumed that the areas reported represent shrubland. Since 1983 (when data in all states first becomes available) the areas burnt in these states represent less than 1% of the total area burnt. Therefore the effect of this assumption is considered insignificant.

Table 7.F1: Model parameters for the Grassland remaining Grassland emissions and removals estimation

Parameter	NSW	Tas	WA	SA	VIC	QLD	NT
Fuel load	6.9	9.0	8.3	3.0	11.7	3.0	4.1
Burn Efficiency	0.72	0.72	0.72	0.72	0.72	0.72	0.72
C%	0.46	0.46	0.46	0.46	0.46	0.46	0.46
C loss/ha	2.29	2.98	2.75	0.99	3.88	0.99	1.36
Years to recover	4	4	4	4	4	4	4

Results

Having been retained under a similar land use over the period since at least 1972, changes in carbon stocks will largely be affected only by land management, natural disturbances and climate. These factors largely determine the amount of live biomass and dead organic matter, as well as the amount of residues, root and manure inputs to soil carbon.

The emissions estimation of the grassland dynamics from the areas of grassland showed an overall trend of being a source of emissions, with strong variability due to climate and fire. The results are reported in three parts (Table 7.F.2) to reflect the three elements of the emission estimation:

- grassland dynamics;
- changes in shrubland extent; and
- fire.

Table 7.F2: Emissions and removals (Mt CO_2) for Grassland remaining Grassland

Year	Emissions Mt CO_2			
	Grass dynamics	Shrub extent	Fire	Total
1990	-3.66	-15.80	1.20	-18.27
1991	46.96	5.30	-29.34	22.93
1992	22.02	-0.37	-10.34	11.31
1993	10.99	9.27	-0.07	20.20
1994	-23.56	-5.05	7.99	-20.62
1995	11.78	28.56	81.09	121.43
1996	-8.87	-14.37	18.86	-4.39
1997	-13.23	-9.46	-17.95	-40.64
1998	36.13	31.85	43.58	111.56
1999	-1.85	-25.09	0.25	-26.69
2000	-104.59	-14.76	41.20	-78.15
2001	-68.27	-32.91	62.53	-38.65
2002	146.37	-12.56	37.62	171.43
2003	33.47	3.81	-64.66	-27.39
2004	39.71	-37.16	-93.36	-90.81
2005	63.38	-6.49	78.92	135.81
2006	157.10	-13.56	-111.83	31.71
2007	121.54	20.30	70.92	212.75

Appendix 7.G: Harvested Wood Products

Introduction

Harvested Wood Product CO_2 emissions are considered under the 1996 (Revised) IPCC Guidelines for the United Nations Framework Convention on Climate Change (IPCC 1997) and associated Good Practice Guidance (IPCC 2003) and are reported in the *Land Use, Land Use Change and Forestry* component of Australia's National Greenhouse Gas Inventory where they arise from the service life of products. Emissions from landfill are reported under the *Waste* sector of the inventory.

A national database of domestic wood production, including import and export quantities, has been maintained in Australia since the 1930's. This consistent and detailed collection of time-series data provides a sound basis for the development of a national wood products model. Jaakko Pöyry Consulting were initially engaged by the National Carbon Accounting System (NCAS) of the Australian Greenhouse Office to develop a national carbon accounting model for wood products, and that work provides the precursor model to that adapted and described here. The model development is reported in detail in the National Carbon Accounting System Technical Reports No. 8 (Jaakko Pöyry Consulting 1999) and No. 24 (Jaakko Pöyry Consulting 2000). Updates and model refinement were subsequently undertaken by MBAC Consulting in conjunction with the NCAS. Jaakko Pöyry Consulting subsequently provided a quality assurance review of the model. The refined model and its sensitivity analysis are reported in Richards et al., (2007). The independent quality assurance for the model is at Attachment 7G.1.

Accounting Approaches

Accounting approaches for carbon emissions from timber harvesting and wood products include emissions from wood products in Australia (wherever the source). This approach accounts for emissions from all wood products within Australia, regardless of their country of origin. Exported wood products are not accounted for and are the responsibility of the importing country. The amount of material exported is deducted from the total production, with total imports added, to derive the amount of material available for emissions within Australia. The origin of imported wood products is not tracked. However, the total flow of imported wood products into various pools within Australia is monitored.

Model Components

Information has been obtained and examined under the following components of the model:

- log flow from the forest: current annual production data were obtained by species groupings, and product classes, e.g., sawlogs, veneer logs, pulp logs, roundwood and other, e.g., sleepers;
- fibre flow from processing: data on the intake of raw materials to the various processing options and the output of products and by-products have been used in the model to estimate the total tonnes of carbon produced each year under various end product classes;
- import and export quantities of wood products;
- recycling;
- entry and decomposition in landfill;
- use for bioenergy; and
- other losses to atmosphere.

Life Cycles and the Wood Products Carbon Pool

Estimates of the life cycles appropriate for each class of wood product have been made and methods for estimating the initial pool of carbon, as represented by wood products in use since 1943, have been proposed. Annual log removals data are available through the Australian Forests Products Statistics published quarterly by the Australian Bureau of Agricultural and Resource Economics (ABARE 2008c).

Data are also available through the Levies Management Unit of the Department of Agriculture, Fisheries and Forests, on behalf of the Forest and Wood Products Research and Development Corporation (FWPRDC). Log removals data are also published by the relevant State Forest Services and these provide a valuable crosscheck on ABARE data.

Cypress pine removals are included under the total for coniferous logs and a separate figure is not provided. It is necessary to extract cypress pine volume and analyse separate from softwood sawmilling because:

- Cypress pine is a significant source of wood products;
- Cypress pine is a native conifer and softwood sawmilling largely refers to exotic species plantations; and
- Cypress pine is a denser wood than exotic pines and is used by a totally separate industry supplying different products to the market.

A Cypress pine figure can be developed from the ABARE information by applying a conversion factor to sawnwood consumption and applying a conversion factor to convert back to equivalent log removals.

Wood Flow

The model develops wood flows separately for each sector and these are integrated to account for cross-linkages. This is particularly important in the accounting for waste or by-products which are themselves used as resources for other segments of the industry. In conjunction with the carbon pool and life cycle of timber products, this model enables the total and projected carbon pools to be estimated.

In broad terms, the components of the models developed for each sector are similar, using:

- an estimate of raw materials input, whether of sawlogs, woodchips ex-sawmill, or pulp logs;
- an estimate of the products of processing, e.g., “x”% sawdust, shavings or sander dust for on site energy generation or compost, “y”% woodchips for other manufacturing processes, “z”% of sawn timber products, panel products, paper, etc.;
- an estimate of the proportion of products by product categories, depending on whether their expected end-use is long-term or short-term; e.g., framing timber, dry dressed boards, cases and pallet stock, panel products for use in house construction, panelboards for use in furniture and cabinets, newsprint paper, writing and printing paper, etc;
- a final figure for total Australian consumption by end use categories, converted to wood fibre content (oven-dry weight) and to tonnes of carbon;
- import and export data were obtained from the ABARE (2008c) by end use categories; and,
- details of the flows are shown in Attachment 7G.1.

Treatment of Bark

There has been no accounting for bark in this study. All bark is regarded as being a component of logging slash (harvesting residue) and accounted for under in-forest logging operations, for the following reasons:

- logs are sold with log volumes recorded on an underbark basis;
- in most hardwood operations, logs are debarked in the field;
- in softwood operations, it is estimated that some bark is lost prior to the logs reaching the mill. Most of this loss occurs during the mechanised delimbing and log docking operations; and
- most softwood bark recovered at the mill is used for garden mulch which it is considered would have decay characteristics similar to that of logging slash.

Softwood bark is a significant source of carbon with total bark varying from about 35% of underbark log volume (not oven dry weight) in Caribbean pine to 20% in radiata pine and hoop pine. It is likely that, in the future, an increasing proportion of softwood bark will be used in the co-generation of energy and it may be reasonable to review this proposal should the situation change.

Basic Density and Carbon Content

Basic density and carbon content estimates are relevant to all of the processing options and the choice of values adopted has a significant bearing on the final outcome. In the case of all sawn timber, treated softwood and hardwood poles, etc., weighted basic densities for the species involved have been applied across each category. Basic density is defined as oven dry weight divided by green volume and the values adopted have been based on Ilic et al. (2000). For board products and paper, however, the situation is different because all have been subjected to varying amounts of compression during manufacture and to compensate for this, their basic densities have been adjusted accordingly from the air-dry density of the finished products.

Carbon content is defined variably throughout the literature with values ranging from 0.4 to 0.53 of the oven dry (bone dry) weight. A figure of 0.5 has been adopted as a starting point to use in the model as a median value extracted from Gifford (2000a).

Apart from the assumptions concerning basic density and carbon content, the other manufacturing assumptions were developed from interviews with representatives from the various industry associations and individual sawmilling companies. The issues addressed included:

- recoveries of green sawn timber, sawdust and chip;
- actual sawn sizes and corresponding dressed sizes; and
- the range and proportions of products produced.

For the softwood sawmilling industry, for example, weighted averages of the information received have provided realistic assumptions. The same applies to the other species/industry sectors, with the exception of hardwood sawmilling.

Table 7.G1: Basic densities, moisture and carbon contents

Carbon Fractions	
Description	**Value**
Fraction of softwood sawmilling dry matter that is carbon, by weight	0.50
Fraction of particleboard dry matter that is carbon, by weight	0.40
Fraction of MDF dry matter that is carbon, by weight	0.40
Basic Densities *	
Description	**Value kg/m^3**
Density of softwood sawmilling	460
Density of hardwood sawmilling	630
Density of cypress sawmilling	600
Density of plywood (softwood and hardwood) and veneer	540
Density of particleboard	520
Density of MDF	600
Density of hardboard	930
Density of softboard	230
Density of pulp and paper: Paper	1,000
Density of pulp and paper: Softwood	430
Density of pulp and paper: Hardwood	500
Density of pulp and paper: Waste paper	1,000
Density of pulp and paper: Pulp	1,000
Density of paper and paperboard imports and exports, on average	1,000
Density of chips and logs for export: Softwood logs	415
Density of chips and logs for export: Hardwood logs	630
Density of hardwood poles, sleepers and miscellaneous	790
* Basic density = (mass of oven dry wood in kg) / (volume of green wood in m^3)	
Moisture Content of Green Wood	
Description	**Value**
Ratio of weight of water to weight of wood substance in softwood chips	1.10
Ratio of weight of water to weight of wood substance in hardwood chips	0.90

Wood Flows from Processing

Wood flows in the various wood products produced in Australia have been developed under the following species/industry headings:

- Softwood sawmilling;
- Hardwood sawmilling;
- Cypress sawmilling;
- Plywood;
- Particleboard and medium density fibreboard (MDF);
- Pulp and paper;

- Preservative treated softwood;
- Hardboard;
- Hardwood poles, sleepers and miscellaneous; and
- Export of woodchips and logs.

Softwood Sawmilling

The softwood sawmilling industry in Australia is largely based on plantations of exotic pines, although the native pine, hoop pine, is grown in southern Queensland. Most plantations were initiated around the 1930s. Early development was slow, but momentum was gained in the 1960s and 1970s.

Softwood processing has become very efficient, highly mechanised and well integrated industry, comparable with any of its overseas counterparts. Most softwood mills are large, with up to 500,000 m^3/year log intake. Most of the sawn timber is seasoned and dressed. Value-adding options such as machine stress grading, glue lamination and finger jointing are common.

Nearly all softwood mills are now operating on zero waste, with all slabs and edgings being chipped for paper pulp or panelboard feedstock and the sawdust and shavings being used for boiler fuel to provide energy for kiln drying. In some cases, some of this material is sold for composting, but this is unlikely to continue if the co-generation of electricity becomes more financially attractive.

A basic density of 415 kg/m^3 is used. This is sourced from Ilic et al., (2000) and Gardner and Ximenes (*pers. comm.*); and is based on a weighted average of the respective densities of radiata pine, slash pine, Caribbean pine and hoop pine that are harvested.

The destinations of sawlogs and sawn timber products were sourced from representative sawmills in South Australia, Tasmania, Queensland and the ACT and from Pine Australia. Import and export figures were derived from ABARE 2008c.

Hardwood Sawmilling

The hardwood sawmilling sector is quite different from the softwood sector being characterised by a large number of small mills; even the very few large hardwood mills are much smaller than the average softwood mill. In recent years, the hardwood industry has undergone considerable change in response to reductions in their traditional resource base and to the impact that softwood framing has had on the traditional green hardwood framing market and also due to growing restrictions in the utilisation of native hardwood forests.

As indicated earlier, the hardwood plantation resource is expanding and removals from hardwood plantations have been included in the total hardwood removals. Most of this material is currently of pulp log quality, but more sawlogs will be harvested as the resource matures. There is a reasonable degree of integration in the hardwood industry, however integration is difficult for the smaller more remote mills.

The hardwood sawmilling industry is far more complex and varied than any of the other sectors. There are at least 10 major species throughout the country, all having different densities and shrinkage rates, and to a great extent having different end uses. This sector has not been addressed in nearly the same detail as was applied to the softwood sawmilling sector and the outcome should be regarded as indicative only.

Assumptions on the product out-turn from hardwood sawmilling were sourced from the Victorian Association of Forest Industries and a large sawmilling company operating mills in Queensland, NSW and Tasmania. Sawlog volumes produced and import/export data have been sourced from ABARE 2008c.

A basic density of 630 kg/m^3 is assumed for hardwood sawlogs. This is an average of the following ten commonly logged hardwoods: spotted gum (*Corymbia maculata*), blackbutt (*Eucalyptus pilularis*), rose gum (*E. grandis*), jarrah (*E. marginata*), karri (*E. diversicolor*), mountain ash (*E. regnans*), alpine ash (*E. delegatensis*), silvertop (*E. sieberi*), brown barrel (*E. fastigata*) and messmate stringybark (*E. obliqua*). The basic density assumed for poles and sleepers is 790 kg/m^3. This is an average of spotted gum, ironbark and blackbutt – the main species used.

Hardwood chips are lower in average density than either sawlogs or poles and sleepers as they contain a wider range of species as well as younger regrowth and plantation material. An average basic density of 570 kg/m³ is assumed. This is sourced from Chin (*pers. comm.*) of CSIRO.

Cypress Sawmilling

The Cypress sawmilling industry is restricted to the native cypress pine forests in Queensland and New South Wales. The quantity of logs removed is small and the data are currently included in the coniferous forest information in the ABARE quarterly reports (ABARE 2008c).

The industry consists of several relatively small, low technology mills operating on a scattered resource. Because of the distances involved, integration with other processing sectors is difficult; however some Cypress pine chips are being used in panelboard manufacture. The products are principally green framing and high value flooring and dressed panelling.

Plywood (Softwood and Hardwood) and Veneer

The Australian plywood industry is based principally on plantation grown softwoods and about 8% hardwoods, both native and plantation grown. Large, high quality logs for which premium prices are paid, are preferred. In volume terms, the plywood industry is small, but it uses high technology and produces a variety of products.

In addition to plywood veneer, sliced or rotary peeled decorative veneer is produced in small quantities for furniture, door and panel overlays. This production is not recorded separately by ABARE. Jaakko Pöyry Consulting (2000) estimated annual production is less than 10,000 m³. Data sources used in the model for plywood were from ABARE 2008c and the Plywood Association of Australia.

Particleboard and Medium Density Fibreboard (MDF)

The characteristics of these two wood panelboards are different, but their feedstock and end use product categories are similar. Their densities are, however, different. Particleboard and MDF plants are large-scale operations and they are usually located close to their resource. Both require low cost material as input using either small logs unsuited to sawmilling, or woodchips produced as a by-product of sawmilling. Most of the feedstock is from softwood plantations, although some regrowth hardwood is being used in a plant in Tasmania and some cypress pine is being used in a plant in Queensland. In terms of trade, Australia is a net exporter of particleboard and MDF. The industry source used for information on processing assumptions in the model was the Australian Wood Panels Association.

Pulp and Paper

Pulp and paper plants are very large-scale industries requiring large volumes of low cost resource. Plantation grown softwood fibre provides the major resource but hardwood and recycled fibre is also important. Accounting for this sector is complicated by the fact that recycled fibre is exported and pulp is imported. Australia has five pulp and paper mills.

While ABARE data provides some information, the Pulp and Paper Manufacturers Federation of Australia (PPMFA) provided a more detailed source of information. The production figures used are derived from assumed raw material usage and conversion figures rather than reported industry figures. This is important for modelling wood flows through the product cycle and is consistent with the approach used in the model for other industry sectors, apart from export woodchips, which uses ABARE statistics for export quantities in bone dry tonnes.

The model-derived paper production estimates are 15% lower than the ABARE or PPMFA figures. The reason for this is that the model calculates the wood-only raw material requirements for pulp and paper in "oven dry tonnes" while pulp reported figures are in "air dry tonnes" which contain approximately 10% moisture and 2-25% of non-wood fillers depending on the process.

A complicating factor in the assumptions on waste with the pulp and paper stream is the fact that mills vary dramatically in their recovery according to type. Kraft pulp mills typically have a low yield of fibre (@ 50%) whereas thermo-mechanical mills have a high yield (@ 95%). The manufacture of recycled paper also results in a lower yield of fibre. Based on weighted inputs, a yield of 70% has been adopted.

Preservative Treated Softwood

Both hardwood and softwood can be preservative treated, but only softwood has been allocated a separate category. This is because treated sawn softwood has some use categories which are different to untreated softwood, whereas hardwood is usually treated so that the sapwood can be protected against borer attack and its use is then the same as for untreated hardwood.

Treated softwood poles and posts have also been included with sawn softwood, but treated hardwood poles and piles have been included with sleepers and other miscellaneous hardwood products. The ABARE statistics do not list treated timber of any description. The information used in the model has been obtained from the Timber Preservers Association of Australia.

Hardboard

The hardboard industry in Australia is quite small, with only two plants in operation. One is at Ipswich (Queensland) and the other is at Raymond Terrace (NSW). Hardwood is used for feedstock, sourced from pulp logs and sawmill residue.

The technology is quite old, but the products are unique and have niche markets that are likely to endure the competition from other panel products. Both hardboard producers were contacted during the study for manufacturing assumptions.

Hardwood Poles, Sleepers and Miscellaneous

The existing stock of hardwood transmission poles in Australia is reputed to number about 6,000,000 and production is estimated to be about 100,000 poles per annum, equivalent to about 75,000 m^3 of log. Railway sleepers also represent a considerable resource, and although concrete sleepers are now used for all new work, timber sleepers will continue to be used for the maintenance of secondary lines. 'Miscellaneous' includes a range of products such as mining, fencing and landscaping timbers. The log removals information for this group is conflicting and difficult to uncover. A provisional constant of 184,400 m^3 has been proposed for use in the model and further work is recommended.

Log and Woodchip Exports

Woodchip Exports

Export woodchips constitute a significant proportion of the annual harvest from Australian forests. The ABARE quarterly forest products statistics report both bone dry tonnes (BDt) of softwood chips and BDt of hardwood chips exported. The model uses the ABARE reported export figures directly in bone dry tonnes.

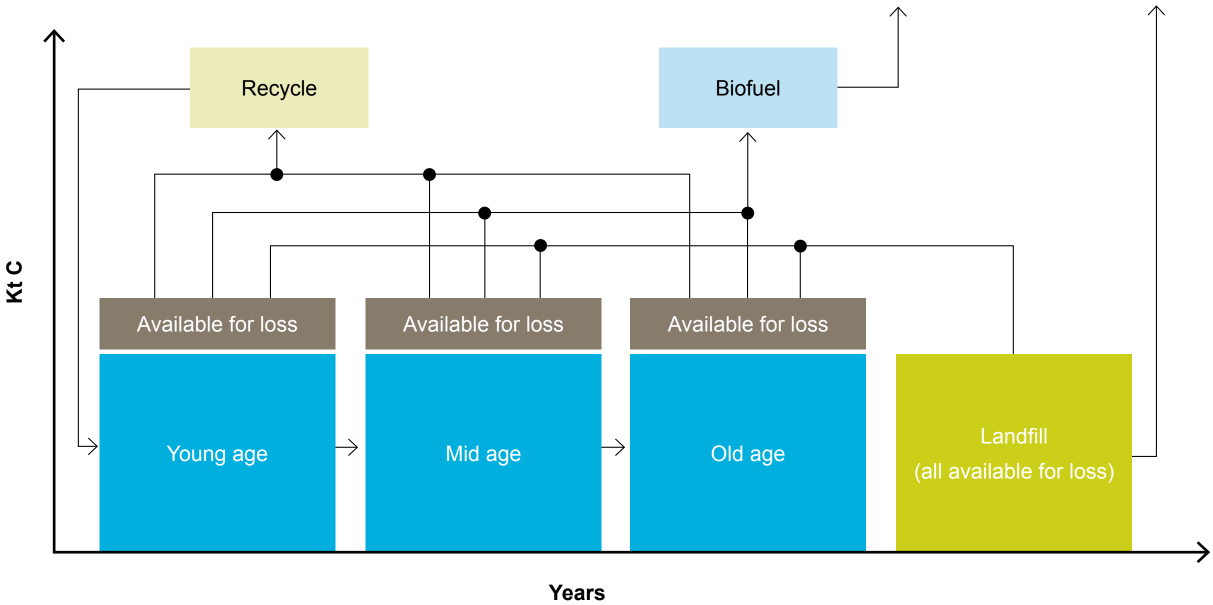
Log Exports

Total exports of coniferous logs reported by ABARE (2008c) consist of both sawlog and pulp log. New South Wales exports approximately 7,000 m^3 of short length poles / year.

Life Span of Timber Products (Recycling and Landfill)

The life span of wood products must be taken into account when ascertaining the quantity of carbon stored in timber products. Considerable attention has been given to subdividing the various timber products pools into different classes based on product and decay rates. The decay rates used assume that losses of material from service life will increase with product age. Therefore the entry and exit of material from production to loss from each product pool is tracked and aged according to three age classes; young, medium and old. The proportion of material lost from each pool may vary (e.g., there may be little loss from young pools (excluding those to the medium age class)). Material is lost at a constant rate and may be placed in landfill, recycled, used for bioenergy or lost to the atmosphere (e.g., burnt with no energy capture) (Figure 7.G1).

Figure 7.G1: Structure of the Wood Products Model



For shorter-term products, the impact of the size of previous stocks is fairly slight as the recent additions to the pools have the major impact. For long-term products, an estimate of the size of the initial pool is essential, but difficult. The size of the housing pool uses housing starts data. Other pools are also only estimates. The proportion of the pool that has been derived from Australian-grown wood is required in order to implement an approach that separately deals with imported wood products. However, this component is difficult to estimate and estimates should be treated with some caution.

Life Span Pools Assumed for the Carbon Model

Very short-term products – Pool 1

- Softwood – pallets and cases.
- Plywood – formboard.
- Paper and paper products.
- Age: young = 1; medium = 2; old = 3

Short-term products – Pool 2

- Hardwood – pallets and palings.
- Particleboard and MDF – shop fitting, DIY, miscellaneous.
- Hardboard – packaging.
- Age: young = 3; medium = 6; old = 10

Medium-term products – Pool 3

- Plywood – other (noise barriers).
- Particleboard and MDF – kitchen and bathroom cabinets, furniture.
- Preservative treated pine – decking and palings.
- Hardwood – sleepers and other miscellaneous hardwood products.
- Age: young = 10; medium = 20; old = 30

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Long-term products – Pool 4

- Preservative treated pine – poles and roundwood.
- Softwood – furniture.
- Hardwood – poles, piles and girders.
- Age: young = 20; medium = 30; old = 50

Very long-term products – Pool 5

- Softwood – framing, dressed products (flooring, lining, mouldings).
- Cypress – green framing, dressed products (flooring, lining).
- Hardwood – green framing, dried framing, flooring and boards, furniture timber.
- Plywood – structural, LVL, flooring, bracing, lining.
- Particleboard and MDF – flooring and lining.
- Hardboard – weathertex, lining, bracing, underlay.
- Preservative treated pine – sawn structural timber.
- Age: young = 30; medium = 50; old =90

A specified proportion of material may be lost annually (an exponential loss) from each age class of each product pool. The amount lost from each age class for each product pool can be capped and different proportions can be lost according to age. This feature of the model provides for 'steps' in product loss rather than functioning on either a simple linear or exponential loss applied to a whole product pool, irrespective of the average age of the pool. If inputs vary over time the average age of products will vary, and this is represented by the amounts of material in each age class of each product pool.

Initial Stock Assumptions

Input data is available for the model since 1944 and this has the benefit of allowing the model to establish new equilibrium pools as the input material may be 'turned-over' several times prior to an equilibrium stock being reached for recent years. Initial stock estimation (for 1944) is more important for Pool 5 as this material may remain in use.

Model Calibration

Once the data on production inputs, processing flows and initial stocks is determined other model calibration requirements include:

- the age at which material moves from young to medium and medium to old pools;
- the amount of each age class for each product pool exposed to loss;
- the rate of loss from each age class in each product pool; and
- the fraction of losses from each age class in-each product pool to each of landfill, recycling, and bioenergy and the atmosphere;

The model estimates used are presented in Tables 7.G2 and 8.5.

Table 7.G2: Decomposition rates and maximum possible loss

Pool	YOUNG		MEDIUM		OLD	
	Loss Yr -1	Max. Possible Loss (%)	Loss Yr -1	Max. Possible Loss (%)	Loss Yr -1	Max. Possible Loss (%)
1	1.0	0.60	0.500	0.65	0.333	0.90
2	0.333	0.30	0.167	0.50	0.100	0.90
3	0.10	0.15	0.050	0.65	0.033	0.45
4	0.05	0.25	0.033	0.65	0.020	0.80
5	0.033	0.20	0.020	0.55	0.011	0.95

To understand the impact of uncertainties, *Monte Carlo* analyses using the Palisade @Risk software (Palisade 1997) was applied. This approach is also able to identify model sensitivities. Through this, it is possible to identify where uncertainty in parameter estimation may be most significant in terms of a probability distribution of expected outcomes, and to focus future data collection on areas that will have greatest impact on reducing uncertainties.

Model Results

By integrating the carbon pools and life cycles of wood products, the model enables the total carbon pools and emissions to be estimated. In broad terms, the components of the models as described for each sector are similar, using:

- an estimate of raw materials input, whether of sawlogs, woodchips ex-sawmill, or pulp logs;
- an estimate of the products of processing, e.g., “x”% sawdust, shavings or sander dust for on site energy generation or compost, “y”% woodchips for other manufacturing processes, “z”% of sawn timber products, panel products, paper, etc;
- an estimate of the proportion of products by product categories, depending on whether their expected end-use is long-term or short-term;
- a final figure for total Australian consumption by end use categories, converted to wood fibre content (oven-dry weight) and to tonnes of carbon; and
- import and export data were obtained from the ABARE 2008c by end use categories.

Table 7.G3 shows the annual additions and losses and carbon pool sizes.

Table 7.G3: Carbon stock and emissions outcomes (ktC)

Year	Domestic Production of New Wood Products	Imports of New Wood Products	Exports of New Wood Products[a]	Increase Due to New Wood Products	Carbon Pool (excl. landfill)
	kt C	kt C	kt C	kt C	kt C
1990	3,715	817	1,438	3,093	77,544
1991	3,780	726	1,592	2,916	78,644
1992	3,855	787	1,619	3,023	79,768
1993	4,027	825	1,706	3,144	80,961
1994	4,219	826	1,856	3,188	82,187
1995	4,494	990	2,184	3,300	83,456
1996	4,467	777	2,001	3,247	84,584
1997	4,608	839	2,135	3,310	85,686
1998	5,168	909	2,608	3,473	86,881
1999	5,022	894	2,468	3,448	87,991
2000	5,127	1,014	2,620	3,522	89,149
2001	5,750	948	3,136	3,561	90,276
2002	5,834	938	3,088	3,685	91,505
2003	6,274	1,010	3,596	3,688	92,764
2004	6,386	1,110	3,531	3,966	94,139
2005	6,342	1,166	3,611	3,896	95,426
2006	6,436	1,114	3,535	4,016	96,741
2007	6,365	1,138	3,543	3,960	97,960

Note: a) Exports of new wood products excludes exports of woodchips

Uncertainty Analysis

With the consistent and comprehensive monitoring of wood production in Australia since 1944, and the confidence in this data gained through cross-verification with other datasets, little uncertainty will likely be derived from the production data. The most likely sources of uncertainty will be derived from the allocation to decomposition and recycling pools, and the rates of decomposition in those pools. To test the relative importance of the pool ages and decomposition rates *Monte Carlo* analyses were implemented using the @ Risk add-in software (Palisade 1997) to the Excel spreadsheet wood products carbon model. The principal model parameters of interest are the decomposition rates within pools (e.g., losses from service life and landfill) and transfers (e.g., to recycling, bioenergy and landfill). *Monte Carlo* analysis samples values from within specified ranges (probability distributions) for nominated parameters within repeated applications of the model. Probability distributions for values within ranges for each variable can be nominated, as can positive and negative correlations between variables so that sampling can reflect these correlations. In this application the nominated probability distributions were ‘triangular’, that is, values within the ranges sampled formed a triangular distribution around a central expected value. No correlations between variables were specified, so that value selection was random within the triangular probability distributions.

The life cycle pools affected and the distributions of their possible values for the *Monte Carlo* analyses are shown in Tables 7.G4, 7.G5, 7.G6 and 7.G7. Distributions of possible outcomes were stabilised over 100,000 model iterations. The Tornado Graph (Figure 7.G2) shows the relative importance of each input variable to the overall uncertainty in the model outcome. The effects of uncertainty in the carbon stock estimates in 1990 and 2004 national harvested wood product emissions estimates can be derived by looking at the annual stock change for the 0.10, 0.50 and 0.90 levels of confidence in potential stock outcome.

Table 7.G4: Pool age uncertainty ranges used in the Monte Carlo Analysis

Life Cycle Pool	Lower Bound (yrs)			Expected Value			Upper Bound (yrs)		
	Young	Medium	Old	Young	Medium	Old	Young	Medium	Old
Very Short Term	0.5	1	2	1	2	3	1.5	3	4
Short Term	1	3	5	2	6	10	3	9	15
Medium Term	5	15	20	10	20	30	15	25	40
Long Term	15	20	40	20	30	50	25	40	60
Very Long Term	20	40	75	30	50	90	40	60	105

Table 7.G5: Decomposition rate uncertainty ranges used in the Monte Carlo Analysis

Age	Pool	Lower Bound	Expected Value	Upper Bound
Young	1	2.000	1.000	0.667
	2	1.000	0.333	0.333
	3	0.200	0.100	0.067
	4	0.067	0.050	0.040
	5	0.050	0.033	0.025
Medium	1	1.000	0.500	0.333
	2	0.333	0.167	0.111
	3	0.067	0.050	0.040
	4	0.050	0.033	0.020
	5	0.025	0.020	0.017
Old	1	0.500	0.333	0.250
	2	0.200	0.100	0.067
	3	0.050	0.033	0.025
	4	0.025	0.020	0.017
	5	0.013	0.011	0.010

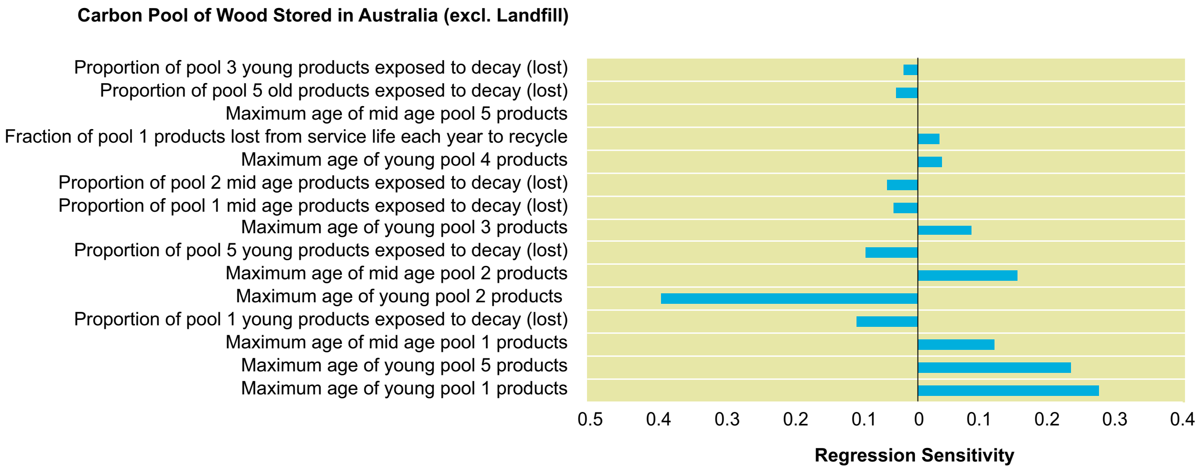
Table 7.G6: Pool fractions exposed to decomposition uncertainty ranges used in the Monte Carlo Analysis

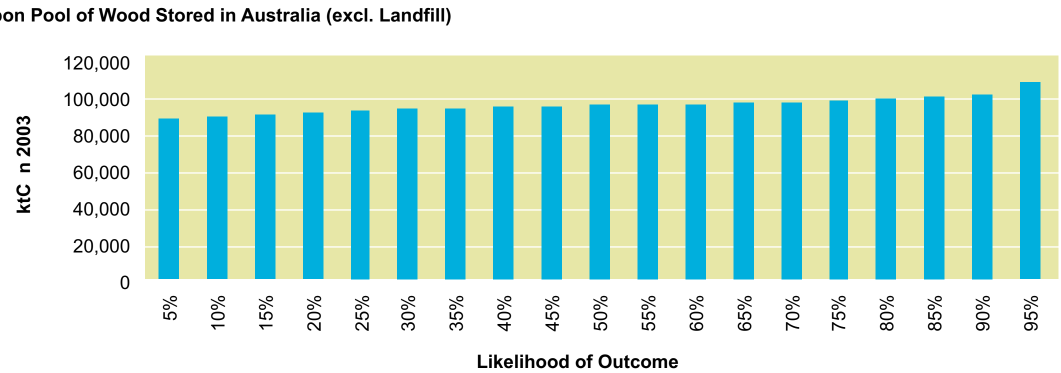
Age	Pool	Lower Bound	Expected Value	Upper Bound
Young	1	0.500	0.600	0.700
	2	0.250	0.300	0.350
	3	0.120	0.150	0.180
	4	0.225	0.250	0.275
	5	0.175	0.200	0.225
Medium	1	0.550	0.650	0.750
	2	0.400	0.500	0.600
	3	0.550	0.650	0.750
	4	0.550	0.650	0.750
	5	0.450	0.550	0.650
Old	1	0.800	0.900	1.100
	2	0.800	0.900	1.100
	3	0.400	0.450	0.500
	4	0.700	0.800	0.900
	5	0.800	0.950	1.150

Table 7.G7: Destination fraction uncertainty ranges used in the Monte Carlo Analysis

Age	Pool	Landfill			Recycle			Biofuel		
		Lower Bound	Expected Value	Upper Bound	Lower Bound	Expected Value	Upper Bound	Lower Bound	Expected Value	Upper Bound
Young	1	0.380	0.440	0.500	0.450	0.490	0.530	0.630	0.040	0.050
	2	0.600	0.750	0.900	0.180	0.200	0.220	0.040	0.050	0.060
	3	0.800	0.950	1.100	0.400	0.050	0.060	-	0	-
	4	0.700	0.850	1.000	0.130	0.150	0.170	-	0	-
	5	0.700	0.850	1.000	0.090	0.100	0.110	0.040	0.050	0.060

Figure 7.G2: Results of the @Risk sensitivity analyses

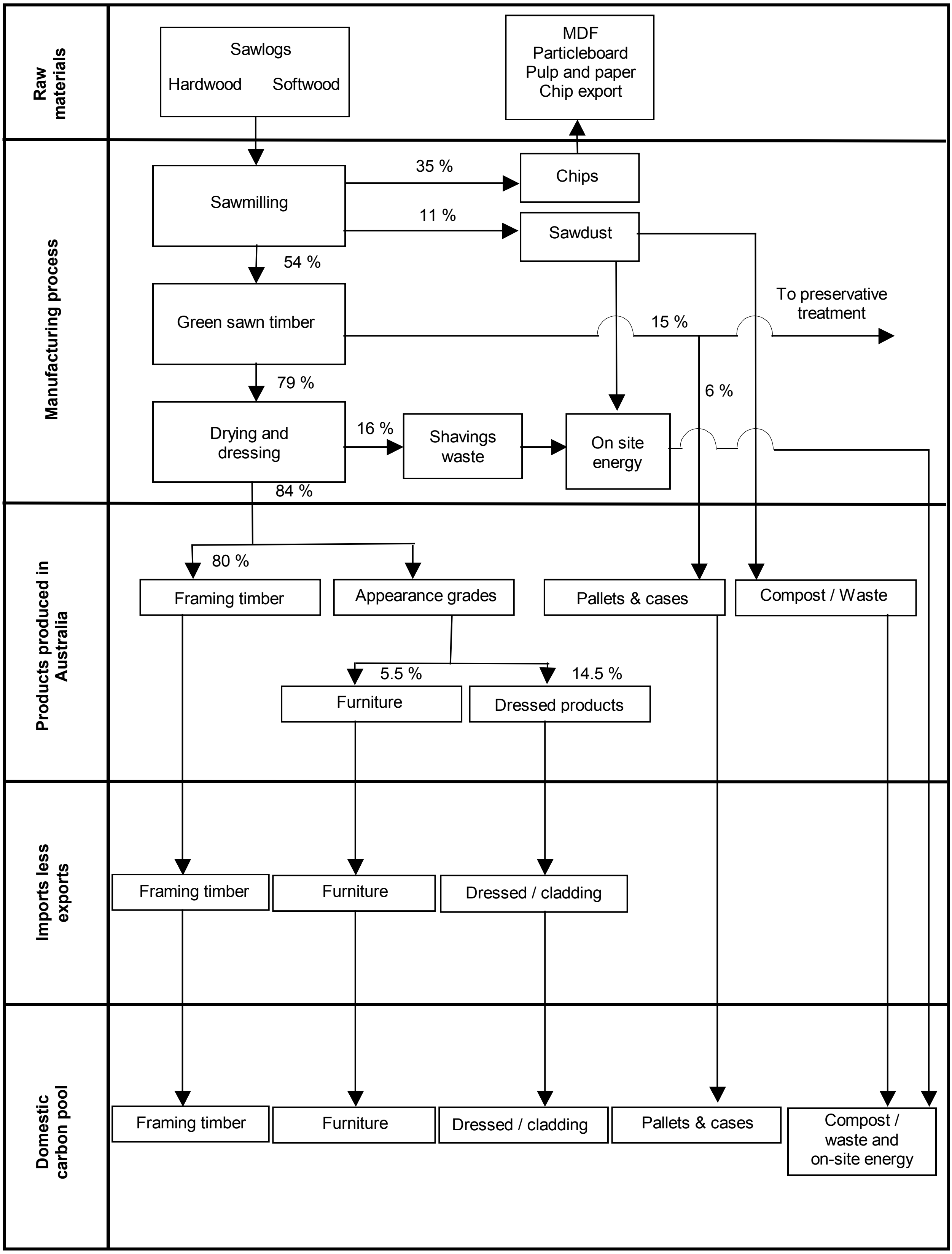




APPENDICES

Attachment 7.G1: Wood Flows by Sector

Figure 7.G3: National Carbon Accounting Model for Wood Products – Sawmilling wood flows *



* Percentages shown for softwood sawmilling, refer to model for hardwood and cypress pine

Figure 7.G4: National Carbon Accounting Model for Wood Products – Wood flows in preservative treated products

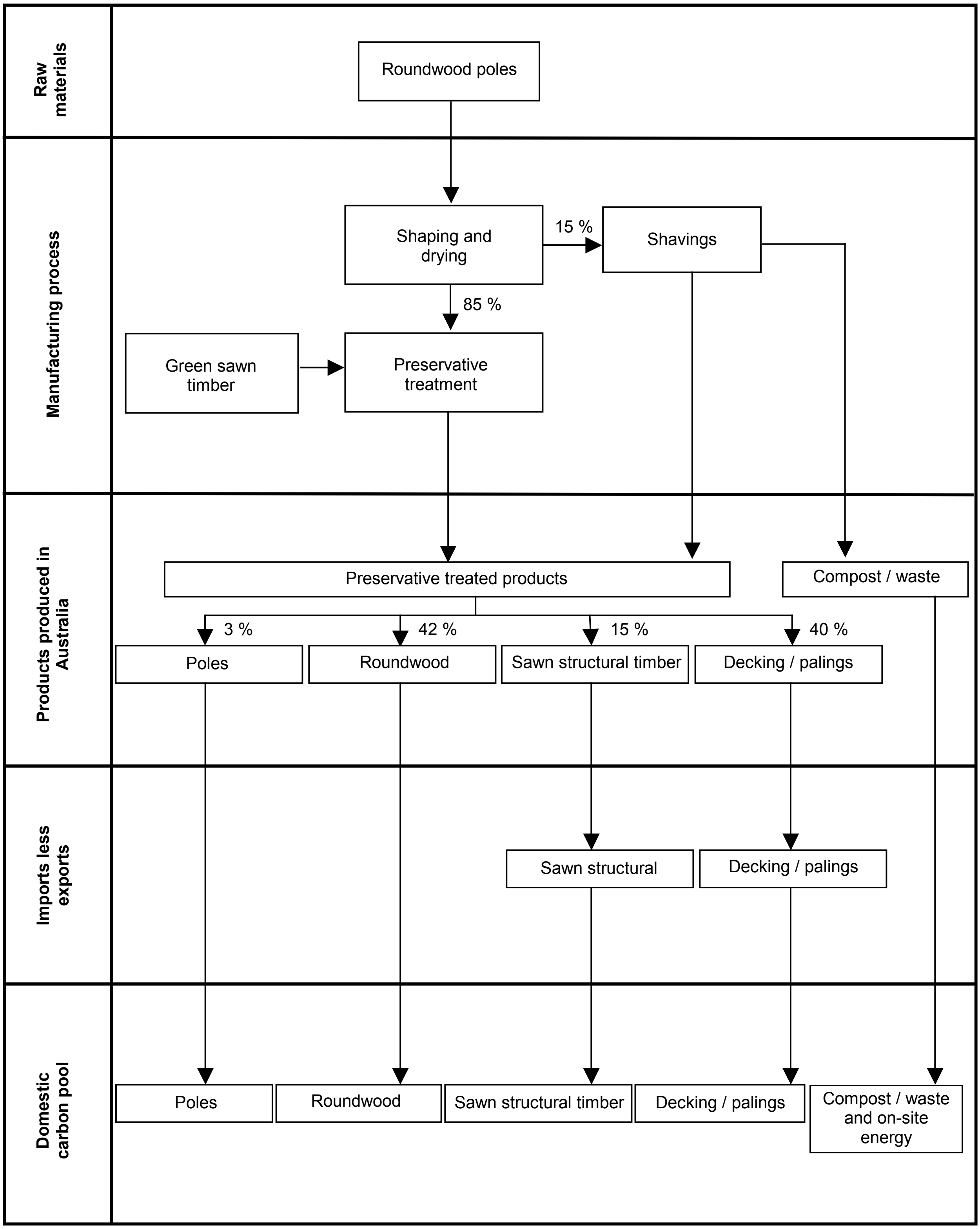


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Figure 7.G5: National Carbon Accounting Model for Wood Products – Wood flows in plywood production

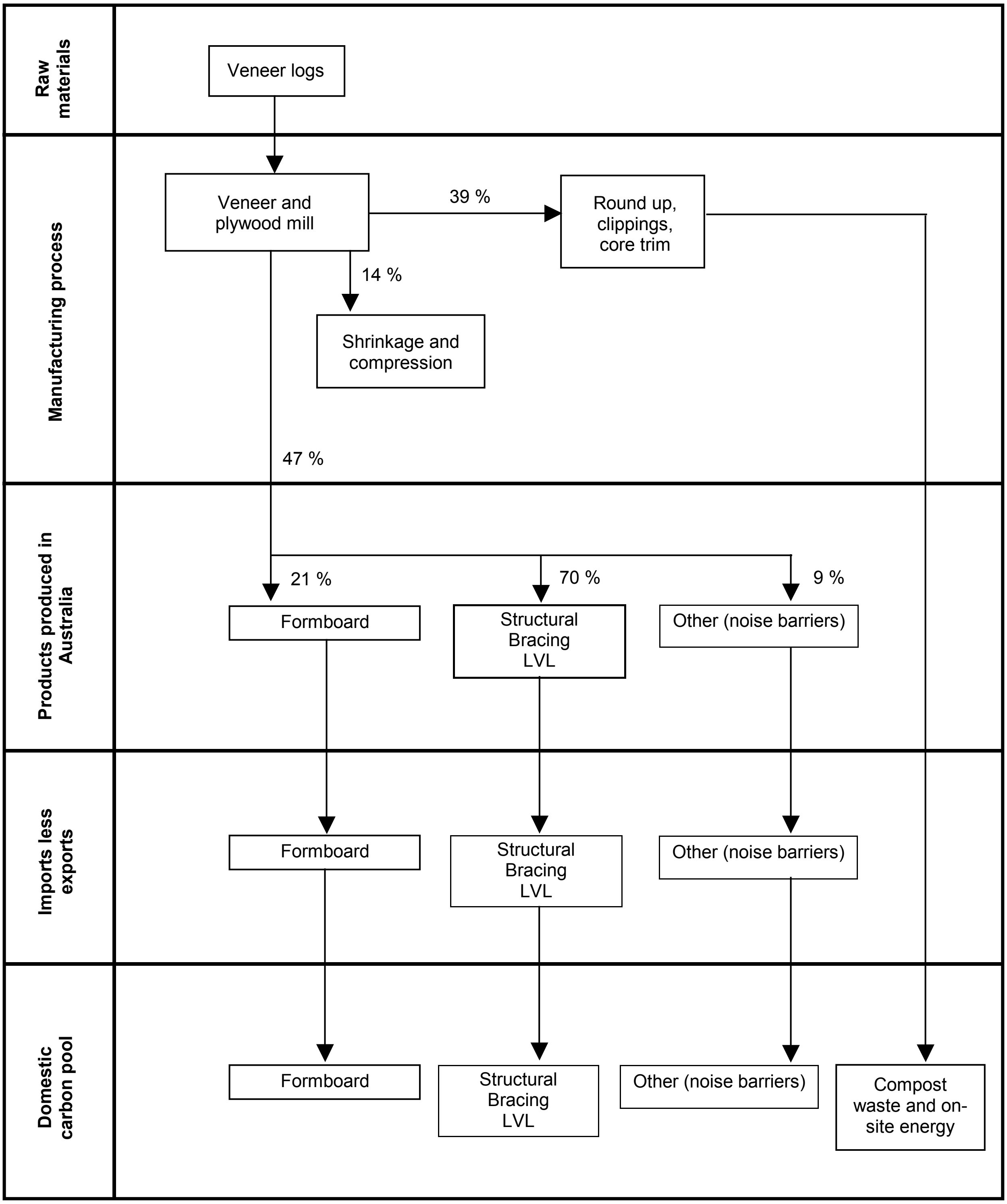
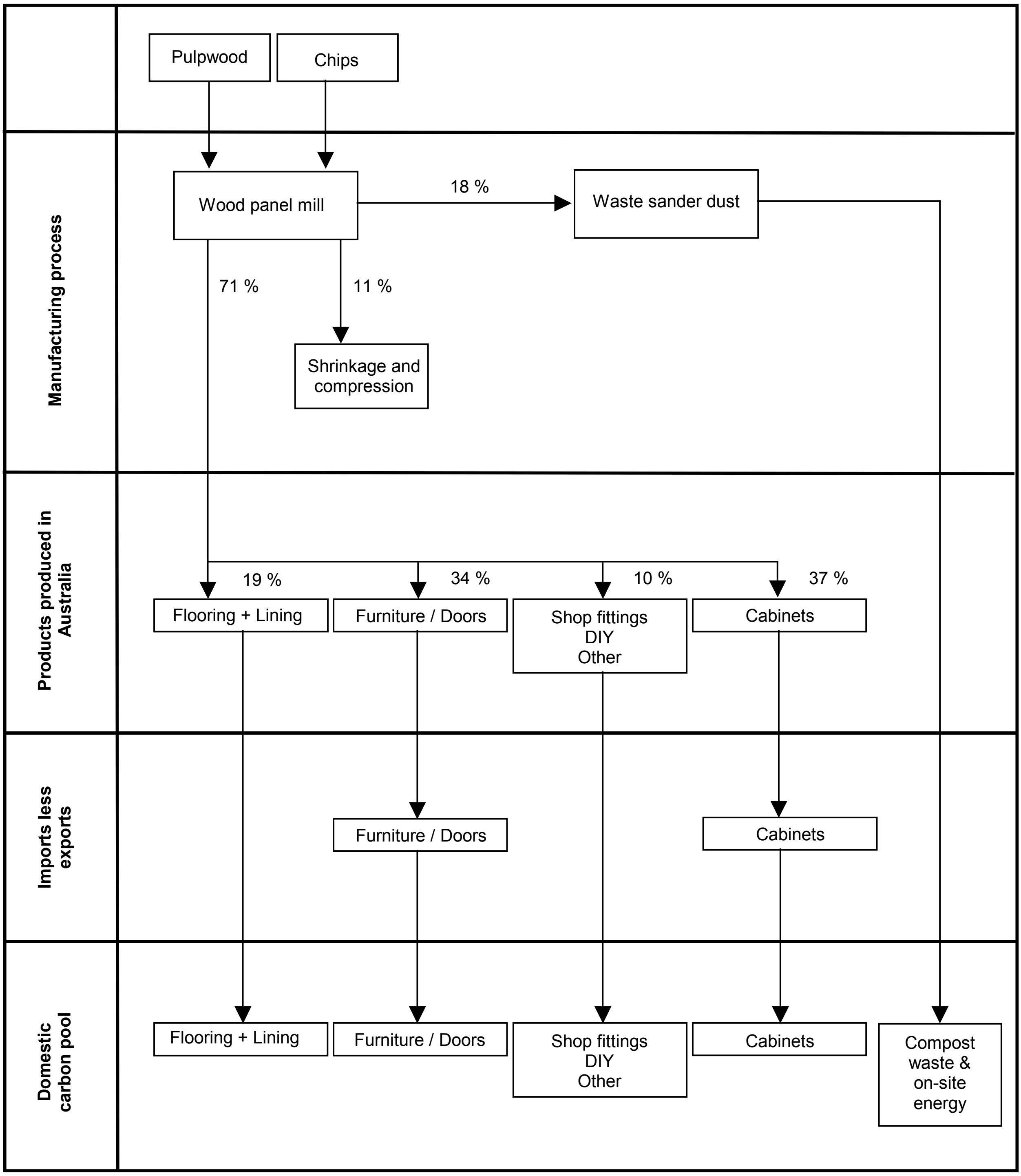


Figure 7.G6: National Carbon Accounting Model for Wood Products – Wood flows in MDF and particleboard manufacture*



* Percentages shown for particleboard manufacture – see model for details on MDF

APPENDICES

Figure 7.G7: National Carbon Accounting Model for Wood Products – Wood flows in pulp and paper manufacture

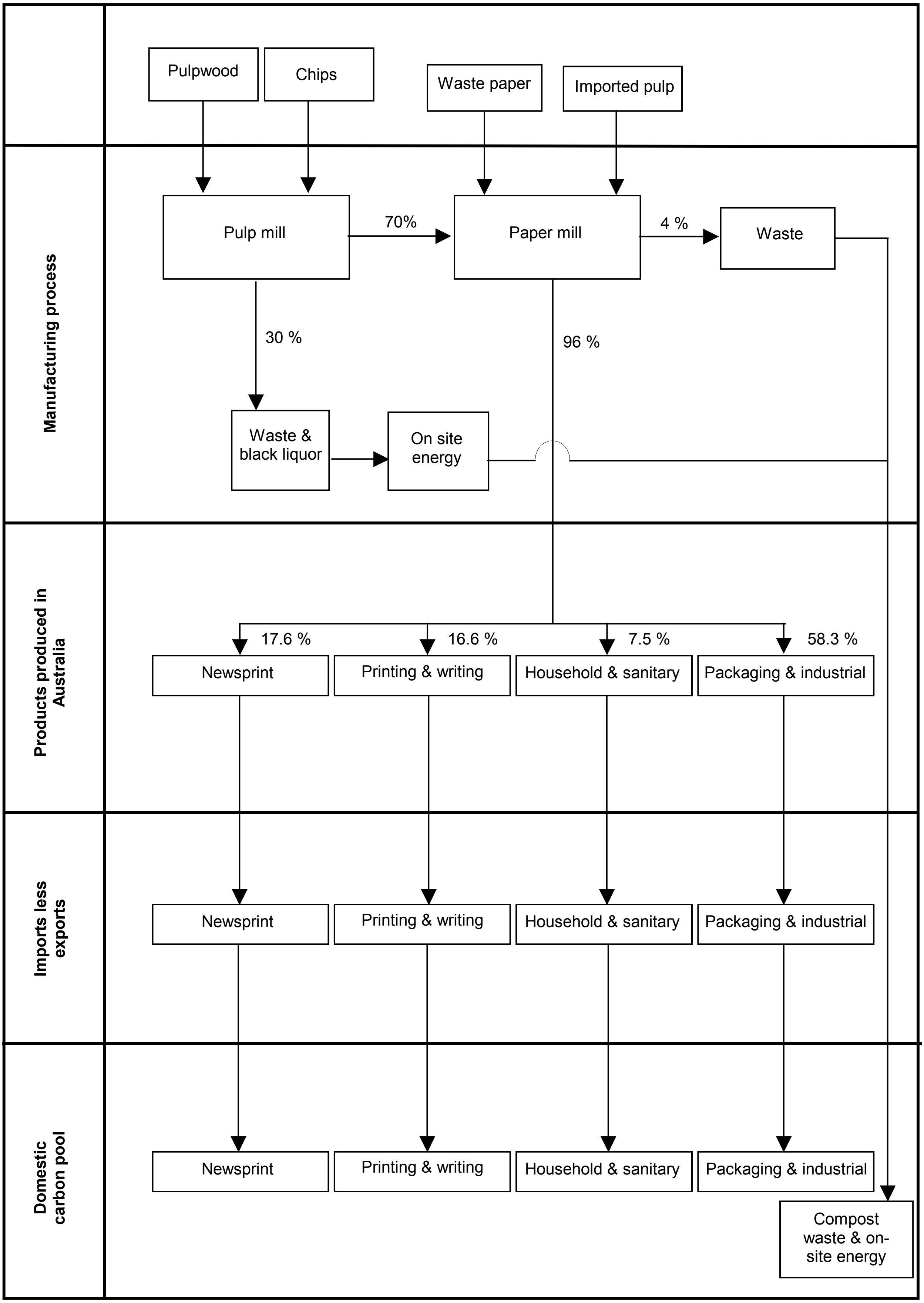
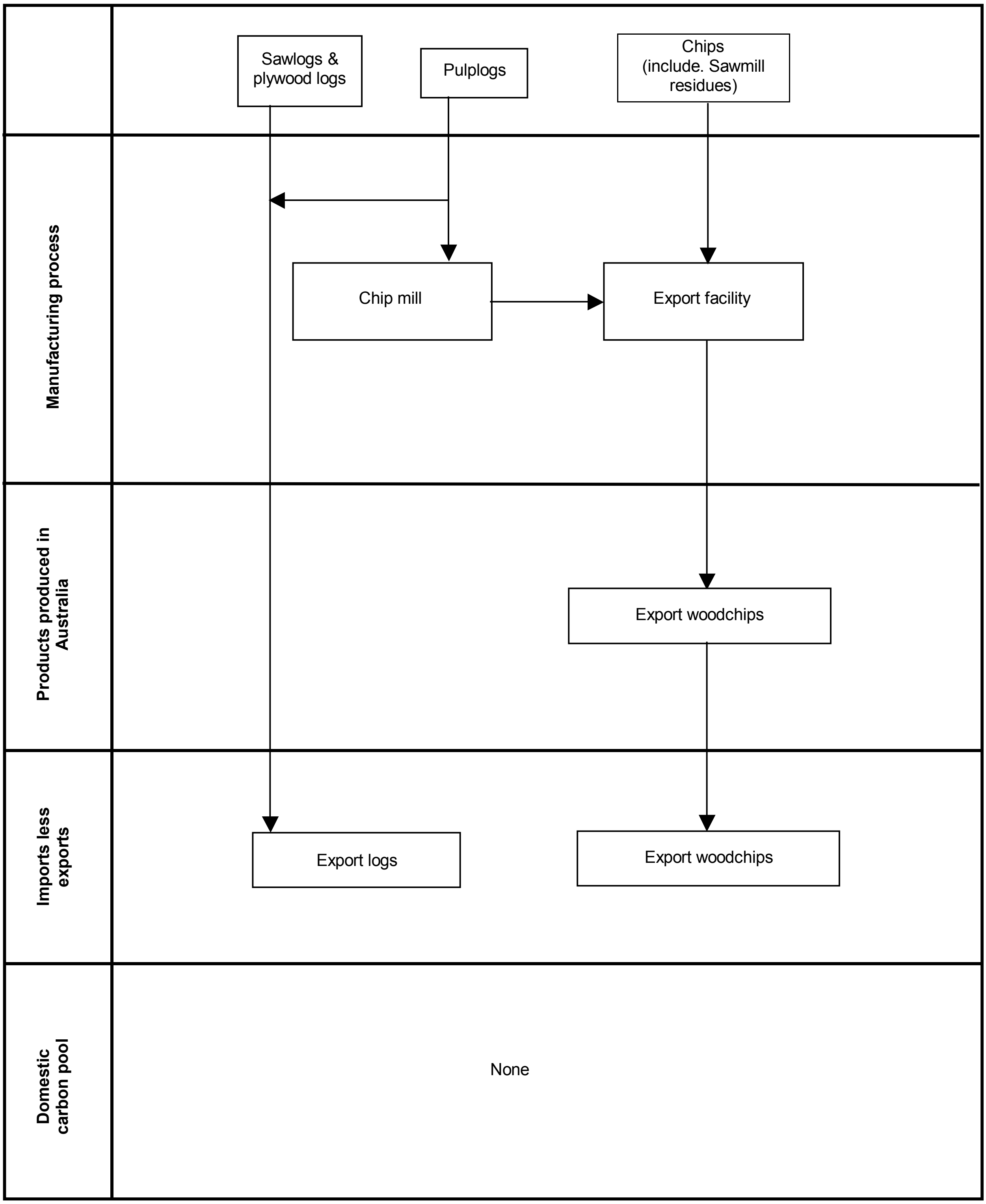


Figure 7.G8: National Carbon Accounting Model for Wood Products – Wood flows in export woodchips and logs



Attachment 7.G2: Quality Assurance

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Date October 4, 2004

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REVIEW OF WOOD PRODUCTS MODEL – UPDATE 2004

Dear Gary

As agreed Jaakko Pöyry Consulting has reviewed the 2004 update of the AGO's Wood Products Model. The update was made by MBAC Consulting in June 2004.

The focus of Jaakko Pöyry Consulting's work was to check that the updated data were consistent with our understanding of the wood products' industry production, import and export statistics and to consider if any recent changes in the industry necessitated adjustments to assumptions or the structure of the model. However, the underlying integrity of the model's calculations has not been checked.

<u>Pulp and paper worksheet</u>

We have no significant concerns about the updated statistics added to the pulp and paper worksheet. The base data entered since 1998 is consistent with the data collected and published by APIC and changes in the industry over the last six years do not require any changes in the assumptions.

In particular, it was considered that the start-up of the new Visy pulp and paper mill at Tumut may have changed the destination fraction of Raw Material for the industry (rows 38 – 40). However, a check of this indicated the destination fraction of wood to pulp had only changed from 71% to 69% with the start-up of the Visy mill, so that the estimate in the model of 70% remains valid.

Some minor points to note are as follows:

- The industry body which is the reference source for the pulp and paper data, has now changed its name from APIC to A3P, so this could be noted to assist in locating data for any subsequent update.
- Similarly, it is noted that the data listed under a particular calendar year in the model, is actually the data for the financial year commencing 1st July in that year. This is unlikely to have any significant impact on the outputs of the model, but again could be noted to assist in any subsequent update.
- Notes by MBAC refer to correcting some of the units from 1000m^3 to tonnes. In fact the units for wood volumes entered in rows 25 – 30 which are sourced

8. Waste

8.1 Overview

Total estimated waste emissions for 2007 were 14.6 Mt CO_2-e, or 2.7% of total net national emissions (Table 8.1). The majority of these emissions were from solid waste disposal on land, contributing 11.1 Mt or 76.2% of waste emissions. Wastewater handling contributed a further 3.4 Mt (23.6%) of waste emissions while waste incineration contributed 0.03 Mt (0.2%). *Waste* emissions are predominantly methane-generated from anaerobic decomposition of organic matter. Small amounts of carbon dioxide are generated through the *incineration of solvents and clinical waste* and nitrous oxide through the *decomposition of human wastes*.

WASTE

Table 8.1: Waste CO_2-e emissions, 2007

Greenhouse gas source and sink categories	CO_2-e emissions (Gg)			
	CO_2	CH_4	N_2O	Total
6 WASTE	**29**	**13,949**	**590**	**14,567**
A. Solid waste disposal on land	NA	11,106	NA	11,106
B. Wastewater handling	NA	2,843	590	3,432
C. Waste incineration	29	NA	NE	29
D. Other waste	NA	NA	NA	NA

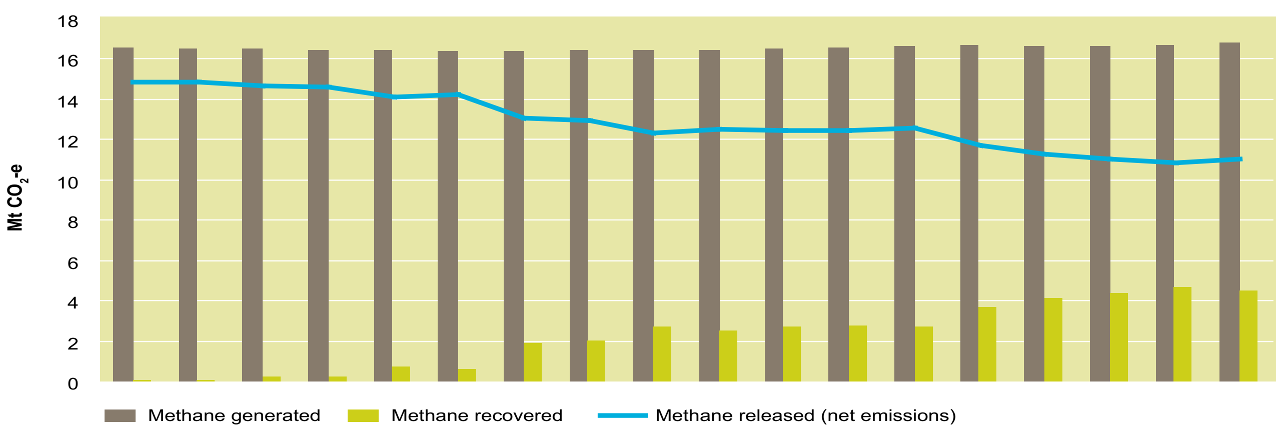
Trends

Waste emissions were 22.5% (4.2 Mt CO_2-e) lower in 2007 than they were in 1990 and 2.7% (0.4 Mt CO_2-e) higher than in 2006.

Emissions from municipal *solid waste disposal on land* decreased by 25.5% (3.8 Mt CO_2-e) over the period 1990 to 2007 (Figure 8.1), and were 2.0% (0.2 Mt CO_2-e) higher than in 2006. As waste degradation is a slow process, estimates of methane generation for 2007 reflect waste disposal over more than 50 years.

Rates of methane recovery from solid waste have improved substantially since 1990, increasing from a negligible amount to 4.5 Mt CO_2-e of methane in 2007.

Figure 8.1: Emissions from solid waste disposal on land, 1990–2007



Wastewater handling emissions decreased by 10.0% (0.4 Mt CO_2-e) over the period 1990 to 2007, with an increase of 5.2% (0.2 Mt CO_2-e) since 2006. Changes in estimates for *wastewater handling* emissions are largely driven by changes in estimates of industry production and population.

Emissions of CO_2 from the incineration of solvents and clinical waste decreased by 66.1% (0.1 Mt) between 1990 and 2007.

WASTE

8.2 Overview of Source Category Description and Methodology – Waste

Table 8.2 Summary of methods and emission factors used to estimate emissions from Waste

Greenhouse gas source and sink categories	CO_2		CH_4		N_2O	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
6. Waste	T2	CS	T2	CS,D	T1	D
A. Solid Waste Disposal on Land	NA	NA	T2	D	NA	NA
B. Wastewater Handling	NA	NA	T2	CS,D	T1	D
C. Waste Incineration	T2	CS	NE	NA	NE	NA
D. Other	NA	NA	NA	NA	NA	NA

T1= Tier 1, T2 = Tier 2, CS = country specific, M = model, D = default, NE = not estimated, NA = not applicable

8.2.1 Solid Waste Disposal On Land (6.A)

Source Category Description

The anaerobic decomposition of organic matter in a landfill is a complex process that requires several groups of microorganisms to act in a synergistic manner under favourable conditions. Emissions emanate from waste deposited over a long period (in excess of 50 years in the Australian inventory). The final products of anaerobic decomposition are CH_4 and CO_2. Emissions of CO_2 generated from solid waste disposal are considered to be from biomass sources and therefore are not included in the waste sector of the inventory. Management of landfill sites is generally a municipal activity, with activity data collected by State Government agencies. CO_2 produced from the flaring of methane from waste is also considered as having been derived from biomass sources.

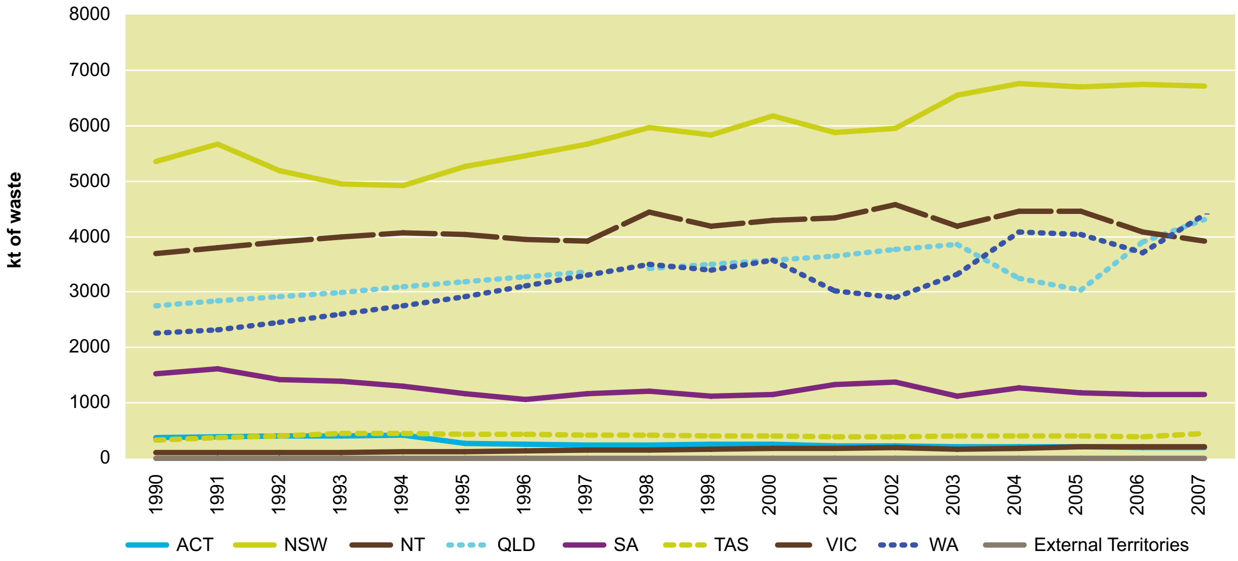
Methodology

The Australian methodology for calculating greenhouse gas emissions from solid waste is consistent with the IPCC Tier 2 First Order Decay (FOD) Model (IPCC 2006). The methodology deployed utilises a dynamic, spatially-explicit model driven by landfill data provided by the relevant State/Territory Government agencies responsible for waste management. Although the structure of the methodology is constant across States, climate-specific parameters introduce variations in estimated emissions depending on location. The model tracks the stock of carbon estimated to be present in the landfill at any given time. Emissions are generated by the decay of that carbon stock, and reflect waste disposal activity over many decades. The methodology is fully integrated with the results of the Harvested Wood Products (HWP) model reported in chapter 7.

Australian waste generation and disposal to landfill

Quantities of waste disposed to landfill are collected by State Government agencies (and in most cases also published). A mix of steady growth and some declines in waste tonnages disposed to landfill has been observed in Australia's States and Territories since 1990 reflecting, in part, differences in population growth (Figure 8.2).

Figure 8.2: Solid waste to landfill by state

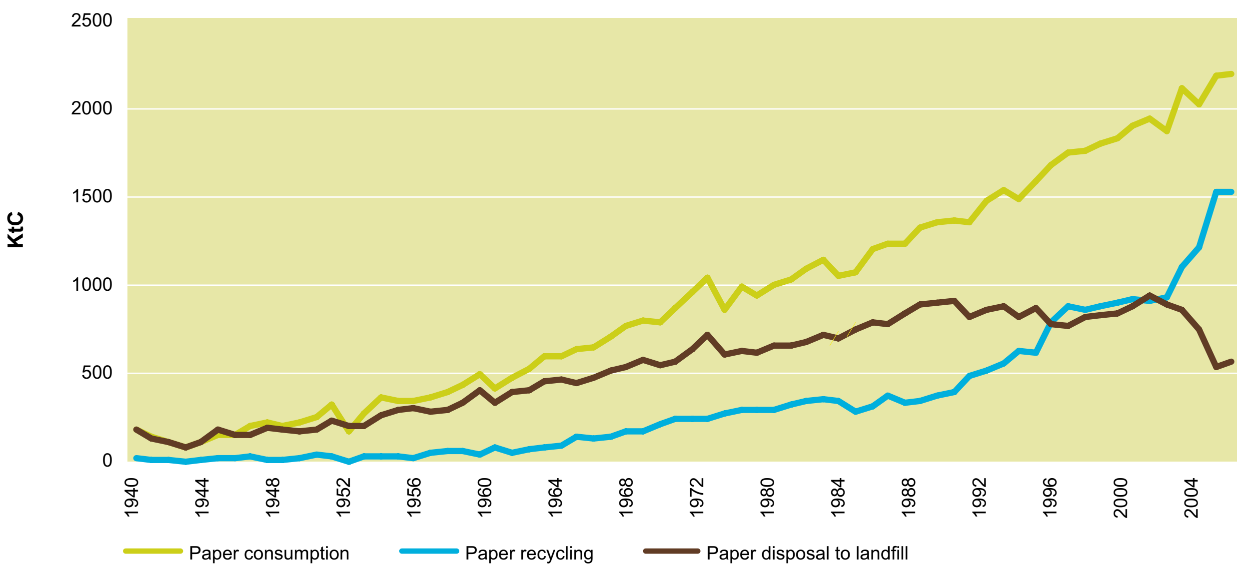


Sources: (1) NSW Environment Protection Authority; (2) EcoRecycle Victoria; (3) QLD Environment Protection Authority; (4) SA Environment Protection Authority; (5) WA Department of Environment; (6) Hobart City Council; (7) ACT Department of Urban Services

The data available from State Government agencies does not extend to the period prior to 1990. Consequently, the Department of Climate Change has used back-casting techniques to derive a time series of waste disposed to landfill for Australia back to 1940 allowing for a carbon stock model with data covering at least 50 years. The principal drivers that have been used to determine total waste to landfill are the amount of waste generated from paper consumption and the estimated amount of waste generated from the production of harvested wood products. The combined share of paper and wastes from harvested wood production in total waste is assumed to be constant at 1990 shares throughout the period. This approach of extrapolation based on key drivers is consistent with the approaches specified in the IPCC Guidelines in relation to the generation of missing data.

The amount of paper generated for disposal to landfill reflects those factors that affect the amount of paper in stock reaching the end of its useful life and therefore available for disposal and the changes that have occurred in disposal behaviour – particularly the increasing shift in disposal from landfill to recycling (Figure 8.3).

Figure 8.3: Paper consumption, recycling and disposal to landfill – Australia: 1940-2007



Over time the amount of paper waste generated for disposal will be consistent with the amount of paper consumption, especially given the short life time assumed for this product. The amount of paper consumption has been increasing significantly in Australia reflecting both increasing population and increasing per capita consumption levels. Per capita consumption of paper has increased from an estimated 26 kgC per person in the 1940s to 105 kgC per person in 2007. Similarly, waste paper generation is estimated to have been 225 ktC in 1940 and 2148 ktC in 2007 (Table 8.3).

An increasing trend to paper recycling has lead to a decrease in the proportion of paper disposed to landfill. The amount of waste paper disposed to recycling as a share of product reaching the end of its useful life has increased from an estimated 12% in 1940 to 71% in 2007, with a sharp jump recorded in 2006 reflecting in part the success of a number of State Government waste management initiatives. The share of paper disposed to landfill has declined commensurately.

The generation of wastes from the production of harvested wood products – mainly sawmill residues – is also a significant source of material for landfill and reflects two conflicting trends. The overall production of harvested wood products – particularly sawnwood from hardwoods – increased significantly between 1940 and 1960. Production has increased significantly again since the early 1990s – particularly sawnwood from softwood species and paper production – which has offset declines in the production of sawnwood from hardwood species. The ratio of waste generated to harvested wood product produced has fallen over time, however, reflecting both efficiencies in production and the changes in the mix of products produced and offsetting the effect of the overall increase in production to a large extent (Table 8.4).

The amount of wastes generated from the production of harvested wood products that are disposed to landfill depends on how much of the wastes are estimated to have been combusted for energy[11], and how much of the wastes generated are used in the production of other products. In Australia, production of softwoods has increased much more rapidly than the production of hardwood in recent years. Consequently, given that there are currently more options for the disposal of softwood wastes either as fuel or as fibre in the production of paper than is the case for hardwood wastes, the proportion of total harvested wood product wastes disposed to landfill has decreased over time.

Table 8.3: Key variables determining the amount of paper waste generation and disposal to landfill

Year	Apparent paper consumption	Per capita paper consumption	Closing stock of paper product	Total paper available for disposal/ waste generation	Paper recycling	Paper disposal to landfill	Recycling share of total disposal	Disposal to land fill as share of total disposal
	kt C	kg C/head	kt C	kt C	kt C	kt C		
1940	190	26	200	225	47	187	0.12	0.85
1990	1,355	80	750	1,344	400	904	0.30	0.67
2000	1,810	95	1,000	1,792	897	842	0.50	0.47
2001	1,885	98	1,035	1,850	920	875	0.50	0.47
2002	1,921	98	1,060	1,896	905	934	0.48	0.49
2003	1,853	94	1,040	1,874	931	887	0.50	0.47
2004	2,091	105	1,126	2,005	1,092	853	0.54	0.43
2005	2,005	99	1,124	2,007	1,203	744	0.60	0.37
2006	2,159	106	1,177	2,106	1,510	533	0.72	0.25
2007	2,176	105	1,204	2,148	1,516	568	0.71	0.26

Source: Department of Climate Change: derived from ABARE 2008c, Department of National Development 1969, Jaakko Pöyry 2000. See Table 8.5.

[11] Non-CO_2 emissions associated with the combustion of HWP wastes are accounted for in the Energy Sector. CO_2 emissions are reported as a memo item.

Table 8.4: Key variables determining the amount of waste generation from the production of harvested wood products and its disposal to landfill

Year	HWP production[(a)] kt C	HWP waste generation kt C	Ratio of HWP waste generation to HWP production	Shares of HWP waste generation combusted (for energy)	Share of HWP waste disposed to landfill	Share of HWP waste used in other products
1940	1817	936	0.52	0.30	0.67	0.00
1990	3,541	1,168	0.33	0.44	0.37	0.16
2000	3,987	1,096	0.28	0.54	0.21	0.22
2001	4,045	1,078	0.27	0.52	0.24	0.21
2002	4,322	1,167	0.27	0.49	0.21	0.27
2003	4,382	1,184	0.27	0.48	0.23	0.26
2004	4,589	1,201	0.26	0.47	0.24	0.26
2005	4,465	1,186	0.27	0.48	0.29	0.19
2006	4,659	1,186	0.25	0.47	0.30	0.19
2007	4,549	1,147	0.25	0.51	0.26	0.20

Note: a) Excludes roundwood log and woodchip exports
Source: Department of Climate Change: derived from ABARE 2008c, Department of National Development 1969, Jaakko Pöyry 2000. See Table 8.5.

Table 8.5: Principal data sources and key assumptions made with respect to disposal of paper; waste from HWP production and wood

	Paper	Waste from HWP production	Wood
Waste generation inputs			
(1) Production and apparent consumption	ABARE 2008c; Jaakko Pöyry 2000, Department of National Development 1969.	Not applicable	ABARE 2008c; Jaakko Pöyry 2000, Department of National Development 1969
(2) End of useful product life	End of useful life function specified in Jaakko Pöyry 2000 (See Appendix 7.G)	Not applicable	End of useful life function specified in Jaakko Pöyry 2000 (See Appendix 7.G)
(3) Waste generation	Derived from (1) and (2)	Jaakko Pöyry 2000 (See Appendix 7.G)	Derived from (1) and (2)
Method of disposal			
Landfill	Balance of paper waste generation (3) and paper disposed through recycling, combustion and decay.	Balance of HWP production waste generation (3) and wastes disposed through recycling, combustion and decay	Determined exogenously based on GHD (2009) and Hyder Consulting (2009)
Recycling	Data on waste paper recovered. Source: ABARE 2008c, Jaakko Pöyry 2000	Recycling is, by definition, assumed to be zero. Data on recovered fibre, described as sawmill residue in Australian Plantations Products and Paper Industry Council (2006), used as inputs into paper production. Source: Jaakko Pöyry 2000, Australian Plantations Products and Paper Industry Council (2006).	Balance of waste generation from wood reaching end-of-useful life and wood disposed to landfill, combustion and decay.
Combusted for energy / waste incineration / decay	3% of product assumed to decay based on expert judgement. Source: Jaakko Pöyry 2000 0% assumed combusted for energy or incineration.	Derived from wood and wood waste combusted by manufacturing industry (Source: ABARE 2008a and 2008c) as the balance of ABARE data on wood and wood waste combustion and combustion of wood. No data is available on waste incineration. 3% of product assumed to decay based on expert judgement. Source: Jaakko Pöyry 2000	Combusted for energy: Various percentages of waste generation ranging from 0-5% for each product class (see appendix 7.G) while decay assumed to be 0% based on expert judgement. Source: Jaakko Pöyry 2000. Zero percent of waste generation assumed to be incinerated (ie not for energy).

The key data sources and assumptions made in relation to the estimation of the data presented in Tables 8.3 and 8.4 are reported in Table 8.5. The amount of paper disposed to landfill is estimated as the balance of the amount of paper waste generated from paper in stock reaching the end of its useful life and the amount of paper disposed to recycling, combustion and decay. This estimator ensures completeness and consistency with the estimates of the stock of harvested wood products presented in appendix 7.G; and is considered to produce robust estimates because of the high quality of the available data on apparent paper consumption (ABARE 2008c and the Department of National Development 1969) and paper recycling (ABARE 2008c). It also allows for the share of paper in total waste disposed to landfill to vary in response to observed rapid changes in disposal behaviour, in particular, the rapid increase in recycling of paper in Australia.

Similarly, data on the wastes from HWP production are considered robust because of the availability of high quality data on HWP production (ABARE 2008c and the Department of National Development 1969), and on the combustion of wood and wood waste (ABARE 2008a). No data is currently available on the amount of waste incinerated as opposed to combusted for energy. The quantity of paper reaching the end of its useful life is a function of data on apparent consumption and the assumptions set out in Appendix 7.G concerning useful lifetimes of paper and other products. This function is a constrained form of the function specified in IPCC 2006. The other important assumption set out in Appendix 7.G concerns the percentage of paper and wastes that are lost through decay and incineration. Obtaining more accurate data on these variables is difficult. Consequently, the assumption made has been the subject of sensitivity testing, which demonstrates that waste disposed to landfill is inversely related to the assumptions on incineration and decay, indicating that there is limited risk of the estimates of paper and waste disposed to landfill used in the inventory being underestimates.

Table 8.6: Additions and deductions from harvested wood products 2007

Additions to the HWP carbon stock	kt C
Apparent consumption of HWP	3960
Generation of HWP wastes	1147
Total additions	5107
Deductions from the HWP carbon stock	
Disposal to landfill	1,374
Disposal through combustion for energy/ waste incineration /decay	714
Recycling/use in other products	1,801
Total deductions	3,888
Net increment in HWP stock	1,219

Combustion for energy and decay of harvested wood products reduces the amount of the harvested wood product stock, and is effectively recorded as a reduction in stock (or, equivalently, a source of emissions). In 2007, the reduction in carbon stock from combustion for energy and decay of harvested wood product and wastes generated from harvested wood product production is estimated at 714 ktC. This source of emissions is effectively recorded within the Harvested Wood Product category (UNFCCC Category 5.D). Non-CO_2 emissions from the combustion of these products is recorded in Fuel Combustion 1. Similarly, the disposal of harvested wood products to landfill reduces the stock of product and is also effectively recorded as a reduction in stock (or source of emissions) against the Harvested Wood Product category. In 2007, the reduction in carbon stock from disposal to landfill is estimated at 1,374 ktC. A portion of this carbon will eventually be converted to methane in the landfills.

Waste streams and waste mixes

Total waste to landfill data is disaggregated into three major waste streams defined according to relevant State and Territory government legislation and broadly consistent with the following:

- municipal solid waste – Waste generated by households and local government in their maintenance of civic infrastructure such as public parks and gardens;
- commercial and industrial waste – waste generated by business and industry, for example shopping centres and office blocks or manufacturing plants; and
- construction and demolition waste – waste resulting from the demolition, erection, construction, alteration or refurbishment of buildings and infrastructure. Construction and demolition waste may also include hazardous materials such as contaminated soil or asbestos.

State/Territory data have been used to determine the stream percentages. Where disaggregated historical data cease, the stream shares have been held constant back to 1940. In Table 8.7 the stream percentages for each State and Territory as applied for the 2007 Inventory are outlined.

Table 8.7: State Waste stream percentages 2007

	NSW[1]	VIC[2]	QLD[3]	NT[3]	SA[4]	WA[5]	TAS[6]	ACT[7]
Municipal Solid Waste	28%	42%	40%	43%	36%	21%	64%	41%
Commercial and Industrial	43%	25%	26%	14%	19%	25%	33%	49%
Construction and Demolition	28%	33%	34%	43%	46%	54%	3%	11%

Source: 1) NSW Environment Protection Authority; 2) EcoRecycle Victoria; 3) QLD Environment Protection Authority; 4) SA Environment Protection Authority; 5) WA Department of Environment; 6) Hobart City Council; 7) ACT Department of Urban Services.

Some states include clean fill in their waste to landfill estimates provided and this has an influence on the waste stream proportions, however, as this type of waste is largely inert, there is little effect on the final emissions estimate.

Each waste stream is further disaggregated into a mix of waste categories that contain significant fractions of biodegradable carbon. The categories considered are as follows:

- Food;
- Paper;
- Garden and green;
- Wood;
- Wastes from the production of harvested wood products;
- Textiles;
- Sludge;
- Nappies;
- Rubber and leather; and
- Inert (concrete, metal, plastics, glass, soil etc).

The waste mix percentages are derived as a simple average of waste mixes presented in studies conducted by GHD (2009) and Hyder Consulting (2009), except for data on paper and wastes from the production of harvested wood products disposed to landfill which are based on data and assumptions set out in Table 8.5. Waste mix percentages change over time as the amount of wood waste and paper entering landfills vary – percentages for 2007 are reported in Table 8.8.

Table 8.8: Waste mix percentage by stream for 2007

	Municipal Solid Waste	Commercial & Industrial	Construction & Demolition
Food	37.2%	22.7%	0.0%
Paper [a]	7.6%	7.5%	1.3%
Garden and Green	17.5%	4.2%	2.3%
Wood [a]	1.1%	7.1%	6.0%
Waste from HWP production [a]		9.2%	
Textiles	2.1%	4.2%	0.1%
Sludge	0.0%	1.6%	0.0%
Nappies	4.3%	0.0%	0.0%
Rubber and Leather	0.5%	3.7%	0.0%
Inert (concrete, metal, plastics and glass, soil etc)	29.7%	39.6%	90.3%

Source: Derived from GHD 2009 and Hyder Consulting (2009); a) Department of Climate Change estimates based on data and assumptions in Table 8.5 and GHD 2009.

WASTE

Table 8.9: Tonnages of total waste and by type of waste – Australia, 1940–2007

Year	Total waste to landfill (a,b)	Food (b)	Paper (b)	Garden (b)	Wood and wood waste (b)	Textiles, Sludge, Nappies, Rubber and Leather (b)	Other (b)
	kt	kt	kt	kt	kt	kt	kt
1940	10,026	1,974	374	923	1,674	433	4,649
1990	16,425	3,067	1,808	1,317	1,591	773	7,870
2000	19,594	3,632	1,684	1,463	1,394	1,009	10,411
2001	19,021	3,622	1,750	1,484	1,402	976	9,787
2002	19,390	3,643	1,869	1,571	1,340	927	10,041
2003	19,818	3,451	1,774	1,496	1,461	896	10,739
2004	20,587	3,561	1,706	1,555	1,524	921	11,320
2005	20,225	3,622	1,487	1,567	1,627	937	10,983
2006	20,396	4,090	1,066	1,675	1,668	1,097	10,799
2007	21,341	4,122	1,136	1,693	1,610	1,118	11,662

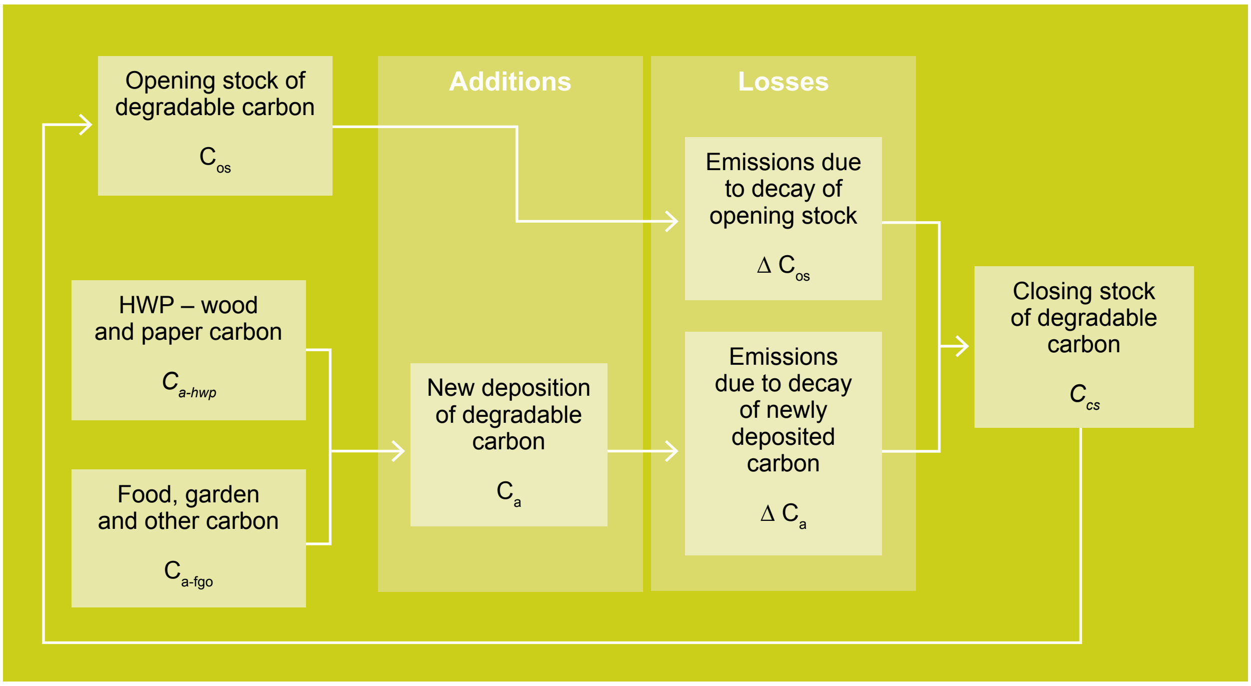
Sources: a) State Government Agencies; b) Department of Climate Change estimates.

Estimation of emissions

The Australian methodology incorporates the IPCC Tier 2 FOD model presented in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006). The IPCC 2006 model provides the flexibility to apply individual decay profiles to each waste mix category. Each waste mix category decays according to an exponential curve which is a function of its individual half-life. Half lives are adjusted according to the prevailing climatic conditions at the landfill site. The FOD model is explained in detail in IPCC 2006.

The IPCC 2006 FOD model takes account of the stock of carbon in a landfill by keeping track of additions of carbon through waste disposal and losses due to anaerobic decay. The concept of the carbon stock model approach is illustrated in Figure 8.4.

Figure 8.4: Carbon stock model flow chart



Carbon enters the landfill system via new deposition of waste C_a. Deposition is based on wood and paper carbon transferred from the HWP carbon pool $C_{a\text{-}hwp}$ and carbon in food, garden and other waste derived from data provided by State and Territory waste authorities $C_{a\text{-}fgo}$. A portion of the newly deposited carbon decays in the first year ΔC_a and the remainder contributes to the closing stock of carbon C_{cs}. Additionally, the opening stock of carbon decays over the year ΔC_{os} with the remainder going to the year's closing stock. The closing stock then becomes the next year's opening stock C_{os}. The total change in carbon stock is estimated simultaneously with estimated emissions of methane.

$$C_{cs} = C_{os} - \Delta C_{os}\text{(emissions lost from opening stock)} + C_a - \Delta C_a\text{(emissions lost from new deposition)}$$

Values for the degradable organic carbon (DOC) content for each waste mix category used in the model are listed in Table 8.10. Unless otherwise stated, the source for these parameters is IPCC (2006).

Table 8.10: Key Model Parameters – DOC values used in the First Order Decay Model

Waste Type	DOC
Food	0.15
Paper	0.40
Garden and Green	0.20
Wood and waste from HWP production	0.43
Textiles	0.24
Sludge	0.05
Nappies	0.24
Rubber and Leather	0.39
Other	-

Source: IPCC 2006

The half lives and associated 'k' values for each waste mix category have been determined based on default half lives reported in IPCC 2006 and on prevailing climatic conditions at the landfill sites of the principal cities in each State and Territory. In each State, average annual temperature and annual rainfall data for the principal landfill sites were taken from data published by the Australian the Bureau of Meteorology. The assumptions of climatic conditions for each State/Territory and 'k' values for each waste mix category are outlined in Table 8.11.

Table 8.11: Key Model Parameters: ’k’ values by waste mix category and State

State / Territory	Climate description	Waste mix category	k value
NSW	Wet Temperate	Food	0.185
		Paper and Textiles	0.06
		Garden and Green	0.10
		Wood	0.03
		Textiles	0.06
		Sludge	0.185
		Nappies	0.04
		Rubber and leather	0.06
VIC, WA, SA, TAS, ACT	Dry Temperate	Food	0.06
		Paper and Textiles	0.04
		Garden and Green	0.05
		Wood	0.02
		Textiles	0.04
		Sludge	0.06
		Nappies	0.04
		Rubber and leather	0.04
QLD, NT	Moist and Wet Tropical	Food	0.4
		Paper and Textiles	0.07
		Garden and Green	0.17
		Wood	0.035
		Textiles	0.07
		Sludge	0.4
		Nappies	0.07
		Rubber and leather	0.07

Source: IPCC 2006

Recent research on the decay of wood products in Australian landfills demonstrated that under conditions experienced at certain landfill sites wood products may decay much more slowly that previously thought (Gardner et al., 2004). This broad conclusion has been partly reflected in IPCC 2006 and is implemented through the long default half lives adopted for wood and paper products in the model.

Permanent storage of carbon in landfills

Certain proportions of organic carbon found in wood and paper products are not available to anaerobic decay leading to a permanent storage of carbon in a landfill. This permanent store of carbon from wood and paper products is also tracked in the first order decay model.

Carbon additions, losses and methane emissions between 1990 and 2007 are shown in Table 8.12. The carbon stocks at 1990 are based on the accumulation of carbon in the landfill since 1940. In 2007, 27,256 kt of degradable organic carbon had been accumulated in Australian landfills whilst 77,143 kt of carbon was permanently stored in wood and paper in landfills.

Table 8.12: Carbon stocks, losses and accumulation 1990 to 2007

Year	Carbon additions to the pool (kt C)	Carbon loss (through emissions) (kt C)	Methane generated (Gg CH_4)
1990	1,165	1,187	791
1991	1,132	1,185	790
1992	1,134	1,183	789
1993	1,163	1,181	787
1994	1,116	1,178	785
1995	1,118	1,177	784
1996	1,085	1,177	784
1997	1,095	1,177	785
1998	1,149	1,179	786
1999	1,133	1,181	787
2000	1,187	1,183	789
2001	1,198	1,188	792
2002	1,212	1,193	795
2003	1,194	1,196	797
2004	1,211	1,194	796
2005	1,197	1,193	795
2006	1,189	1,197	798
2007	1,197	1,205	803

Source: Department of Climate Change

Methane recovery

Net emissions are derived after accounting for methane recovery undertaken at the landfill site. Methane recovery for flaring and power is estimated for Australia from a survey of the main landfill power and flaring operators. Methane recovered (R(t)) is subtracted from the amount generated before applying the oxidation factor, because only landfill gas that is not captured is subject to oxidation in the upper layer of the landfill. It is assumed that all solid waste disposal on land in Australia is disposed to anaerobic or covered managed landfills (not open dumps or unmanaged sites), hence a methane correction factor of 1.0 applies. The methane correction factor data was obtained from companies and reported in Hyder Consulting 2007b.

Non-Methane Volatile Organic Compounds (NMVOC)

Small quantities of NMVOC are contained in landfill gas emitted from landfills in Australia. Some of these NMVOC are generated by the decomposition process and others are residuals from the particular types of waste dumped in the landfill.

The CSIRO Division of Coal and Energy Technology in Sydney (Duffy, Nelson & Williams 1995) investigated NMVOC emissions from four landfills in the Sydney region. They found significant concentrations, up to 10 parts per million by volume (ppmv), for approximately 60 different compounds. Researchers in the UK (Baldwin & Scott 1991) have found between 2,200 and 4,500 milligrams per cubic metre (mg/m^3) of NMVOC present in landfill gas.

In Australian landfills, liquid waste is rarely disposed of with solid waste whereas co-disposal is common practice in the UK. On this basis the lower range of 2,000 mg/m^3 found by the UK researchers is used for NMVOC emissions from Australian landfills unless other site-specific information is available.

It is assumed that NMVOC emissions from landfills comprise 0.2% of total landfill gas emissions; the average methane fraction of landfill gas as generated before release to the atmosphere is 0.5. (This quantity is a weighted mean for all previous years of waste data used to calculate any inventory year's data) and the proportion of methane emitted after oxidation is 0.9.

8.2.2 Wastewater Handling (6.B)

Source Category Description

The anaerobic decomposition of organic matter in wastewater results in emissions of CH_4. In Australia wastewater is usually treated at municipal wastewater treatment plants, which receive wastewater from:

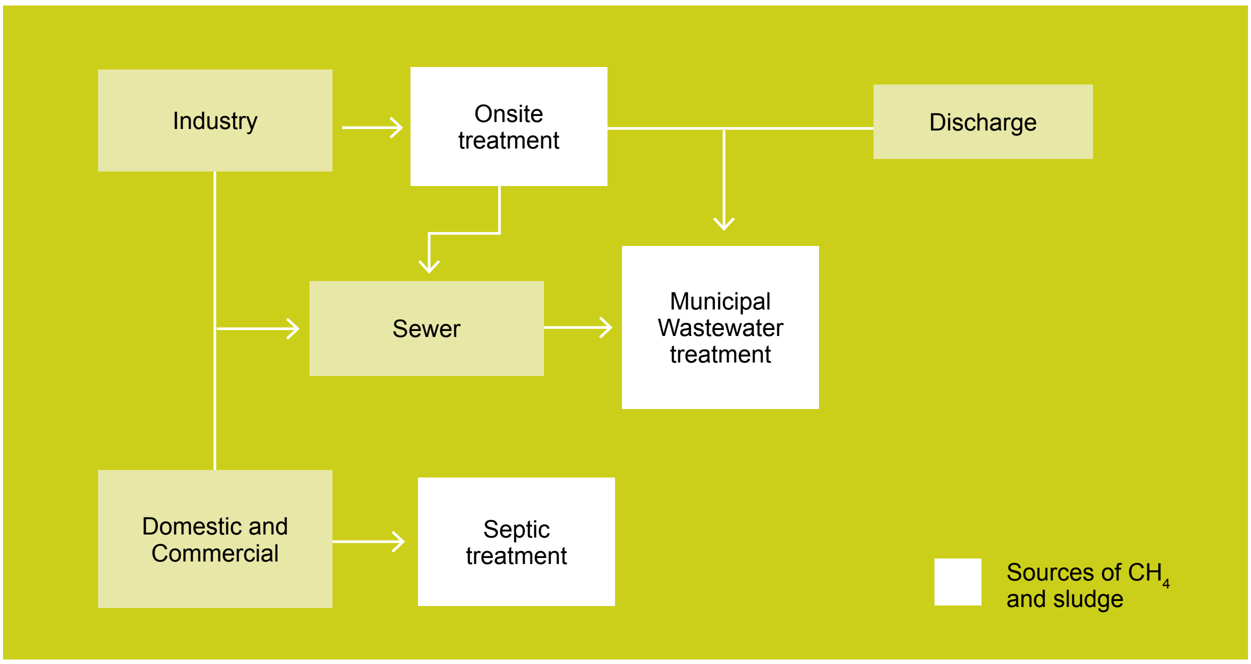
- domestic premises,
- commercial establishments, and
- industrial processing plants.

Municipal wastewater treatment plants in Australia treat a major portion of the domestic sewage and commercial wastewater, and a significant part of industrial wastewater. The main greenhouse gas emitted from wastewater treatment is CH_4. Wastewater treatment also produces N_2O and NMVOC. Carbon dioxide emissions are excluded from this sector except where they are derived from non-biomass sources of carbon. A schematic diagram of the pathways for wastewater in Australia is shown in Figure 8.5.

Emissions are estimated from the sum of the following four sources:

- municipal wastewater treatment plants,
- industrial wastewater,
- on-site domestic and commercial wastewater treatment, and
- disposal of sludge generated from the above.

Figure 8.5: Pathways for Wastewater



As shown in the figure, industry treats its wastewater onsite either for direct disposal or for discharge to the sewer. In sewered areas the domestic and commercial sectors discharge directly to the sewer, and in unsewered areas some form of on-site treatment such as septic tanks is used. From the sewer, the wastewater flows to the municipal wastewater treatment plant (MWTP) where it is treated and later discharged.

Methane gas is the principal by-product of anaerobic decomposition of organic matter in wastewater. Large quantities of methane are not usually found in wastewater due to the fact that even small amounts of oxygen are toxic to the anaerobic bacteria that produce the methane. In wastewater treatment plants, however, there are a number of processes that foster the growth of these organisms by providing anaerobic conditions.

As methane is generated by the decomposition of organic matter, the principal factor which determines the methane generation potential of wastewater is the amount of organic material in the wastewater stream. This is most commonly measured (in the case of municipal wastewater) by the Biochemical Oxygen Demand (BOD) of the wastewater. BOD is a measure of the amount of oxygen consumed by the microorganisms that feed on the organic matter over a period of time. For industrial wastewater, Chemical Oxygen Demand (COD) is used. COD is a measure of the total material available for chemical oxidation (both biodegradable and non-biodegradable) (IPCC 2006).

Industrial Wastewater (6.B.1)

Industrial wastewater emissions are estimated using IPCC default methods, COD and wastewater generation rates, supplemented with Australian data where available. Emission trends are driven by changes in production levels of key industries.

Methods for dealing with industrial wastewater in Australia are varied. Some is treated entirely on-site, while a large amount is treated entirely off-site at municipal wastewater treatment plants. Increasingly industrial wastewater is partially treated on-site before being recycled or discharged to the sewer and treated at municipal wastewater treatment plants. This is due to trade waste discharge licence compliance requirements for a certain quality of wastewater to be achieved prior to sewer discharge.

Most of the industrially produced COD in wastewater comes from the manufacturing industry. According to the IPCC, sectors like food and beverage manufacturing produce significant amounts of COD, some of which is anaerobically treated. Some concentrated industrial wastewater is removed from factories in tankers operated by specialised waste disposal services. This wastewater is usually transported to a special treatment facility.

Methodology

The methodology to determine the amount of CH_4 generated from industrial wastewater is given in IPCC 2000 and focuses on 9 industrial sectors which are considered to generate the most significant quantities of wastewater:

- Dairy production
- Pulp and paper production
- Meat and poultry processing
- Organic chemicals production
- Sugar production
- Beer production
- Wine production
- Fruit processing
- Vegetable processing

The level of methane emissions is driven largely by estimates of chemical oxygen demand (COD) in the wastewater anaerobically treated flowing from each of the nine major wastewater generating industries. The estimates of COD in wastewater anaerobically treated are generated using country specific data. The variables required to estimate COD are reported in Table 8.13.

Table 8.13: Key parameters for industrial wastewater emissions, 2007

Commodity	Wastewater generation rate (m^3/t)	COD generation rate (kg COD/m^3)	Fraction COD anaerobically treated
Dairy	5.70	0.9	0.4
Pulp and Paper	26.7 [b]	0.4	0
Meat and Poultry	13.7	6.1	0.4
Organic Chemicals	67.0 [a]	3.0 [a]	0.1 [a]
Sugar	0.4 [a]	3.8	0.3
Beer	5.3	6	0.5
Wine	23.0 [a]	1.5 [a]	0
Fruit	20	0.2	1
Vegetables	20	0.2	1

Source: O'Brien 2006a unless o herwise stated.
a) NGGIC 1995;
b) Australian Plantation Products and Paper Industry Council 2006

Methane emissions are calculated from the level of COD in the wastewater treated anaerobically using an emission factor 0.25 kg CH_4/kg BOD (IPCC 2000). Fractions of methane recovered by industry are sourced from empirical data presented in NGGIC 1995 and O'Brien 2006a. The fractions of methane recovery by commodity are presented in Table 8.14.

Table 8.14: Methane recovered as a percentage of industrial wastewater treatment 2006

Commodity	Fraction of methane recovered/flared (%)
Dairy [b]	6%
Pulp and Paper [b]	0%
Meat and Poultry [b]	6%
Organic Chemicals [b]	6%
Sugar [b]	0%
Beer [a]	100%
Wine [b]	0%
Fruit [b]	100%
Vegetables [b]	100%

Source: a) O'Brien 2006a
b) NGGIC 1995

Methane Emissions from Disposal of Sludge Generated by Industrial Wastewater Treatment

A proportion of the COD generated in the industrial wastewater ultimately treated as sludge (a constant value of 0.15 is assumed to be treated as sludge (NGGIC 1995)). Sludge is treated via two main methods, land-spread and landfill. Sludge that is disposed to landfill is accounted for in the solid waste sub-sector. It is estimated that 60 % of industrial sludge is treated via the land-spread method.

Domestic and Commercial Wastewater (6.B.2)

Methane Emissions from Wastewater Treatment at Municipal Wastewater Treatment Plants (MWTPs)

The IPCC 2000 default method is used for the estimation of methane emissions from this Domestic and Commercial Wastewater treatment.

The key variable in the estimation of methane from domestic and commercial wastewater is the biochemical oxygen demand (BOD) from wastewater anaerobically treated. Quantities of BOD treated by Australia's major wastewater treatment plants are based on per-capita BOD generation values for each State/Territory. Sewered populations are based on data reported in WSAA 2005.

Methane emissions from wastewater are calculated from the level of BOD in the wastewater (excluding sludge). The country-specific methane emission factor, 0.65 kg CH4/ kg BOD, is based on the IPCC 2000 default emission factor of 0.25 kg CH4/kg COD and research conducted by Water Services Association of Australia (WSAA) which has shown COD/BOD ratios of approximately 2.6:1.

Methane Emissions from Disposal of Sludge Generated by Municipal Wastewater Treatment Plants

All wastewater treatment plants produce sludge that needs to be disposed in some way. Sludge generated in Australia is often disposed in sludge lagoons, sludge drying beds or anaerobic digesters. Disposal of this sludge can produce methane if it is allowed to decompose anaerobically. The amount of methane generated is variable depending on the type of treatment process generating the sludge and the method of sludge disposal. Emissions arising from the decomposition of sludge disposed to landfill are included elsewhere (in the solid waste sector).

A constant value of 0.54 is used to determine the quantity of domestic and commercial BOD load ultimately treated as sludge (NGGIC 1995). This quantity of BOD relevant to sludge treatment is subtracted from total BOD before emissions are calculated from wastewater treatment. Of this BOD load in sludge, a constant value of 0.29 is considered to be anaerobically treated (NGGIC 1995). The default wastewater treatment methane emission factor per unit of BOD is used to derive emissions from the treatment of sludge.

Methane Emissions from On-Site Domestic and Commercial Wastewater Treatment

The total unsewered population on a State by State basis is calculated according to the Australian Bureau of Statistics (2008b) and WSAA data and the assumption that each person in unsewered areas in Australia produces 22.5 kg BOD per year (NGGIC 1995). The amount of BOD that settles out as solids and undergoes anaerobic decomposition is assumed to be 15%, which is the IPCC default fraction for total urban wastewater (IPCC Vol. 3 1997).

Nitrous Oxide

The methodology used to estimate N_2O emissions from human sewage is the IPCC default methodology (IPCC 1997 Vol. 3).

Default values were used to derive the estimate of N_2O. Per capita protein consumption of 99.4g/day (36.28kg/year) was sourced from the Australian Institute of Health and Welfare (de Looper and Bhatia 1998).

Non-Methane Volatile Organic Compounds (NMVOC)

There has been little research into the release of NMVOC from wastewater treatment plants. BOD values obtained and used for calculations of methane emissions are used for the calculation of NMVOC from domestic and commercial wastewater and for industrial wastewater. A default value of 0.3 kg NMVOC/ tonne BOD for municipal wastewater treatment plants is used.

8.2.3 Incineration (6.C)

Emissions are estimated from the incineration of solvents and municipal and clinical waste. Blue Scope Steel (formerly BHP) incinerates a quantity of solvent generated through various metal product coating and finishing processes. In this instance, incineration is used as a method to minimize emissions of solvents and VOCs to the atmosphere and leads to emissions of CO_2. Emissions from this source have been based on data estimated by the Department of Climate Change for the last three years.

Carbon dioxide emissions from incineration of solvents are estimated by converting the volume of solvent incinerated to the weight of solvent, deriving the energy content of the mass of solvent, and using a carbon dioxide emission factor per petajoule of solvent.

Between 1990 and 1996, there were 3 incinerators receiving municipal solid waste. These were located in NSW and QLD. All 3 incinerators ceased operations in the mid-1990's

In addition to the incineration of municipal solid waste, a quantity of clinical waste is incinerated in four major facilities located in QLD, NSW, SA and WA. Data on clinical waste incineration have been obtained from O'Brien 2006b.

The quantity of carbon dioxide emitted as a result of the incineration of municipal and clinical waste is based upon the quantity of clinical waste incinerated, the carbon content of the waste and the proportion of that carbon which is of fossil origin. Emissions of N_2O from the incineration of municipal solid waste are also estimated based on the IPCC default emission factor.

8.2.4 Uncertainties and Time Series Consistency

The tier 1 uncertainty analysis in Annex 7 provides estimates of uncertainty according to IPCC source category and gas. Time series consistency is ensured by use of consistent models, model parameters and datasets for the calculations of emissions estimates. Where changes to emission factors or methodologies occur, a full time series recalculation is undertaken.

8.2.5 Source Specific QA/QC

The solid waste disposal methodology has been subject to external independent review (Guendehou 2009). This review was considered necessary given that recalculations performed for this inventory were a response to recommendations made by the UNFCCC ERT that critiqued Australia's National Inventory Report submitted in 2007. The reviewer is a Lead Reviewer on the UNFCCC Roster of Experts, an IPCC author and a member of the IPCC Emission Factor Database Editorial Board and was asked to imitate a UNFCCC ERT review to the maximum extent possible. All recalculations were made available to the reviewer. A number of the reviewer's recommendations were immediately implemented while a number of other items are being built into longer term planning for the development of the inventory.

The waste sector source categories are also covered by the general QA/QC of the greenhouse gas inventory in Section 1.6. Data provided by waste agencies are compared with known published data sources.

8.2.6 Recalculations Since the 2006 Inventory

The estimates for 1990 to 2007 have been recalculated in response to recommendations of the UNFCCC ERT report on Australia's Initial Report. The Review team recommended that the estimates of the volumes of wood and paper disposed to landfill, previously derived using the HWP model developed by Jaakko Pöyry 2000, should be validated with reference to the available literature.

In response to the review team's recommendation the DCC engaged two independent consultants (GHD and Hyder Consulting) to conduct a review of the available literature on the mix of products disposed to landfill in Australia. For this inventory, the final mix of waste disposed to landfill is based on the results of this research. The mix of products disposed to landfill identified by GHD and Hyder Consulting is also the default mix of waste types that must be adopted by companies reporting under the National Greenhouse and Energy Reporting Scheme, in the absence of facility level data.

In implementing the recommendation of the ERT it was important that consistency between the solid waste disposal and HWP models was maintained. Consequently some changes were made to the assumptions governing closure of the HWP model with respect to wood, paper and HWP production wastes. The principal changes were:

- estimates of wood tonnages disposed to landfill are now determined by the results of GHD 2009 and Hyder Consulting 2009, replacing the previous assumption of a constant share of wood product reaching the end-of-useful life disposed to landfill over all years (as assumed in the National Inventory Report 2006 and in Jaakko Pöyry 2000);
- disposal of paper to landfill has been separated from the disposal of HWP wastes, replacing the previous classification of a common 'pool 1' of paper and HWP wastes and which had been labelled simply as 'paper';
- the quantity of paper disposed to landfill is determined as the balance of the amount of paper waste generated that is not recycled or combusted or lost through decay, replacing the previous assumption of a constant share of waste generation being disposed to landfill (as in National Inventory Report 2006 and in Jaakko Pöyry 2000);
- the quantity of paper recycled is based on data on actual tonnages reported by ABARE 2008c and by Jaakko Pöyry 2000, replacing the previous assumption of a constant share of paper waste generated being recycled (as assumed in the National Inventory Report 2006 and in Jaakko Pöyry 2000);
- the quantity of waste from HWP production disposed to landfill is determined as the balance of waste generated that is not recycled or re-used or combusted or lost through decay, replacing the previous assumption of a constant share of waste generated being disposed to landfill (as assumed in the National Inventory Report 2006 and in Jaakko Pöyry 2000);
- the quantity of waste from HWP production recycled is assumed to be zero, although a quantity of wastes are re-used as inputs into the production of other products (based on Australian Plantations Products and Paper Industry Council 2006 and Jaakko Pöyry 2000), replacing the previous assumption of a constant share of HWP waste generation being recycled (as in the National Inventory Report 2006 and in Jaakko Pöyry 2000);
- the quantity of waste from HWP production combusted as fuel is derived from ABARE 2008a. Wood waste is the balance of ABARE data on wood and wood waste combusted by the manufacturing industry and the assumption of 0-5% of wood product, depending on wood product type, that is combusted for energy (replacing the previous assumption of 4% of wood waste as assumed for the National Inventory Report 2006 and as assumed in Jaakko Pöyry 2000).

Two corrections were made to the implementation of the HWP model in Jaakko Pöyry 2000 to ensure consistency with the mass balance constraint.

The separate classification of paper and wastes from HWP production for this inventory has enabled a distinction to be made with respect to the carbon content and landfill decay rates for the two categories. Wastes from HWP production have been given the same carbon content and decay rates as wood in this inventory (previously HWP wastes were not distinguished from paper).

The changes to the estimates of paper and wastes from HWP production disposed to landfill lead to revised estimates for total waste disposed to landfill for the period 1940-1989 and adjustments to the estimated amounts of other waste mix types to ensure completeness.

The impact of the recalculations has lead to a minor revision to the estimated emissions in 1990. Estimated emissions in 2007 have decreased by a more significant fraction, principally reflecting the impact of increasing rates of recycling of paper over the period that have been captured through the use of actual data on recovered paper for the first time in this inventory.

In addition to the recalculations in the solid waste sector, revisions have been made to sugar production data used in the industrial wastewater treatment estimates. Raw sugar data are now used in the place of cane crushing data throughout the time-series.

In aggregate, these changes resulted in a minor increase in the 1990 estimate and a 2.4 Mt CO_2-e decrease to the 2006 estimate.

8.2.7 Source Specific Planned Improvements

Current assumptions on the quantities of HWP products and wastes used for energy will be reviewed in the light of data that will become available with reporting by companies under the NGERs Act, which will begin to become available from October 2009. There is also the prospect of accessing improved data on the mix of wastes disposed to landfill under NGERs over time. Data on incineration of wastes, apart from waste combusted for energy, are limited and is an area of planned development.

Research is being conducted into the carbon content and decay functions applicable to Australian timber and paper products both under laboratory conditions and *in situ*. When finalised, these results will be reviewed for their appropriateness to Australian conditions and to the Australian national inventory.

Further data on domestic wastewater treatment is expected to become available in the near future. These data will be used to further refine the assumptions behind the municipal wastewater treatment methodology and better reflect measures implemented by utilities to reduce greenhouse emissions.

9. Other (UNFCCC Sector 7)

Australia does not report any emissions under the UNFCCC category 7, ‘Other’.

10. Recalculations and Improvements

National greenhouse gas inventories have been produced for a comparatively short time, especially when compared with other major national statistics, such as gross domestic product. Emissions processes are pervasive and complex and, consequently, emissions estimation techniques and data sources for the Australian inventory are still evolving, particularly in some sectors. Internationally, this is also the case for the inventories of other countries. In addition, the IPCC guidelines on national inventory preparation themselves have recently been revised.

The development of improved estimation techniques is a resource intensive exercise and the IPCC encourages the allocation of development resources into priority areas. A number of recalculations have been undertaken for the 2007 inventory and these have been summarised in section 10.1-10.3 below. More generally, the development effort behind recalculations is undertaken in line with the Inventory Improvement Plan for the Australian inventory. This plan is aimed at reducing existing emission estimate uncertainties as much as possible, with development focused on key source categories, sources with high uncertainties and where implementation of new methods is feasible (for example, as a result of new data becoming available). The Australian improvement plan also seeks to respond to international expert reviews and revisions to international guidelines on inventory preparation. Some of the principal elements of the research programme that is underway to inform that and subsequent inventories are set out in section 10.4.

10.1 Explanations and Justifications for Recalculations

Estimates of emissions presented in past inventory reports have been recalculated for a number of reasons including end-of-series averaging effects (for the *agriculture* sector), revisions of data, the inclusion of additional sources of data or from refinements in the estimation methodology. To ensure the accuracy of the estimates, and to maintain consistency of the series through time, recalculations of past emission estimates are undertaken for all previous years.

Within the 1990–2006 time series there have been a number of sectors where recalculations have been undertaken. The major changes implemented since the *National Inventory Report 2006* have been adopted in response to recommendations of the UNFCCC expert reviews conducted in 2008. Details of these recalculations are given in the sectoral chapters and are summarised here in Table 10.1. With the exception of the LULUCF sector the recalculation are principally due to revisions and corrections to activity data as well as some minor corrections to oxidation factors and emission factors. For the LULUCF sector the recalculations are primarily due to the inclusion of estimates for three new categories as well as revisions to the preliminary forest conversion estimates following completion of the 2006 land cover analysis.

Table 10.1: Reasons for the recalculations for the 2007 inventory (compared with the 2006 inventory)

Sector		Category	Reason for Recalculation
1.A	**Energy**		
	Stationary Combustion	1.1	Correction to oxidation factors used for electricity and the update of an emission factor for one electricity generator
		1.2	Correction to oxidation factor for chemical liquid and gas fuels
		1.1, 1.2, 1.4	Revision of ABARE national energy statistics primarily for 2005 and 2006.
	Transport	1.3, 1.5	Revision to the allocation of fuel consumption between international and domestic uses in 2006 Correction of minor transcription errors in the activity data
	Fugitive Emissions	1.B.1	Revision to the gassy classification of one underground mine and inclusion of additional methane recovery data for another underground mine Correction to the opening and closure dates for several decommissioned mines.

Sector	Category	Reason for Recalculation
2. Industrial Processes		
	2.C.1	Revision of the 2005 and 2006 emission factor for the use of coke as a reductant in iron and steel production
	2.C.3	Revision of PFC emission factors for 2005 and 2006 as a result of revised plant-level data
	2.G	Updated 2006 production data for the confidential sources.
4. Agriculture		
	4. A-F	End of time-series recalculations due to 3 year averaging of reported emissions
	4A, 4B, 4D	Correction of errors for some minor livestock classes for 2005 and 2006
	4D	Update to the fraction of N fertiliser applied to different production systems for 2006 using the land area data from the 2006 ABS census.
	4C, 4D, 4F	Preliminary 2006 production estimates replaced with the final estimates for some minor crop types
	4E, 4D	changes in the savanna burning activity data for 1997 and 2006
5 LULUCF		
	5.1	Inclusion of emission and removals from *other native forest* [(a)], and revision to *fuelwood consumed* time-series and *harvest native forest* estimates for 2001-2006 due to rounding corrections and recalculation of ABARE data
		For non-CO_2 emissions from biomass burning there is an end of time-series recalculation due to 3 year averaging of reported emissions. In addition, for some States preliminary 2006 wildfire areas have been updated and for another State data are now available for 2003-2006.
	5.B1	Inclusion of emissions and removals from *cropland remaining cropland* [(a)]
	5.B2	No change in methods recalculation due to randomisation of date of clearing and confirmation of areas cleared when next land use cover becomes available.
	5.C.1	Inclusion of emissions and removals from *grassland remaining grassland*[(a)]
	5.C2	No change in methods recalculation due to randomisation of data of clearing and confirmation of areas cleared when next land use cover becomes available.
	5.G	Revision to methods used to determine the disposal of HWP stocks.
		Revision to *N_2O from soil disturbance associated with land use conversion to grasslands* following revised land areas cleared.
6 Waste		
	6.A	Revision to the estimates of paper and wastes from HWP production disposed to landfill and adjustments to the estimated amounts of other waste mix types.
	6.B	In the estimation of industrial wastewater treatment raw sugar data used in the place of cane crushing data

Note: Emission and removals from other native forest, cropland remaining cropland and grassland remaining grassland were reported in Australia's revised 2007 submission submitted to the UNFCCC in October 2008 following the review of Australia's Initial Report under the Kyoto Protocol.

10.2 Implications for Emission Levels

The net impact of the recalculations on emission levels was relatively small for the sectors excluding LULUCF, increasing the estimate of total emissions excluding LULUCF by 0.1 Mt or less than 0.1% in 1990 and decreasing emissions by 1.6 Mt or 0.3% in 2006 (see Table 10.2) compared with the *National Inventory Report 2006*. The changes associated with the LULUCF sector were more significant decreasing the estimate of total emissions by 62.1 Mt or 12.0% in 1990 and increasing emissions by 1.2 Mt or 0.2% in 2006.

Table 10.2: Recalculations for the 2007 inventory by sector (compared with the 2006 inventory) – 1990, 2004-2006

Sector	1990	2004	2005	2006
	Mt	Mt	Mt	Mt
1.A Fuel Combustion	0.0	0.0	-2.4	-0.7
1.1,2, 4, 5 Stationary Energy	0.0	0.0	-0.7	-0.2
1.3 Transport	0.0	0.0	-1.8	-0.4
1.B Fugitives	0.0	0.4	0.2	-0.1
2 Industrial Processes	0.0	-0.6	-0.7	1.0
4 Agriculture	0.0	0.0	0.2	0.7
6 Waste	0.0	-2.0	-2.1	-2.4
Total recalculation (excluding LULUCF)	**0.1**	**-2.2**	**-4.9**	**-1.6**
5 Land use, land use change and forestry	-62.1	-209.6	46.3	2.8
Total recalculation (including LULUCF)	**-62.1**	**-211.8**	**41.4**	**1.2**

10.3 Implications for Emission Trends, Including Time Series Consistency

The net effect of the recalculations on aggregate emission trends for the sectors excluding LULUCF is small as the recalculations have been applied throughout the time series 1990 to 2006. The full time series of estimated recalculations is set out in Table 10.3. As the recalculation associated with the LULUCF sector introduce estimates that are primarily driven by inter-annual climate variability and natural disturbance there is a significant change to the aggregate emission trends as year to year the LULUCF sector changes from a net source to a net sink.

Table 10.3: Estimated recalculations for the 2007 inventory – 1990-2006

Year	Net Emissions Excluding LULUCF				Net Emissions Including LULUCF			
	Previous Estimate	Current Estimate	Difference		Previous Estimate	Current Estimate	Difference	
	Mt CO_2-e	Mt CO_2-e	Mt	%	Mt CO_2-e	Mt CO_2-e	Mt	%
1990	416.2	416.2	0.1	0.0	515.9	453.8	-62.1	-12.0
1991	417.6	417.5	-0.1	0.0	493.6	550.7	57.1	11.6
1992	422.5	422.5	0.0	0.0	478.0	483.0	5.0	1.0
1993	426.6	426.2	-0.5	-0.1	467.6	423.6	-44.0	-9.4
1994	429.2	428.6	-0.6	-0.1	469.9	385.3	-84.7	-18.0
1995	442.3	441.4	-0.9	-0.2	472.1	542.4	70.4	14.9
1996	447.3	446.1	-1.3	-0.3	472.9	430.8	-42.1	-8.9
1997	459.5	457.4	-2.1	-0.4	481.9	400.5	-81.5	-16.9
1998	473.2	472.2	-1.0	-0.2	503.3	602.1	98.8	19.6
1999	484.0	482.6	-1.5	-0.3	508.3	436.6	-71.7	-14.1
2000	495.2	494.9	-0.3	-0.1	524.9	404.4	-120.5	-23.0
2001	507.6	505.7	-1.9	-0.4	534.6	427.1	-107.5	-20.1
2002	509.7	507.2	-2.5	-0.5	542.8	791.1	248.3	45.7
2003	518.0	515.9	-2.1	-0.4	528.9	630.0	101.2	19.1
2004	524.2	522.1	-2.2	-0.4	540.2	328.5	-211.8	-39.2
2005	529.5	524.6	-4.9	-0.9	554.8	596.2	41.4	7.5
2006	536.1	534.5	-1.6	-0.3	549.9	551.1	1.2	0.2

Source: Previous estimate- DCC 2008

10.4 Recalculations, Including in Response to the Review Process, and Planned Improvements to the Inventory

Future refinements will be informed by the ongoing technical review of sectoral methodologies and data sources undertaken by the Department of Climate Change as part of Australia's efforts to comply with inventory good practice. Priorities for the inventory development process have been informed by analysis of key sources and key trends; by analysis of the level of uncertainty surrounding existing emission estimates; and the comments received from previous international reviews of Australia's inventory.

The links between the inventory development programme and both the key source analysis presented in Annex 1 and the uncertainty analysis presented in Annex 7 are clearly shown in Table 10.4. A key area for development is in the land use, land use change and forestry sector, where the full details are set out in the *National Carbon Accounting System, Development Plan 2004-2008* (AGO 2005).

Table 10.4: Summary of planned improvements to the Australian inventory

Category	Key source?	Sectoral uncertainty estimate	Description
Energy			
All	Yes	-	New data collection processes under the National Greenhouse and Energy Reporting Act will generate high quality data on activity, emission factors and emissions.
Industrial processes			
Review of minor new sources	No	-	Exploration of new data sources
All	Yes	-	New data collection processes under the National Greenhouse and Energy Reporting Act will generate high quality data on activity, emission factors and emissions.
Agriculture			
4.A Enteric fermentation – cattle (CH_4)	Yes	6%	Field research into emission factors
4.E Burning of savannas (CH_4)	Yes	120%	Field research into fire dynamics and fuel loads
4.E Burning of savannas (N_2O)	Yes	131%	Field research into fire dynamics and fuel loads
4.D Agricultural soils (N_2O)	Yes	102%	Review of methodologies for fertiliser application and conservation practices
LULUCF			
5.A Forest lands (CO_2, N_2O)	Yes	20%, 40%	Full incorporation of plantations into the NCAS Incorporation of N cycle capability
5.B and 5.C. Croplands and Grasslands (CO_2, N_2O)	Yes		Ongoing development including N cycle capability
Waste			
All	Yes	50%	New data collection processes under the National Greenhouse and Energy Reporting Act will generate high quality data on activity, emission factors and emissions.

Sources: Annex 1, Annex 7.

Annex 1: Key Source Analysis

A *key source category* has a significant influence on a country's total inventory of direct greenhouse gases in terms of absolute level of emissions, the trend in emissions, or both. Australia has identified the key sources for the UNFCCC inventory using the Tier 1 level and trend assessments as recommended in the IPCC *Good Practice* report. This approach identifies sources that contribute to 95% of the total emissions or 95% of the trend of the inventory in absolute terms.

When the LULUCF sector is included in the analysis, Australia has identified *grassland remaining grassland, public electricity (solid fuel)* and *forest conversion to grasslands* as the most significant of the key categories (i.e. contributing more than 10% of the level or trend) in 2007. The full results for the 2007 key source analysis are reported in Tables A.1.1 to A.1.3.

When the LULUCF sector is excluded from the analysis the most significant key categories in 2007 are *public electricity (solid fuel), road transportation and enteric fermentation (sheep)*. The results of this latter analysis are presented in Tables A.1.4 to A.1.6

The Australian analysis has been undertaken using a relatively high degree of disaggregation of sources, which permits a greater degree of understanding of Australia's key categories. Past analyses by the UNFCCC secretariat of Australian data, using higher levels of aggregation common in the analyses undertaken by other countries, have not produced any important distinctions.

Table A.1.1: Key source categories for Australia's 2007 inventory – level assessment including LULUCF

A		B	C	D	E	F
	IPCC Source Category	Gas	Base Year Estimate	Current Year Estimate	Level Assessment	Cumulative Total
5.C.1	Grassland remaining Grassland	CO_2	18265.48	212752.81	0.24	0.24
1.A.1.a	Public Electricity and Heat Production \ Solid Fuels	CO_2	117908.73	179851.53	0.20	0.45
5.C.2	Land converted to Grassland	CO_2	104146.06	67766.31	0.08	0.52
1.A.3.b	Road Transportation \ Liquid Fuels	CO_2	53152.79	66367.37	0.08	0.60
4.A.1	Enteric Fermentation \ Cattle	CH_4	39010.80	44984.46	0.05	0.65
5. A.2	Land converted to Forest Land	CO_2	2045.68	21150.32	0.02	0.67
1. A.1.a	Public Electricity and Heat Production \ Gaseous Fuels	CO_2	8239.20	17124.25	0.02	0.69
5.B.1	Cropland remaining Cropland	CO_2	24503.14	16716.32	0.02	0.71
1.B.1.a.1.1	Fugitives/Coal Mining/Underground	CH_4	12012.94	16044.26	0.02	0.73
4.A.3	Enteric Fermentation \ Sheep	CH_4	24563.18	12311.28	0.01	0.75
6. A.1	Managed Waste Disposal on Land	CH_4	14909.41	11106.03	0.01	0.76
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Gaseous Fuels	CO_2	4592.63	10911.69	0.01	0.77
1.B.1.a.2.1	Fugitives\Coal Mining\Surface mines	CH_4	3385.22	8341.40	0.01	0.78
4.E	Prescr bed Burning of Savannas	CH_4	4642.54	8122.21	0.01	0.79
2.C.1.4	Iron and Steel\Coke	CO_2	9018.39	7345.53	0.01	0.80
1.A.2.b	Non-Ferrous Metals \ Gaseous Fuels	CO_2	4139.63	7330.49	0.01	0.81
1.A.2.f	Other (please specify) \ Mining \ Liquid Fuels	CO_2	1740.80	7043.32	0.01	0.81
1.A.4.b	Residential \ Gaseous Fuels	CO_2	4612.51	6988.15	0.01	0.82
2.G	Other (please specify) \ Confidential emissions reported as CO_2-e	CO_2	1885.19	6387.74	0.01	0.83
5.B.2	Land converted to Cropland	CO_2	23024.03	5979.92	0.01	0.84
1.A.4.c	Agriculture/Forestry/Fisheries \ Liquid Fuels	CO_2	3371.87	5841.25	0.01	0.84
1.A.3.a	Civil Aviation \ Liquid Fuels	CO_2	2895.15	5291.94	0.01	0.85
1.A.2.b	Non-Ferrous Metals \ Solid Fuels	CO_2	4221.13	5065.07	0.01	0.85
5.G	Other (Harvested Wood Products)	CO_2	4638.33	4469.67	0.01	0.86
1.A.1.b	Petroleum Refining \ Liquid Fuels	CO_2	5160.26	4345.02	0.00	0.86
4.D.2	Pasture, Range and Paddock Manure	N_2O	4882.80	3922.02	0.00	0.87
2.A.1	Cement Production	CO_2	3462.87	3895.26	0.00	0.87
4.D.3.1	Atmospheric Deposition	N_2O	3245.38	3575.77	0.00	0.88
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Liquid Fuels	CO_2	957.85	3485.96	0.00	0.88
4.E	Prescr bed Burning of Savannas	N_2O	1965.72	3462.56	0.00	0.89

A		B	C	D	E	F
	IPCC Source Category	Gas	Base Year Estimate	Current Year Estimate	Level Assessment	Cumulative Total
1.B.2.c.1.2	Fugitives\Venting and Flaring, Venting	CO_2	1966.46	3385.93	0.00	0.89
1.A.2.c	Chemicals \ Liquid Fuels	CO_2	3263.23	3343.19	0.00	0.89
2.C.3	Aluminium Production	CO_2	2020.53	3196.13	0.00	0.90
1.A.2.f	Other (please specify) \ Mineral industry \ Gaseous Fuels	CO_2	2950.31	3084.64	0.00	0.90
1.A.2.f	Other (please specify) \ Mineral industry \ Solid Fuels	CO_2	2178.14	2919.90	0.00	0.90
1.B.2.b.4	Fugitives\Natural Gas\Distribution	CH_4	4092.56	2914.53	0.00	0.91
4.D.1.1	Synthetic Fertilizers	N_2O	1557.60	2872.31	0.00	0.91
4.D.3.2	Nitrogen Leaching and Run-off	N_2O	2503.98	2615.87	0.00	0.91
1.A.2.b	Non-Ferrous Metals \ Liquid Fuels	CO_2	2967.57	2609.04	0.00	0.92
2.F.1	Refrigeration and Air Conditioning Equipment	HFC-134a	0.00	2482.13	0.00	0.92
1.B.2.c.2.3	Fugitives\Oil and Natural Gas\ Flaring	CO_2	3601.38	2322.42	0.00	0.92
1.A.4.a	Commercial/Institutional \ Gaseous Fuels	CO_2	1810.69	2258.55	0.00	0.92
1.A.4.a	Commercial/Institutional \ Liquid Fuels	CO_2	1233.07	2206.25	0.00	0.93
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Solid Fuels	CO_2	2309.92	2116.65	0.00	0.93
5.A.1	Forest Land remaining Forest Land	CH_4	1663.98	2101.97	0.00	0.93
1.A.3.c	Railways \ Liquid Fuels	CO_2	1727.66	1916.87	0.00	0.93
1.A.1.a	Public Electricity and Heat Production \ Liquid Fuels	CO_2	2863.74	1771.19	0.00	0.94
1.A.2.a	Iron and Steel \ Solid Fuels	CO_2	1191.25	1762.08	0.00	0.94
1.B.1.c	Fugitives\ Coal mining \ Decommissioned Mines	CH_4	355.90	1736.72	0.00	0.94
5.C.2	Land converted to Grassland	CH_4	2518.58	1714.93	0.00	0.94
1.A.3.b	Road Transportation \ Liquid Fuels	N_2O	683.39	1615.54	0.00	0.94
1.A.2.f	Other (please specify) \ Construction \ Liquid Fuels	CO_2	2809.26	1590.38	0.00	0.95
1.A.2.a	Iron and Steel \ Gaseous Fuels	CO_2	1383.28	1534.65	0.00	0.95
1.A.2.e	Food Processing, Beverages and Tobacco \ Gaseous Fuels	CO_2	1246.35	1529.53	0.00	0.95

Table A.1.2: Key source categories for Australia's 2007 inventory – trend assessment including LULUCF

A		B	C	D	E	F	G
	IPCC Source Category	Gas	1990 Emissions	2007 Emissions	Trend Assessment	% Contribution to Trend	Cumulative Total of Column F
5.C.1	Grassland remaining Grassland	CO_2	18265.48	212752.81	0.16	0.29	0.29
5.C.2	Land converted to Grassland	CO_2	104146.06	67766.31	0.08	0.14	0.43
5.A.1	Forest Land remaining Forest Land	CO_2	47415.02	440.92	0.06	0.10	0.53
5.B.1	Cropland remaining Cropland	CO_2	24503.14	16716.32	0.04	0.07	0.60
5.B.2	Land converted to Cropland	CO_2	23024.03	5979.92	0.02	0.04	0.65
1.A.1.a	Public Electricity and Heat Production \ Solid Fuels	CO_2	117908.73	179851.53	0.02	0.04	0.69
4.A.3	Enteric Fermentation \ Sheep	CH_4	24563.18	12311.28	0.02	0.04	0.73
1.A.3.b	Road Transportation \ Liquid Fuels	CO_2	53152.79	66367.37	0.02	0.04	0.76
4.A.1	Enteric Fermentation \ Cattle	CH_4	39010.80	44984.46	0.02	0.03	0.79
5.A.2	Land converted to Forest Land	CO_2	2045.68	21150.32	0.01	0.02	0.81
6.A.1	Managed Waste Disposal on Land	CH_4	14909.41	11106.03	0.01	0.02	0.83
2.C.1.4	Iron and Steel\Coke	CO_2	9018.39	7345.53	0.01	0.01	0.84
1.B.1.a.1.1	Fugitives/Coal Mining/ Underground	CH_4	12012.94	16044.26	0.00	0.01	0.85
2.C.3	Aluminium Production	CF_4	3336.77	424.18	0.00	0.01	0.85
1.A.1.b	Petroleum Refining \ Liquid Fuels	CO_2	5160.26	4345.02	0.00	0.01	0.86
4.D.2	Pasture, Range and Paddock Manure	N_2O	4882.80	3922.02	0.00	0.01	0.87
1.B.2.b.4	Fugitives\Natural Gas\ Distr bution	CH_4	4092.56	2914.53	0.00	0.01	0.87
1.B.2.c.2.3	Fugitives\Oil and Natural Gas\ Flaring	CO_2	3601.38	2322.42	0.00	0.00	0.88
5.G	Other (Harvested Wood Products)	CO_2	4638.33	4469.67	0.00	0.00	0.88
1.A.2.f	Other (please specify) \ Mining \ Liquid Fuels	CO_2	1740.80	7043.32	0.00	0.00	0.89
1.A.2.f	Other (please specify) \ Construction \ Liquid Fuels	CO_2	2809.26	1590.38	0.00	0.00	0.89
1.A.1.a	Public Electricity and Heat Production \ Liquid Fuels	CO_2	2863.74	1771.19	0.00	0.00	0.89
2.G	Other (please specify) \ Confidential emissions reported as CO_2-e	CO_2	1885.19	6387.74	0.00	0.00	0.90
5.C.2	Land converted to Grassland	CH_4	2518.58	1714.93	0.00	0.00	0.90
1.A.2.b	Non-Ferrous Metals \ Liquid Fuels	CO_2	2967.57	2609.04	0.00	0.00	0.90
1.A.2.b	Non-Ferrous Metals \ Solid Fuels	CO_2	4221.13	5065.07	0.00	0.00	0.91
1.A.2.c	Chemicals \ Liquid Fuels	CO_2	3263.23	3343.19	0.00	0.00	0.91
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Gaseous Fuels	CO_2	4592.63	10911.69	0.00	0.00	0.91

A		B	C	D	E	F	G
	IPCC Source Category	Gas	1990 Emissions	2007 Emissions	Trend Assessment	% Contribution to Trend	Cumulative Total of Column F
1.B.2.c.1.2	Venting and Flaring, Venting	CH_4	1733.89	661.33	0.00	0.00	0.92
2.F.1	Refrigeration and Air Conditioning Equipment	HFC-134a	0.00	2482.13	0.00	0.00	0.92
2.A.1	Cement Production	CO_2	3462.87	3895.26	0.00	0.00	0.92
6.B.1	Industrial Wastewater \ Wastewater	CH_4	1783.36	861.65	0.00	0.00	0.92
4.D.3.1	Atmospheric Deposition	N_2O	3245.38	3575.77	0.00	0.00	0.93
1.A.2.f	Other (please specify) \ Mineral industry \ Gaseous Fuels	CO_2	2950.31	3084.64	0.00	0.00	0.93
1.A.4.b	Residential \ Biomass	CH_4	1711.86	919.37	0.00	0.00	0.93
1.B.1.a.2.1	Fugitives\Coal Mining\Surface mines	CH_4	3385.22	8341.40	0.00	0.00	0.94
1.A.1.a	Public Electricity and Heat Production \ Gaseous Fuels	CO_2	8239.20	17124.25	0.00	0.00	0.94
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Solid Fuels	CO_2	2309.92	2116.65	0.00	0.00	0.94
2.E.1.1	Production of HCFC-22	HFC-23	1126.27	0.00	0.00	0.00	0.94
1.3.d	Navigation \ Liquid Fuels \ Residual Oil	CO_2	1368.43	509.79	0.00	0.00	0.95
4.D.3.2	Nitrogen Leaching and Run-off	N_2O	2503.98	2615.87	0.00	0.00	0.95
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Liquid Fuels	CO_2	957.85	3485.96	0.00	0.00	0.95

Table A.1.3: Key source categories for Australia's 2007 inventory – summary including LULUCF

A		B	C	D
	IPCC Source Categories	Direct Greenhouse Gas	Key Source Category Flag	If Column C is Yes, Criteria for Identification
1.A.1.a	Public Electricity and Heat Production \ Solid Fuels	CO_2	YES	Level, trend
1.A.1.a	Public Electricity and Heat Production \ Gaseous Fuels	CO_2	YES	Level, trend
1.A.1.a	Public Electricity and Heat Production \ Liquid Fuels	CO_2	YES	Level, trend
1.A.1.b	Petroleum Refining \ Liquid Fuels	CO_2	YES	Level, trend
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Gaseous Fuels	CO_2	YES	Level, trend
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Liquid Fuels	CO_2	YES	Level, trend
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Solid Fuels	CO_2	YES	Level, trend
1.A.2.a	Iron and Steel \ Solid Fuels	CO_2	YES	Level
1.A.2.a	Iron and Steel \ Gaseous Fuels	CO_2	YES	Level
1.A.2.b	Non-Ferrous Metals \ Gaseous Fuels	CO_2	YES	Level
1.A.2.b	Non-Ferrous Metals \ Solid Fuels	CO_2	YES	Level, trend
1.A.2.b	Non-Ferrous Metals \ Liquid Fuels	CO_2	YES	Level, trend
1.A.2.c	Chemicals \ Liquid Fuels	CO_2	YES	Level, trend
1.A.2.e	Food Processing, Beverages and Tobacco \ Gaseous Fuels	CO_2	YES	Level
1.A.2.f	Other (please specify) \ Construction \ Liquid Fuels	CO_2	YES	Level, trend
1.A.2.f	Other (please specify) \ Mineral industry \ Gaseous Fuels	CO_2	YES	Level, trend
1.A.2.f	Other (please specify) \ Mineral industry \ Solid Fuels	CO_2	YES	Level
1.A.2.f	Other (please specify) \ Mining \ Liquid Fuels	CO_2	YES	Level, trend
1.A.3.a	Civil Aviation \ Liquid Fuels	CO_2	YES	Level
1.A.3.b	Road Transportation \ Liquid Fuels	CO_2	YES	Level, trend
1.A.3.b	Road Transportation \ Liquid Fuels	N_2O	YES	Level
1.A.3.c	Railways \ Liquid Fuels	CO_2	YES	Level
1.A.3.d	Navigation \ Liquid Fuels \ Fuel Oils	CO_2	YES	Trend
1.A.4.a	Commercial Institutional \ Gaseous Fuels	CO_2	YES	Level
1.A.4.a	Commercial Institutional \ Liquid Fuels	CO_2	YES	Level
1.A.4.b	Residential \ Gaseous Fuels	CO_2	YES	Level
1.A.4.b	Residential \ Biomass Fuels	CH_4	YES	Trend
1.A.4.c	Agriculture Forestry Fisheries \ Liquid Fuels	CO_2	YES	Level
1.B.1.A.1.1	Fugitives\Coal Mining\Underground	CH_4	YES	Level, trend
1.B.1.A.2.1	Fugitives\Coal Mining\Surface mines	CH_4	YES	Level, trend
1.B.1.C	Fugitives\ Coal mining \ Decommissioned Mines	CH_4	YES	Level
1.B.2.B.4	Fugitives\Natural Gas\Distribution	CH_4	YES	Level, trend
1.B.2.C.1.2	Fugitives\Oil and Natural Gas\Venting	CO_2	YES	Level
1.B.2.C.1.2	Fugitives\Oil and Natural Gas\Venting	CH_4	YES	Trend
1.B.2.C.2.3	Fugitives\Oil and Natural Gas\Flaring	CO_2	YES	Level, trend

A	IPCC Source Categories	B Direct Greenhouse Gas	C Key Source Category Flag	D If Column C is Yes, Criteria for Identification
2.A.1	Cement Production	CO_2	YES	Level, trend
2.C.1.4	Iron and Steel\Coke	CO_2	YES	Level, trend
2.C.3	Aluminium Production	CO_2	YES	Level
2.C.3	Aluminium Production	CF4	YES	Trend
2.E.1.1	Production of HCFC-22	HFC-23	YES	Trend
2.F.1	Refrigeration and Air Conditioning Equipment	HFC-134a	YES	Level, trend
2.G	Other (please specify) \ Confidential emissions reported as CO_2-e	CO_2	YES	Level, trend
4.A.1	Enteric Fermentation \ Cattle	CH_4	YES	Level, trend
4.A.3	Enteric Fermentation \ Sheep	CH_4	YES	Level, trend
4.D.1.1	Synthetic Fertilizers	N_2O	YES	Level
4.D.2	Pasture, Range and Paddock Manure	N_2O	YES	Level, trend
4.D.3.1	Atmospheric Deposition	N_2O	YES	Level, trend
4.D.3.2	Nitrogen Leaching and Run-off	N_2O	YES	Level, trend
4.E	Prescribed Burning of Savannas	CH_4	YES	Level
4.E	Prescribed Burning of Savannas	N_2O	YES	Level
5.A.1	Forest Land remaining Forest Land	CO_2	YES	Trend
5.A.1	Forest Land remaining Forest Land	CH_4	YES	Level
5.A.2	Land converted to Forest Land	CO_2	YES	Level, trend
5.B.1	Cropland remaining Cropland	CO_2	YES	Level, trend
5.B.2	Land converted to Cropland	CO_2	YES	Level, trend
5.C.1	Grassland remaining Grassland	CO_2	YES	Level, trend
5.C.2	Land converted to Grassland	CO_2	YES	Level, trend
5.C.2	Land converted to Grassland	CH_4	YES	Level, trend
5.G	Harvested Wood Products	CO_2	YES	Level, trend
6.1	Managed Waste Disposal on Land	CH_4	YES	Level, trend
6.B.1	Industrial Wastewater \ Wastewater	CH_4	YES	Trend

Table A.1.4: Key source categories for Australia's 2007 inventory – level assessment excluding LULUCF

A		B	C	D	E	F
	IPCC Source Category	Gas	Base Year Estimate	Current Year Estimate	Level Assessment	Cumulative Total
1.A.1.a	Public Electricity and Heat Production \ Solid Fuels	CO_2	117908.73	179851.53	0.33	0.33
1.A.3.b	Road Transportation \ Liquid Fuels	CO_2	53152.79	66367.37	0.12	0.45
4.A.1	Enteric Fermentation \ Cattle	CH_4	39010.80	44984.46	0.08	0.54
1.A.1.a	Public Electricity and Heat Production \ Gaseous Fuels	CO_2	8239.20	17124.25	0.03	0.57
1.B.1.a.1.1	Fugitives/Coal Mining/Underground	CH_4	12012.94	16044.26	0.03	0.60
4.A.3	Enteric Fermentation \ Sheep	CH_4	24563.18	12311.28	0.02	0.62
6.A.1	Managed Waste Disposal on Land	CH_4	14909.41	11106.03	0.02	0.64
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Gaseous Fuels	CO_2	4592.63	10911.69	0.02	0.66
1.B.1.a.2.1	Fugitives\Coal Mining\Surface mines	CH_4	3385.22	8341.40	0.02	0.68
4.E	Prescribed Burning of Savannas	CH_4	4642.54	8122.21	0.01	0.69
2.C.1.4	Iron and Steel\Coke	CO_2	9018.39	7345.53	0.01	0.71
1.A.2.b	Non-Ferrous Metals \ Gaseous Fuels	CO_2	4139.63	7330.49	0.01	0.72
1.A.2.f	Other (please specify) \ Mining \ Liquid Fuels	CO_2	1740.80	7043.32	0.01	0.73
1.A.4.b	Residential \ Gaseous Fuels	CO_2	4612.51	6988.15	0.01	0.75
2.G	Other (please specify) \ Confidential emissions reported as CO_2-e	CO_2	1885.19	6387.74	0.01	0.76
1.A.4.c	Agriculture/Forestry/Fisheries \ Liquid Fuels	CO_2	3371.87	5841.25	0.01	0.77
1.A.3.a	Civil Aviation \ Liquid Fuels	CO_2	2895.15	5291.94	0.01	0.78
1.A.2.b	Non-Ferrous Metals \ Solid Fuels	CO_2	4221.13	5065.07	0.01	0.79
1.A.1.b	Petroleum Refining \ Liquid Fuels	CO_2	5160.26	4345.02	0.01	0.80
4.D.2	Pasture, Range and Paddock Manure	N_2O	4882.80	3922.02	0.01	0.80
2.A.1	Cement Production	CO_2	3462.87	3895.26	0.01	0.81
4.D.3.1	Atmospheric Deposition	N_2O	3245.38	3575.77	0.01	0.82
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Liquid Fuels	CO_2	957.85	3485.96	0.01	0.82
4.E	Prescribed Burning of Savannas	N_2O	1965.72	3462.56	0.01	0.83
1.B.2.c.1.2	Venting and Flaring, Venting	CO_2	1966.46	3385.93	0.01	0.84
1.A.2.c	Chemicals \ Liquid Fuels	CO_2	3263.23	3343.19	0.01	0.84
2.C.3	Aluminium Production	CO_2	2020.53	3196.13	0.01	0.85
1.A.2.f	Other (please specify) \ Mineral industry \ Gaseous Fuels	CO_2	2950.31	3084.64	0.01	0.85
1.A.2.f	Other (please specify) \ Mineral industry \ Solid Fuels	CO_2	2178.14	2919.90	0.01	0.86
1.B.2.b.4	Fugitives\Natural Gas\Distribution	CH_4	4092.56	2914.53	0.01	0.86
4.D.1.1	Synthetic Fertilizers	N_2O	1557.60	2872.31	0.01	0.87
4.D.3.2	Nitrogen Leaching and Run-off	N_2O	2503.98	2615.87	0.00	0.87
1.A.2.b	Non-Ferrous Metals \ Liquid Fuels	CO_2	2967.57	2609.04	0.00	0.88

A		B	C	D	E	F
	IPCC Source Category	Gas	Base Year Estimate	Current Year Estimate	Level Assessment	Cumulative Total
2.F.1	Refrigeration and Air Conditioning Equipment	HFC-134a	0.00	2482.13	0.00	0.88
1.B.2.c.2.3	Fugitives\Oil and Natural Gas\Flaring	CO_2	3601.38	2322.42	0.00	0.89
1.A.4.a	Commercial/Institutional \ Gaseous Fuels	CO_2	1810.69	2258.55	0.00	0.89
1.A.4.a	Commercial/Institutional \ Liquid Fuels	CO_2	1233.07	2206.25	0.00	0.90
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Solid Fuels	CO_2	2309.92	2116.65	0.00	0.90
1.A.3.c	Railways \ Liquid Fuels	CO_2	1727.66	1916.87	0.00	0.90
1.A.1.a	Public Electricity and Heat Production \ Liquid Fuels	CO_2	2863.74	1771.19	0.00	0.91
1.A.2.a	Iron and Steel \ Solid Fuels	CO_2	1191.25	1762.08	0.00	0.91
1.B.1.c	Fugitives\ Coal mining \ Decommissioned Mines	CH_4	355.90	1736.72	0.00	0.91
1.A.3.b	Road Transportation \ Liquid Fuels	N_2O	683.39	1615.54	0.00	0.92
1.A.2.f	Other (please specify) \ Construction \ Liquid Fuels	CO_2	2809.26	1590.38	0.00	0.92
1.A.2.a	Iron and Steel \ Gaseous Fuels	CO_2	1383.28	1534.65	0.00	0.92
1.A.2.e	Food Processing, Beverages and Tobacco \ Gaseous Fuels	CO_2	1246.35	1529.53	0.00	0.92
1.A.2.f	Other (please specify) \ Mining \ Gaseous Fuels	CO_2	45.94	1527.69	0.00	0.93
2.F.1	Refrigeration and Air Conditioning Equipment	HFC-143a	0.00	1414.63	0.00	0.93
6.B.2.1	Domestic and Commercial Wastewater \ Sludge	CH_4	961.42	1379.77	0.00	0.93
1.A.1.b	Petroleum Refining \ Gaseous Fuels	CO_2	576.79	1365.83	0.00	0.94
2.B.5	Other (please specify) \ Synthetic Rutile and Titanium Dioxide	CO_2	406.82	1317.16	0.00	0.94
1.A.2.c	Chemicals \ Gaseous Fuels	CO_2	1445.08	1249.69	0.00	0.94
4.B.8	Manure Management \ Swine	CH_4	1050.39	1216.50	0.00	0.94
1.A.2.e	Food Processing, Beverages and Tobacco \ Liquid Fuels	CO_2	422.50	1098.35	0.00	0.94
1.A.5.b	Mobile (please specify) \ Military use \ Liquid Fuels	CO_2	447.90	1093.25	0.00	0.95
1.A.2.e	Food Processing, Beverages and Tobacco \ Solid Fuels	CO_2	1189.68	1069.83	0.00	0.95

Table A.1.5: Key source categories for Australia's 2007 inventory – trend assessment excluding LULUCF

A		B	C	D	E	F	G
	IPCC Source Categories	Gas	1990 Emissions	2007 Emissions	Trend Assessment	% Contribution to Trend	Cumulative Total of Column F
1.A.1.a	Public Electricity and Heat Production \ Solid Fuels	CO_2	117908.73	179851.53	0.04	0.17	0.17
4.A.3	Enteric Fermentation \ Sheep	CH_4	24563.18	12311.28	0.03	0.12	0.29
6.A.1	Managed Waste Disposal on Land	CH_4	14909.41	11106.03	0.01	0.05	0.34
1.A.1.a	Public Electricity and Heat Production \ Gaseous Fuels	CO_2	8239.20	17124.25	0.01	0.04	0.38
4.A.1	Enteric Fermentation \ Cattle	CH_4	39010.80	44984.46	0.01	0.04	0.41
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Gaseous Fuels	CO_2	4592.63	10911.69	0.01	0.03	0.44
1.A.2.f	Other (please specify) \ Mining \ Liquid Fuels	CO_2	1740.80	7043.32	0.01	0.03	0.47
2.C.1.4	Iron and Steel\Coke	CO_2	9018.39	7345.53	0.01	0.03	0.50
1.B.1.a..2.1	Fugitives\Coal Mining\Surface mines	CH_4	3385.22	8341.40	0.01	0.02	0.53
2.G	Other (please specify) \ Confidential emissions reported as CO_2-e	CO_2	1885.19	6387.74	0.01	0.02	0.55
2.C.3	Aluminium Production	CH_4	3336.77	424.18	0.01	0.02	0.57
1.A.3.b	Road Transportation \ Liquid Fuels	CO_2	53152.79	66367.37	0.00	0.02	0.59
2.F.1	Refrigeration and Air Conditioning Equipment	HFC-134a	0.00	2482.13	0.00	0.02	0.61
4.D.2	Pasture, Range and Paddock Manure	N_2O	4882.80	3922.02	0.00	0.02	0.62
1.B.2.b.4	Fugitives\Natural Gas\ Distribution	CH_4	4092.56	2914.53	0.00	0.01	0.64
1.A.1.b	Petroleum Refining \ Liquid Fuels	CO_2	5160.26	4345.02	0.00	0.01	0.65
1.B.2.c.2.3	Fugitives\Oil and Natural Gas\ Flaring	CO_2	3601.38	2322.42	0.00	0.01	0.67
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Liquid Fuels	CO_2	957.85	3485.96	0.00	0.01	0.68
4.E	Prescribed Burning of Savannas	CH_4	4642.54	8122.21	0.00	0.01	0.69
1.A.2.f	Other (please specify) \ Construction \ Liquid Fuels	CO_2	2809.26	1590.38	0.00	0.01	0.71
1.A.1.a	Public Electricity and Heat Production \ Liquid Fuels	CO_2	2863.74	1771.19	0.00	0.01	0.72
1.A.2.b	Non-Ferrous Metals \ Gaseous Fuels	CO_2	4139.63	7330.49	0.00	0.01	0.73
1.B.2.c.1.2	Venting and Flaring, Venting	CH_4	1733.89	661.33	0.00	0.01	0.74
1.A.3.a	Civil Aviation \ Liquid Fuels	CO_2	2895.15	5291.94	0.00	0.01	0.75
1.A.2.f	Other (please specify) \ Mining \ Gaseous Fuels	CO_2	45.94	1527.69	0.00	0.01	0.76
2.E.1.1	Production of HCFC-22	HFC-23	1126.27	0.00	0.00	0.01	0.77
1.A.4.c	Agriculture/Forestry/Fisheries \ Liquid Fuels	CO_2	3371.87	5841.25	0.00	0.01	0.78
6.B.1	Industrial Wastewater \ Wastewater	CH_4	1783.36	861.65	0.00	0.01	0.79
2.F.1	Refrigeration and Air Conditioning Equipment	HFC-143a	0.00	1414.63	0.00	0.01	0.79
1.A.4.b	Residential \ Biomass	CH_4	1711.86	919.37	0.00	0.01	0.80

A		B	C	D	E	F	G
	IPCC Source Categories	Gas	1990 Emissions	2007 Emissions	Trend Assessment	% Contribution to Trend	Cumulative Total of Column F
1.B.1.c	Fugitives\ Coal mining \ Decommissioned Mines	CH_4	355.90	1736.72	0.00	0.01	0.81
1.A.3.d	Navigation \ Liquid Fuels \ Residual Oil	CO_2	1368.43	509.79	0.00	0.01	0.82
1.A.2.b	Non-Ferrous Metals \ Liquid Fuels	CO_2	2967.57	2609.04	0.00	0.01	0.83
2.F.1	Refrigeration and Air Conditioning Equipment	HFC-125	0.00	1016.64	0.00	0.01	0.83
1.A.4.b	Residential \ Gaseous Fuels	CO_2	4612.51	6988.15	0.00	0.01	0.84
4.E	Prescribed Burning of Savannas	N_2O	1965.72	3462.56	0.00	0.01	0.84
1.A.2.c	Chemicals \ Liquid Fuels	CO_2	3263.23	3343.19	0.00	0.01	0.85
1.A.1.c	Manufacture of Solid Fuels and Other Energy Industries \ Solid Fuels	CO_2	2309.92	2116.65	0.00	0.01	0.86
4.D.1.1	Synthetic Fertilizers	N_2O	1557.60	2872.31	0.00	0.01	0.86
1.B.2.c.1.2	Venting and Flaring, Venting	CO_2	1966.46	3385.93	0.00	0.01	0.87
1.A.2.c	Chemicals \ Solid Fuels	CO_2	1183.45	730.72	0.00	0.01	0.87
2.B.5	Other (please specify) \ Synthetic Rutile and Titanium Dioxide	CO_2	406.82	1317.16	0.00	0.00	0.88
1.A.2.f	Other (please specify) \ Mineral industry \ Gaseous Fuels	CO_2	2950.31	3084.64	0.00	0.00	0.88
1.A.4.b	Residential \ Liquid Fuels	CO_2	1315.97	971.49	0.00	0.00	0.88
4.B.13	Manure Management \ Solid storage and dry lot	N_2O	201.82	996.66	0.00	0.00	0.89
1.A.3.b	Road Transportation \ Liquid Fuels	N_2O	683.39	1615.54	0.00	0.00	0.89
2.C.3	Aluminium Production	C_2F_6	613.35	77.97	0.00	0.00	0.90
1.A.2.f	Other (please specify) \ Other non-specified \ Gaseous Fuels	CO_2	1046.39	665.01	0.00	0.00	0.90
4.D.3.1	Atmospheric Deposition	N_2O	3245.38	3575.77	0.00	0.00	0.91
4.D.3.2	Nitrogen Leaching and Run-off	N_2O	2503.98	2615.87	0.00	0.00	0.91
1.A.2.c	Chemicals \ Gaseous Fuels	CO_2	1445.08	1249.69	0.00	0.00	0.91
1.A.1.b	Petroleum Refining \ Gaseous Fuels	CO_2	576.79	1365.83	0.00	0.00	0.92
1.A.2.d	Pulp, Paper and Print \ Solid Fuels	CO_2	333.53	1049.58	0.00	0.00	0.92
2.A.1	Cement Production	CO_2	3462.87	3895.26	0.00	0.00	0.93
1.A.4.a	Commercial Institutional \ Liquid Fuels	CO_2	1233.07	2206.25	0.00	0.00	0.93
1.B.2.c.2.3	Fugitives\Oil and Natural Gas\ Flaring	CH_4	944.37	637.37	0.00	0.00	0.93
2.C.3	Aluminium Production	CO_2	2020.53	3196.13	0.00	0.00	0.94
1.A.2.e	Food Processing, Beverages and Tobacco \ Liquid Fuels	CO_2	422.50	1098.35	0.00	0.00	0.94
1.A.5.b	Mobile (please specify) \ Military use \ Liquid Fuels	CO_2	447.90	1093.25	0.00	0.00	0.94
1.A.2.e	Food Processing, Beverages and Tobacco \ Solid Fuels	CO_2	1189.68	1069.83	0.00	0.00	0.95
4.C.1.1	Rice Cultivation	CH_4	490.50	196.42	0.00	0.00	0.95

Table A.1.6: Key source categories for Australia's 2007 inventory – summary excluding LULUCF

A		B	C	D
	IPCC Source Categories	Gas	Key Source Category Flag	If Colum C is Yes, Criteria for Identification
1.A.1.a	Public Electricity and Heat Production \ Solid Fuels	CO_2	YES	Level, Trend
1.A.1.A	Public Electricity and Heat Production \ Gaseous Fuels	CO_2	YES	Level, Trend
1.A.1.A	Public Electricity and Heat Production \ Liquid Fuels	CO_2	YES	Level, Trend
1.A.1.B	Petroleum Refining \ Liquid Fuels	CO_2	YES	Level, Trend
1.A.1.B	Petroleum Refining \ Gaseous Fuels	CO_2	YES	Level, Trend
1.A.1.C	Manufacture of Solid Fuels and Other Energy Industries \ Liquid Fuels	CO_2	YES	Level, Trend
1.A.1.C	Manufacture of Solid Fuels and Other Energy Industries \ Solid Fuels	CO_2	YES	Level, Trend
1.A.1.C.	Manufacture of Solid Fuels and Other Energy Industries \ Gaseous Fuels	CO_2	YES	Level, Trend
1.A.2.A	Iron and Steel \ Solid Fuels	CO_2	YES	Level
1.A.2.A	Iron and Steel \ Gaseous Fuels	CO_2	YES	Level
1.A.2.B	Non-Ferrous Metals \ Gaseous Fuels	CO_2	YES	Level, Trend
1.A.2.B	Non-Ferrous Metals \ Liquid Fuels	CO_2	YES	Level, Trend
1.A.2.B	Non-Ferrous Metals \ Solid Fuels	CO_2	YES	Level
1.A.2.C	Chemicals \ Liquid Fuels	CO_2	YES	Level, Trend
1.A.2.C	Chemicals \ Solid Fuels	CO_2	YES	Trend
1.A.2.C	Chemicals \ Gaseous Fuels	CO_2	YES	Level, Trend
1.A.2.D	Pulp, Paper and Print \ Solid Fuels	CO_2	YES	Trend
1.A.2.E	Food Processing, Beverages and Tobacco \ Solid Fuels	CO_2	YES	Level, Trend
1.A.2.E	Food Processing, Beverages and Tobacco \ Gaseous Fuels	CO_2	YES	Level
1.A.2.E	Food Processing, Beverages and Tobacco \ Liquid Fuels	CO_2	YES	Level, Trend
1.A.2.f	Other (please specify) \ Construction \ Liquid Fuels	CO_2	YES	Level, Trend
1.A.2.f	Other (please specify) \ Mineral industry \ Gaseous Fuels	CO_2	YES	Level, Trend
1.A.2.f	Other (please specify) \ Mineral industry \ Solid Fuels	CO_2	YES	Level
1.A.2.f	Other (please specify) \ Mining \ Gaseous Fuels	CO_2	YES	Level, Trend
1.A.2.f	Other (please specify) \ Mining \ Liquid Fuels	CO_2	YES	Level, Trend
1.A.2.f	Other (please specify) \ Other non-specified \ Gaseous Fuels	CO_2	YES	Trend
1.A.3.a	Civil Aviation \ Liquid Fuels	CO_2	YES	Level, Trend
1.A.3.b	Road Transportation \ Liquid Fuels	CO_2	YES	Level, Trend
1.A.3.b	Road Transportation \ Liquid Fuels	N_2O	YES	Level, Trend
1.A.3.c	Railways \ Liquid Fuels	CO_2	YES	Level
1.A.3.d	Navigation \ Liquid Fuels\ Fuel Oils	CO_2	YES	Trend
1.A.4.a	Commercial Institutional \ Gaseous Fuels	CO_2	YES	Level
1.A.4.a	Commercial Institutional \ Liquid Fuels	CO_2	YES	Level, Trend
1.A.4.b	Residential \ Biomass	CH_4	YES	Trend
1.A.4.b	Residential \ Gaseous Fuels	CO_2	YES	Level, Trend

A		B	C	D
	IPCC Source Categories	Gas	Key Source Category Flag	If Colum C is Yes, Criteria for Identification
1.A.4.b	Residential \ Liquid Fuels	CO_2	YES	Trend
1.A.4.c	Agriculture ForestryFisheries \ Liquid Fuels	CO_2	YES	Level, Trend
1.A.5.b	Mobile \ Military use \ Liquid Fuels	CO_2	YES	Level, Trend
1.B.1.a	Fugitives\Coal Mining\Underground	CH_4	YES	Level
1.B.1.a	Fugitives\Coal Mining\Surface mines	CH_4	YES	Level, Trend
1.B.1.c	Fugitives\ Coal mining \ Decommissioned Mines	CH_4	YES	Level, Trend
1.B.2.b	Fugitives\Natural Gas\Distribution	CH_4	YES	Level, Trend
1.B.2.C.1.2	Fugitives\Oil and Natural Gas\Venting	CH_4	YES	Trend
1.B.2.C.1.2	Fugitives\Oil and Natural Gas\Venting	CO_2	YES	Level, Trend
1.B.2.C.2.3	Fugitives\Oil and Natural Gas\Flaring	CO_2	YES	Level, Trend
1.B.2.C.2.3	Fugitives\Oil and Natural Gas\Flaring	CH_4	YES	Trend
2.A.1	Cement Production	CO_2	YES	Level, Trend
2.B.5	Other (please specify) \ Synthetic Rutile and Titanium Dioxide	CO_2	YES	Level, Trend
2.C.1	Iron and Steel\Coke	CO_2	YES	Level, Trend
2.C.3	Aluminium Production	CO_2	YES	Level, Trend
2.C.3	Aluminium Production	CF_4	YES	Trend
2.C.3	Aluminium Production	C2F6	YES	Trend
2.E.1	Production of HCFC-22	HFC-23	YES	Trend
2.F.1	Refrigeration and Air Conditioning Equipment	HFC-134a	YES	Level, Trend
2.F.1	Refrigeration and Air Conditioning Equipment	HFC-143a	YES	Level, Trend
2.F.1	Refrigeration and Air Conditioning Equipment	HFC-125	YES	Trend
2.G	Other (please specify) \ Confidential emissions reported as CO_2-e	CO_2	YES	Level, Trend
4.A.1.	Enteric Fermentation \ Cattle	CH_4	YES	Level, Trend
4.A.3	Enteric Fermentation \ Sheep	CH_4	YES	Level, Trend
4.B.8	Manure Management \ Swine	CH_4	YES	Level
4.B.13	Manure Management \ Solid storage and dry lot	N_2O	YES	Trend
4.C	Rice Cultivaion	CH_4	YES	Trend
4.D.1.1	Synthetic Fertilizers	N_2O	YES	Level, Trend
4.D.2	Pasture, Range and Paddock Manure	N_2O	YES	Level, Trend
4.D.3.1	Atmospheric Deposition	N_2O	YES	Level, Trend
4.D.3.2	Nitrogen leaching and runoff	N_2O	YES	Level, Trend
4.E	Prescribed Burning of Savannas	CH4	YES	Level, Trend
4.E	Prescribed Burning of Savannas	N_2O	YES	Level, Trend
6.A.1	Managed Waste Disposal on Land	CH_4	YES	Level, Trend
6.B.1	Industrial Wastewater \ Wastewater	CH_4	YES	Trend
6.B.2.1	Domestic and Commercial Wastewater \ Sludge	CH_4	YES	Level

Annex 2: Methodology and Data for Estimating Carbon Dioxide Emissions from Fossil Fuel Combustion

The Australian methodology and data descriptions for the estimation of this inventory have been documented in chapter 3.

Annex 3: Other Detailed Methodological Descriptions

The Australian methodology for the estimation of this inventory is documented in the relevant chapters.

Annex 4: Carbon Dioxide Reference Approach for the Energy Sector

Estimation of CO_2 Using the IPCC Reference Approach

The reference approach estimates CO_2 emissions from *fuel combustion activities* (covering both *stationary energy* and *transport*). It is calculated using a top-down approach based on national energy statistics for production, imports, exports and stock change. Data are obtained from the ABARE Australian national energy statistics balance, supplemented by specific sectoral data where available. The Australian Petroleum Statistics are used as a basis for the liquid fossil fuel data. The ABARE Australian national energy statistics balance is shown below in Table A.4.1.

Comparison of Australian Methodology with IPCC Reference Approach

Total CO_2 emissions estimated using Australia's National approach methodology are 366.0 Mt. Total CO_2 emissions estimated using the reference approach are 365.1 Mt. This is an overall 0.24% difference between the two methods. The main reason for the difference relates to a discrepancy in liquid fuel emissions of 1.9 %, which is driven by uncertainty within the reference approach. This arises from the sensitivity of final apparent consumption and emission figures to the average density and energy content values used to convert production, exports, imports and stock change from volumetric units into energy units.

Table A.4.1: Australian Energy Statistics

A1 Australian energy supply and disposal, 2006-07 - energy units

	Black coal	Brown coal	BKB briquettes	Met. coke	Coal by-products	Natural gas, CSM	Crude oil and ORF	Propane, butane, LPG	Refined products	Liquid/gas biofuels	Biomass wood	Biomass bagasse	Solar/wind electricity	Hydro-electricity	Total electricity	Solar hotwater	U_3O_8 Uranium
	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ
Supply																	
Primary indigenous	8 650.3	642.4				1 792.6	1 056.6	120.6		12.8	93 8	110.8	22 5	52 0		5.9	4 509 0
plus all imports						214.0	984.9	19.2	642 3								
less all exports	6 943.3					826.9	593.9	72.6	144.1								4 473.9
less stock changes and discrepancies	42.7	- 32.2	- 6.6	21.1		22.0	- 60.4	6 8	77 0								35.1
Total domestic availability	1 664.3	674.6	6.6	- 21.1		1 157.8	1 508.1	60.4	421.2	12.8	93 8	110.8	22 5	52 0		5.9	
less conversions																	
Coke ovens	136.6			- 97.4	- 26 0				0.9		204.6				0.1		
Briquetting		6 3	- 1 8												0.2		
Petroleum refining						22.3	1 514.2	- 36 0	- 1 478.2						7.1		
Gas manufacturing						3.7		1.4							0.1		
Electricity generation a	1 373.4	668.2	2.9		5.7	284.2		0.1	25 3	7.3	4.7		22 5	52 0	- 901.0		
Other conversion				67.2	- 25 0		- 8.9	- 7.4	14.9						- 46.0		
Fuel use in conversion						24.6		2.1	120.1						134.7		
Final domestic availability	154.3		5 5	9.1	45.4	823.0	2.7	100.2	1 738.2	5.6	89.2	110.8			804 8	5.9	
Disposal																	
Agriculture						0.1		1.6	83.2						6.7		
Mining	5.6		0 5	0.2	1 5	242.2	1.3	1.2	147 5						69.4		
Food, beverages, textiles	9.6		0.7		3.1	38.6	0.6	1 0	15 3	1.8	4.7	110.8			29.1		
Wood, paper and printing	11.9					20.7		0 8	1 5		18.7				21.1		
Chemical	2.3		1 5	0.9	7 8	88.2		14.2	61.2						22.7		
Iron and steel	22.3			1.4	32 0	26.2		0 5	1 8						27 3		
Non-ferrous metals	66.3			6.3	0.6	144.8	0.8	0.6	49.2		2 3				185.4		
Other industry	30.1			0.3	0.4	80.1		5 3	10.7	1.9	0.9				25.9		
Construction						3.1		0 3	22.7						0 3		
Road transport						1.6		61.4	951 0	1.9							
Rail transport									27.7						8.1		
Air transport									217 8								
Water transport	5.2					0.1			61.7								
Commercial and services	0.9		2 8			43.8		3.0	23 0		0 3				178.2	3.7	
Residential	0.1		0.1			133 5		10.2	1 3		62 3				230 5	2.2	
Lubes, bitumen, solvents									62.7								
Gross final energy disposal	154.3		5 5	9.1	45.4	823 0	2.7	100.2	1 738.2	5.6	89.2	110.8			804 8	5.9	

Totals may not add due to rounding

a Grid connected power stations only, except for Total electricity. b Includes return streams to refineries from the petrochemical industry, consumption of coke in blast furnaces, blast furnace gas manufacture, electricity produced through cogeneration and lignite tar in char manufacture.

c After conversion sector use and losses. Equals gross final energy disposal which is the final disposal of energy within the end use sectors.

Because it is not possible to separate the fuels used to produce embedded electricity, those fuels are included in the industry in which production occurs although the electricity produced is included under Total electricity against Electricity generation and Other conversion.

Annex 5: Assessment of Completeness

The UNFCCC Guidelines require inventory compilers to assess inventories for the level of completeness of national inventories. The sources of greenhouse gas emissions are many and diverse and, in general, are not directly observable without considerable cost. Many emission sources are minor and resource intensive to estimate. Consequently, all national inventories have minor omissions which, for transparency, need to be identified. This section addresses the completeness of key activity datasets, such as the consumption of fossil fuels, and the completeness of the coverage of emissions and removals sources for the Australian inventory.

Completeness of Activity Data

The emission estimates were reviewed for internal consistency and completeness through the application of mass balance approaches to ensure the reconciliation of carbon supplies and carbon uses within the economy for fossil fuels, carbonates and biomass entering the economy. Details have been provided in the respective sectoral chapters.

Omitted Emission Sources

The UNFCCC reporting guidelines provide standard reporting templates that are designed to accommodate the circumstances of as many countries as possible. The reporting templates are not always closely aligned with Australia's circumstances. Consequently, in Australia's reporting tables there are a number of categories where the term "not occurring" has been reported for certain cells because of an absence of a certain economic activity. An example is *adipic acid* production, which does not occur in Australia. In some cases, Australia has chosen to report emissions for a particular category as "included elsewhere" where existing data collections or methodologies do not allow for the splitting of the sources of emissions. An example is the reporting of all emissions from the use of fossil fuels for *ammonia production* under the Industrial Processes sector, rather than being split between the Industrial Process and Energy sectors, because the data do not support an accurate splitting of emissions between the two.

Nonetheless, there are a small number of emission sources which are believed to be minor and which are reported as 'not estimated' either because of a lack of data or because the emission processes are not well enough understood to permit the development of reliable methodologies. In some instances, default methodologies are not specified by the IPCC due to limited understanding internationally of these processes.

With each new inventory, a number of emission sources and removals have been added to the national inventory, resources permitting, as the remaining outstanding sources are generally minor while at the same time resource-intensive to estimate.

CO_2 from Burning of Coal Deposits and Waste Piles (1B1)

The spontaneous combustion of waste piles is a known source of CO_2 emissions. Research undertaken on the measurement of this emission source has not yet been able to develop any reliable approach to the estimation of this emission source. Similarly, neither the 1996 IPCC Guidelines nor the 2006 IPCC Guidelines include a default methodology that could be applied in the absence of information on this source.

Fugitive Emissions From Bore Holes

The use of bore water from the Great Artesian Basin and other sources has been an important source of irrigation for Australia's agricultural industries. Carbon dioxide is often released in small quantities from the bore holes during pumping. Government programmes for capping the bores to improve the efficiency of water use may have led to reductions in this source of emissions in recent years. More research is being conducted into this source of emissions to develop adequate datasets and methodologies.

CO_2 From Metal Production (2.C.5)

Coke is used as a reducing agent in the production of some metals for certain types of production technologies. CO_2 emissions from this source have been reported in the industrial process and energy sectors of this inventory. Emissions may also arise if the metallic ores being processed contain carbonates. In Australia, metallic ores are predominantly sulphide ores, rather than carbonate ores, and so emissions from this source, if any, are thought to be negligible.

CO_2 From Food and Drink Production (2.D.2)

The IPCC Guidelines do not provide a method that may be used for estimating CO_2 emissions from this source and, in the absence of an international methodology, Australia has not estimated CO_2 emissions from this source.

Miscellaneous SF_6 uses (2.F)

In the Australian inventory SF_6 emissions are reported from the use of this gas in the electricity industry. SF_6 may also be used in a number of other applications, such as in the production sport shoes, tyres and tennis balls, but no data is available to support estimates for any of these uses.

CH4 from the production of Dichloroethylene and Methanol (2.B.5)

Company level activity data and emission factors are used as the basis for the estimation of emissions from the production miscellaneous organic chemicals. In the case of Dichloroethylene and Methanol production, company-level data are not available for an estimate to be made. Emissions of methane from these sources are considered to be negligible.

HFC emissions from Metered Dose Inhalers (2.F.4)

Imports of MDIs containing HFC propellants are not covered under the Ozone Protection and *Synthetic Greenhouse Gas Management Act*. Advice from the Department of Environment Water Heritage and Arts indicates that the importation of HFC containing MDIs is insignificant. However, this source is being kept under review.

Annex 6: Additional Information: Carbon Balance For Energy and Non-Energy Fuel Use

The Australian inventory utilises a very large number of disaggregated data inputs for energy-related emission calculations (< 15,000 per year). Consequently, a carbon balance was undertaken comparing carbon input to carbon output for all years. The carbon input represents the carbon embodied within the total quantity of energy and non-energy fuels which have been consumed in a year, and are entered into the AGEIS for calculation. The carbon output represents the distribution of the carbon utilised throughout the economy, as determined by the output of the calculations within the AGEIS. The carbon output is distributed as either emissions from fuel combustion, emissions from the use of fossil fuels as reductants, non-energy uses (eg feedstocks, bitumen, coal oils and tar), use of biomass sources of energy and international bunkers. While the predominant outcome of carbon entering the economy is emissions, a small portion of the carbon is stored in carbon-containing products or non-oxidised as ash. A flow chart detailing the results of the carbon balance for 2007 can be found in Figure A.6.1.

Results from the carbon balance have shown that all carbon is effectively accounted for. For 2007, it can be seen in Figure A.6.1 that all carbon has been accounted for down to 0.0003% (3/10,000 of a percent). This discrepancy relates to carbon from biofuels, within the memo items. Further work will continue on resolving this discrepancy.

The carbon balance analysis effectively tests the integrity of the calculations within the AGEIS by checking that all carbon consumed is accounted for and has been used to uncover several errors within data entries and the emission calculation process. Although the errors were of a very minor nature, they were of the type that are difficult to trace with standard QC tools. The errors found by the carbon balance were:

- Chemicals feedstocks

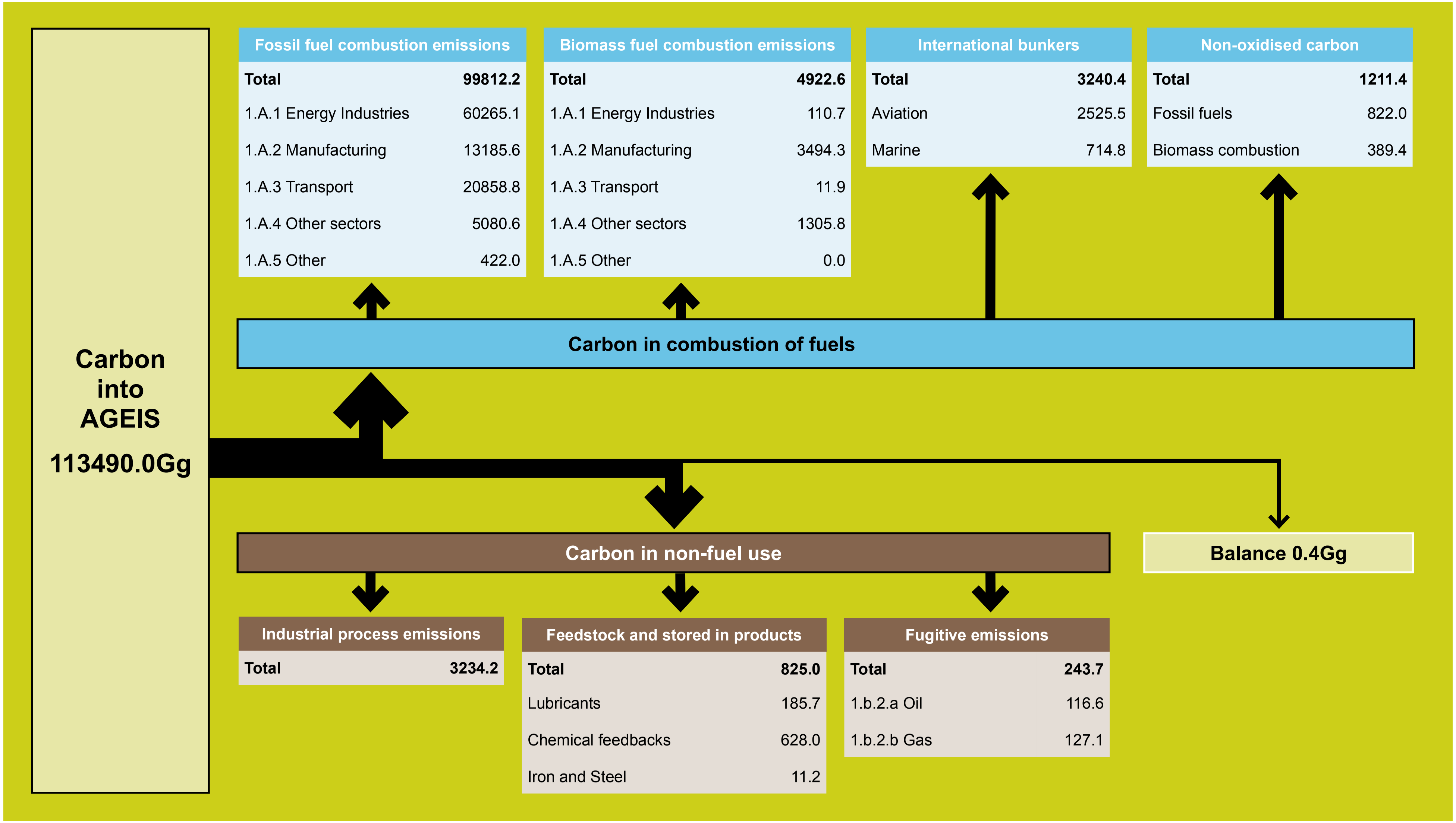
  A small calculation error was uncovered by the carbon balance QC check relating to the application of the oxidation factor to chemical liquid and gas fuels. This error was fixed for all years and was of the order of 13 Gg CO_2-e in size.

- Electricity generation

  In the electricity sector the carbon balance identified a minor data entry error relating to oxidation factors used in the emission calculations. This resulted in changes of less than 20 Gg CO_2-e for a number of years.

These errors were corrected in this submission.

Figure A.6.1: Carbon balance flow chart showing carbon inputs and distribution of outputs for 2007



Annex 7: Uncertainty Analysis

Uncertainty is inherent within any kind of estimation—be it an estimate of the national greenhouse gas emissions, or the national gross domestic product. While it is in some cases possible to continuously monitor emissions, it is not usually practical or economic to do so. This leads to estimations based on samples or studies being used which carry a degree of additional uncertainty attached to them. Uncertainty also arises from the limitations of the measuring instruments, and over the complexities of the modelling of key relationships between observed variables and emissions.

The purpose of estimating the uncertainty attached to emissions estimates is principally to provide information on where inventory resources should be allocated to maximise the future improvements to inventory quality.

Assessing uncertainty is, itself, a difficult exercise, especially in the absence of quantitative data. Australia has conducted an uncertainty analysis for the individual sectors in line with the IPCC *Good Practice* guidelines. Monte Carlo and Latin Hypercube approaches were used to estimate emission uncertainty in some sectors, which is equivalent to the IPCC Tier 2 methodology.

The estimates have been mainly prepared by the judgement of the sectoral expert consultants. However, the estimates of uncertainty for the Australian inventory have been reviewed in 2005 by independent experts under protocols developed by the Australian CSIRO Atmospheric Research Division. The CSIRO report confirmed, with one or two exceptions, the quantitative judgements made in relation to uncertainty of inventory estimates and provide a strong basis for confidence in the assessments reported in this chapter.

The uncertainties for individual sectors are reported in more detail below. The estimated uncertainties tend to be low for carbon dioxide from energy consumption as well as from some industrial process emissions. Uncertainty surrounding estimates from these sources are typically as low as ± 4–5%. Uncertainty surrounding estimates of emissions are higher for agriculture, land use change and forestry, reflecting inherently high uncertainty due to the very nature of the processes involved (e.g. biological processes). A medium band of uncertainty applies to estimates from fugitive emissions, most industrial processes and non-CO_2 gases in the energy sector. The ranges presented are broadly consistent with the typical uncertainty ranges expected for each sector, as identified in the IPCC *Good Practice Report*.

Table A.7.1: General Reporting Table for Uncertainty (IPCC Good Practice Guidance Reporting Table 6.1)

A	B	C	D	E	F	G	H	I	J	K	L	M	Q
IPCC Source category	Gas	Base year emissions	Year t emissions	Activity data Uncert'y	Emission factor uncert'y	Combined uncert'y	Uncert'y in total inventory	Type A Sensit'y	Type B Sensit'y	Uncert'y in trend of EF	Uncert'y in activity data	Uncert'y in total emissions	footnote ref no.
		1990 Gg CO_2 e	2007 Gg CO_2 e	%	%	%	%	%	%	%	%	%	
1.A Coal	CO_2	132194	196044	2	5	5.39	1.736	0.075	0.384	0.377	1.1	1.1	1,2
	CH_4	28	41.6825	2	5	5.39	0.000	0.000	0.000	0.000	0.0	0.0	1
	N_2O	443	631.754	2	20	20.10	0.021	0.000	0.001	0.004	0.0	0.0	1
1.A Liquid	CO_2	88192.4	113054	2	3	3.61	0.670	0.016	0.221	0.047	0.6	0.6	1
	CH_4	664.926	655.019	2	40	40.05	0.043	0.000	0.001	-0.011	0.0	0.0	1
	N_2O	818.847	1800.48	2	60	60.03	0.178	0.002	0.004	0.097	0.0	0.1	1
1.A Gaseous	CO_2	32918.8	56880.2	2	3	3.61	0.337	0.035	0.111	0.104	0.3	0.3	1
	CH_4	28.6446	177.423	2	5	5.39	0.002	0.000	0.000	0.001	0.0	0.0	1
	N_2O	20.1492	34.1267	2	20	20.10	0.001	0.000	0.000	0.000	0.0	0.0	1
1.A. Biomass	CH_4	1729.82	978.632	0	20	20.00	0.032	-0.002	0.002	-0.042	0.0	0.0	8
	N_2O	186.402	212.421	0	20	20.00	0.007	0.000	0.000	0.000	0.0	0.0	8
1.B.1 Fugitives coal mining	CH_4	16229.7	26832.5	5	20	20.62	0.910	0.015	0.053	0.294	0.4	0.5	1,3
1.B.2 Fugitives oil	CO_2	405	442.767	5	5	7.07	0.005	0.000	0.001	0.000	0.0	0.0	1,4
1.B.2 Fugitives Natural gas	CO_2	10	8.8202	10	3	10.44	0.000	0.000	0.000	0.000	0.0	0.0	1,4
1.B.2 Fugitives venting & flaring	CO_2	5568	5708.35	5	5	7.07	0.066	-0.002	0.011	-0.009	0.1	0.1	1,4
1.B.2 Fugitives oil	CH_4	66	173.316	5	5	7.07	0.002	0.000	0.000	0.001	0.0	0.0	1,4
1.B.2 Fugitives Natural gas	CH_4	4215	3162.78	10	3	10.44	0.054	-0.004	0.006	-0.011	0.1	0.1	1,4
1.B.2 Fugitives venting & flaring	CH_4	2678	1298.7	5	5	7.07	0.015	-0.004	0.003	-0.018	0.0	0.0	1,4
2.A.1 Cement	CO_2	3463	3895.26	2.5	2.5	3.54	0.023	0.000	0.008	-0.001	0.0	0.0	5
2.A.2 Lime	CO_2	705	1006.96	2.5	2.5	3.54	0.006	0.000	0.002	0.001	0.0	0.0	5
2.A.3 Limestone Consumption	CO_2	955	964.502	4	2.5	4.72	0.007	0.000	0.002	-0.001	0.0	0.0	5
2.B.5 Rutile	CO_2	407	1317.16	2.5	2.5	3.54	0.008	0.002	0.003	0.004	0.0	0.0	5
2.B.5 Polymers	CH_4	9	9.10626	5	5	7.07	0.000	0.000	0.000	0.000	0.0	0.0	5
2.C 1 Steel	CO_2	9018	7345.53	2.5	5	5.59	0.068	-0.007	0.014	-0.033	0.1	0.1	5
2.C.1 Steel	CH_4	59	62.5405	2.5	5	5.59	0.001	0.000	0.000	0.000	0.0	0.0	5
2.C.3 Aluminium	CO_2	2021	3196.13	2.5	2.5	3.54	0.019	0.002	0.006	0.004	0.0	0.0	5
2.C.3 Aluminium	PFCs	3950	502.153	27	0	27.00	0.022	-0.008	0.001	0.000	0.0	0.0	5
2.F HFCs	HFCs	1126	5117.61	27	0	27.00	0.227	0.007	0.010	0.000	0.4	0.4	5
2.F SF_6	SF_6	521	521	27	0	27.00	0.023	0.000	0.001	0.000	0.0	0.0	5

A	B	C	D	E	F	G	H	I	J	K	L	M	Q
IPCC Source category	Gas	Base year emissions	Year t emissions	Activity data Uncert'y	Emission factor uncert'y	Combined uncert'y	Uncert'y in total inventory	Type A Sensit'y	Type B Sensit'y	Uncert'y in trend of EF	Uncert'y in activity data	Uncert'y in total emissions	footnote ref no.
		1990 Gg CO_2 e	2007 Gg CO_2 e	%	%	%	%	%	%	%	%	%	
2.G Other	CO_2-e	1885	5252	5	5	7.07	0.061	0.006	0.010	0.029	0.1	0.1	5
4.A Enteric fermentation	CH_4	63881	57561.3	0	5.5	5.50	0.521	-0.036	0.113	0.000	0.0	0.0	6
4.B Manure management	CH_4	1540	1859.31	0	10.5	10.50	0.032	0.000	0.004	0.000	0.0	0.0	6
4.B Manure management	N_2O	524	1594.04	0	10.3	10.30	0.027	0.002	0.003	0.020	0.0	0.0	6
4.C Rice Cultivation	CH_4	490	196.421	5	10	11.18	0.004	-0.001	0.000	-0.008	0.0	0.0	7
4.D Agricultural Soils	N_2O	13496	15001.6	0	52	52.00	1.283	-0.002	0.029	-0.109	0.0	0.1	7
4.E Burning of Savannas	CH_4	4643	8122.21	50	15	52.20	0.697	0.005	0.016	0.076	1.1	1.1	7
4.E Burning of Savannas	N_2O	1966	3462.56	50	15	52.20	0.297	0.002	0.007	0.033	0.5	0.5	7
4.F Agricultural Residues	CH_4	193	210.535	5	20	20.62	0.007	0.000	0.000	-0.001	0.0	0.0	7
4.F Agricultural Residues	N_2O	99	98.1111	5	20	20.62	0.003	0.000	0.000	-0.001	0.0	0.0	7
5.A.1 Forest land remaining forest land	CO_2	-35094.9	-8681.9	0	30	30.00	-0.428	0.065	-0.017	1.945	0.0	1.9	8
	CH_4	1663.98	2101.97	0	77	77.00	0.266	0.000	0.004	0.018	0.0	0.0	8
	N_2O	454.085	573.607	0	93	93.00	0.088	0.000	0.001	0.006	0.0	0.0	8
5.C.2 Conversion to Grasslands	CO_2	104146	67766.3	0	10	10.00	1.114	-0.110	0.133	-1.098	0.0	1.1	8
	CH_4	2518.58	1714.93	0	20	20.00	0.056	-0.003	0.003	-0.050	0.0	0.1	8
	N_2O	688.392	468.735	0	20	20.00	0.015	-0.001	0.001	-0.014	0.0	0.0	8
5.B.2 Conversion to Croplands	CO_2	23024	5979.92	0	10	10.00	0.098	-0.042	0.012	-0.419	0.0	0.4	8
	CH_4	916.853	666.808	0	20	20.00	0.022	-0.001	0.001	-0.017	0.0	0.0	8
	N_2O	250.599	182.256	0	20	20.00	0.006	0.000	0.000	-0.005	0.0	0.0	8
5.G Other	CO_2	-4468.47	-2971.9	0	20	20.00	-0 098	0.005	-0.006	0.092	0.0	0.1	8
	N_2O	558.829	329.287	0	20	20.00	0.011	-0.001	0.001	-0.013	0.0	0.0	8
6.A Solid Waste	CH_4	14909.4	11106	0	3.25	3.25	0.059	-0.013	0.022	-0.042	0.0	0.0	5
6.B Wastewater handling	CH_4	3333.81	2842.54	0	50	50.00	0.234	-0.002	0.006	-0.110	0.0	0.1	5
6.B Wastewater handling	N_2O	479.053	589.705	0	50	50.00	0.048	0.000	0.001	0.002	0.0	0.0	5
6.C Waste incineration	CO_2	73.2601	28.8355	0	50	50.00	0.002	0.000	0.000	-0.006	0.0	0.0	5
Total Emissions		**510802**	**608130**										
Total Uncertainties							**2.4**					**2.8**	

Source: 1) Energy Strategies; 2) George Wilkenfeld & Associates; 3) Dr David Williams, CSIRO; 4) Australian Petroleum Production & Exploration Association; 5) Burnbank Consulting; 6) Dr Mark Howden, CSIRO; 7) Dr Carl Meyer, CSIRO; 8) Dr Gary Richards, Department of Climate Change.

The estimates of uncertainty surrounding the emissions estimates for individual sectors may be combined to present an estimate of the overall uncertainty for the inventory as a whole. Following the recommendations of the IPCC Good Practice Guidance, the emission estimates across the energy sector have been aggregated because of the hidden dependencies that exist between sectoral activity levels as a result of the constraint of overall consumption and since aggregate fuel consumption is more accurately known than the consumption in individual sectors. The results of the application of the IPCC Tier 1 approach to estimating the uncertainty of the inventory as a whole, which identifies separately estimates of uncertainty for both activity and emission factors where available, and which does not account for correlations between variables (unlike some of the sectoral analyses), are presented in Table A.7.1.

As indicated in the *IPCC Good Practice Guidance* the Tier 1 approach is valid as long as a number of restrictive assumptions are met. An alternative, more flexible approach, which relies on Monte Carlo analysis and a more detailed specification of the sources of uncertainty, is currently under consideration for development by the Department of Climate Change for use in future national inventory reports. This analysis would be equivalent to the IPCC Tier 2 approach and would take into consideration a number of refinements proposed by the CSIRO independent review.

The Tier 1 results presented in Table A.7.1 show the estimated uncertainty surrounding the aggregate inventory estimate for 2004 to be ±2.4 %. The reported estimated uncertainty for the trend in emissions is ± 2.8 %. This estimate has been calculated on the assumption that the total uncertainty for parts of agriculture, land use, land use change and forestry, and the waste sectors are uncorrelated through time. The overall estimate of uncertainty in the trend is sensitive to this assumption. If the alternative assumption was applied, that of full correlation in the total uncertainty of these sectors over time, the uncertainty in the trend estimate is estimated at ± 6 %. Further analysis will be conducted into this issue for future inventories.

Energy

Stationary Energy

Uncertainty analyses were conducted for emissions from three sectors: 1.A.1.a. *Electricity*, 1.A.1.b. *Petroleum refining* and 1.A.1.c. *Manufacture of solid fuels and other energy industries* (Table A.7.2). The overall uncertainty in estimated emissions from *electricity generation* was ±5%. The highest uncertainty was for N_2O emissions, with an associated uncertainty of up to ±16%. However, as emissions of N_2O (and CH_4) account for only a small fraction, 0.4%, of the subsector's total emissions, there is a negligible impact on overall uncertainty for this sector.

Table A.7.2: Quantified uncertainty values for key stationary energy subcategories [(a)]

Greenhouse gas source and sink category	Uncertainty (%)			
	CO_2	CH_4	N_2O	Total CO_2-e
1. ENERGY				
A Fuel combustion activities				
1.A.1.a Electricity	**±5**	**±9**	**±15**	**±5**
Black coal	±6	±9	±15	±6
Brown coal	±4	±9	±15	±4
Petroleum	±4	±9	±7	±4
Natural gas	±4	±9	±16	±4
Biomass	NA	±9	±4	±4
Biogas	NA	±9	±16	±4
1.A.1.b Petroleum refining	**±4**	**±9**	**±12**	**±4**
Petroleum	±4	±9	±12	±4
Gas	±4	±9	±12	±4
1.A.1.c Manufacture of solid fuels and other energy industries	**±4**	**±9**	**±12**	**±4**
Coal	±4	±9	±12	±4
Petroleum	±4	±9	±12	±4
Gas	±4	±9	±12	±4

Note: a) Uncertainty reported at 95% confidence limits estimated using Latin Hypercube (a type of Monte Carlo) analysis

Overall uncertainty associated with emissions estimates from both 1.A.1.b. *Petroleum refining* and 1.A.1.c. *Manufacture of solid fuels and other energy industries* sectors was ±4%. Again, the uncertainty associated with emissions of N_2O and CH_4 has negligible impact on overall uncertainty. An uncertainty analysis on minor, mobile source categories of the *stationary energy* sector gave uncertainty values ranging from ±16.4% to ±24.5% for CO_2, from ±25.4% to ±63.9% for CH_4, and ±44.7% to ±64.2% for N_2O.

Table A.7.3: Quantified uncertainty values for mobile source categories [(a)]

Greenhouse gas source and sink category	Uncertainty (%)		
	CO_2	CH_4	N_2O
1.A.4 Other sectors			
b. Residential			
Lawn mowers	±24.5	±45.2	±46.3
1.A.5 Other			
b. Mobile	**±16.4**	**±25.4**	**±44.7**
Military transport—land	±18.5	±32.9	±54.6
Military transport—water	±24.4	±63.9	±62.7
Military transport—aviation	±24.0	±47.2	±64.2

Note: a) Uncertainty reported at 95% confidence limits estimated using Monte Carlo analysis

Transport

Monte Carlo analyses were conducted for all subsectors and fuel types. The uncertainty distributions for emission factors and activity data were developed on the basis of expert judgment.

The total estimated uncertainties in the *transport* subsector were ±4% for CO_2, ±24% for CH_4, and ±42% for N_2O. Uncertainties in the emissions from individual source categories ranged from ±1% to ±24% for CO_2, ±23% to ±59% for CH_4, and ±32% to ±63% for N_2O. The largest source of uncertainty is in the emission factors.

The estimates also reflect the relatively higher uncertainty attached to the emission estimates for particular vehicle types, which are drawn from ABS data and its survey of motor vehicle use, than for the sector as a whole. This outcome reflects the dependency between activity variables; and because overall transport fuel consumption is more accurately known than the individual segments.

Table A.7.4: Emissions and quantified uncertainty values for key transport subcategories [(a)]

Greenhouse gas source and sink category	Uncertainty (%)		
	CO_2	CH_4	N_2O
1.A.3 Transport	**±4**	**±24**	**±42**
	±4	±23	±41
a. Civil aviation	**±9**	**±52**	**±52**
b. Road transport	**±4**	**±25**	**±42**
i. Passenger cars	±6	±31	±44
ii. Light trucks	±7	±38	±41
iii. Medium trucks	±9	±41	±60
iv. Heavy trucks	±10	±44	±61
v. Buses	±8	±36	±53
vi. Motorcycles	±10	±43	±61
c. Railways	**±5**	**±39**	**±39**
d. Navigation	**±8**	**±59**	**±32**
e. Other transportation	**±24**	**±46**	**±63**
International bunkers			
Aviation	±10	±58	±59
Marine	±4	±47	±52

Note: a) Uncertainty reported at 95% confidence limits

ANNEXES

Fugitives

The overall uncertainty for *fugitive* emissions was estimated to be ±11% (Table A.7.5). The estimated uncertainty for *solid fuels* CH_4 was ±19%. Uncertainties in oil and natural gas emissions were estimated to be ±4% for CO_2, ±5% for CH_4 and ±4% for N_2O.

Table A.7.5: Quantified uncertainty values for key fugitive emissions subcategories (a)

Greenhouse gas source and sink category	Uncertainty (%)			
	CO_2	CH_4	N_2O	CO_2-e
1. ENERGY				
B. Fugitive emissions	**±4**	**±14**	**±4**	**±11**
1.B.1 Solid fuels	**NE**	**±19**	**NE**	**±19**
1.B.1.a.i Underground mines	NE	±21	NE	±21
Underground activities	NE	±21	NE	±21
Post mining	NE	±17	NE	±17
1.B.1.i.i Surface mining	NE	±17	NE	±17
1.B.2 Oil and natural gas	**±4**	**±5**	**±4**	**±4**
1.B.2 Oil	±8	±5	±8	±7
1.B.2.b Natural gas	±9	±9	NA	±9
1.B.2.c Venting and flaring	±4	±4	±4	±4

Note: a) Uncertainty reported at 95% confidence limits estimated using Latin Hypercube analysis

Industrial Processes

An analysis of uncertainty was conducted using the methods recommended in the *Revised 1996 IPCC Guidelines* and random sampling techniques described in the IPCC *Good Practice* report (Latin Hypercube simulations). Uncertainty estimates of the components of each emission estimate (activity levels and emission factors) are based on expert judgement.

As the IPCC Tier 1 approach is not suitable for assessing uncertainty where approximately normal distribution assumptions cannot be sustained, an analysis was undertaken using Latin Hypercube techniques. These techniques can take into account asymmetric probability distributions associated with emission factors. For example, as the average emission factor for PFCs tends to the minimum limit that is understood to be technically feasible, the probability of the emission factor being lower than estimated is less than the probability of it being higher than estimated.

The Latin Hypercube analysis gave an uncertainty of ±5% (Table A.7.6). The uncertainty in the *industrial processes* subsectors ranged from ±4% to ±20%.

Table A.7.6: Quantified uncertainty values for key industrial processes subsectors using different techniques [a]

Source	Uncertainties and distribution		Emission factors – uncertainties and distributions								
	Production /use	Distribution	CO_2	Distribution	CH_4	Distribution	N_2O	Distribution	CF_4	Distribution	C_2F_6
Cement clinker	±5.00	Normal	±4.99	Normal	NA	NA	NA	NA	NA	NA	NA
Cement kiln dust	±7.01	Normal	±5.01	Normal	NA	NA	NA	NA	NA	NA	NA
Cement total organic carbon	NA	Normal	±5.00	Normal	NA	NA	NA	NA	NA	NA	NA
Commercial lime	±5.00	Normal	±4.99	Normal	NA	NA	NA	NA	NA	NA	NA
In-house lime	±4.01	Normal	±5.01	Normal	NA	NA	NA	NA	NA	NA	NA
Limestone use	±8.01	Normal	±5.00	Normal	NA	NA	NA	NA	NA	NA	NA
Dolomite use	±8.00	Normal	±4.99	Normal	NA	NA	NA	NA	NA	NA	NA
Soda ash production	±5.00	Normal	NA	Stoichiometry	NA	NA	NA	NA	NA	NA	NA
Soda ash use	±5.00	Normal	NA	Stoichiometry	NA	NA	NA	NA	NA	NA	NA
Magnesia	±5.00	Normal	±5.00	Normal	NA	NA	NA	NA	NA	NA	NA
Ammonia	±7.02	Normal	±5.00	Normal	NA	NA	NA	NA	NA	NA	NA
Nitric acid	±10.00	Normal	NA	NA	NA	NA	±9.99	Normal	NA	NA	NA
Nitrous oxide	±5.00	Normal	NA	NA	NA	NA	NA	NA	NA	NA	NA
Synthetic rutile	±5.00	Normal	±5.00	Normal	NA	NA	NA	NA	NA	NA	NA
Titanium dioxide	±20.00	Normal	±5.00	Normal	NA	NA	NA	NA	NA	NA	NA
Iron and steel	±5.01	Normal	±2.05	Triangular	±3.82	Triangular	±16.33	Triangular	NA	NA	NA
Hot briquetted iron	±5.00	Normal	±4.08	Triangular	±4.34	Triangular	±9.07	Triangular	NA	NA	NA
Aluminium	±5.01	Normal	±5.00	Normal	NA	NA	NA	NA	±16.22	Triangular	Function of CF_4
Total emissions	**26019.09**										
Aggregate uncertainty	±2.88										

Note: a) Uncertainty reported at 95% confidence limits assuming approximately normal distributions.
Source: Burnbank Consulting.

Agriculture

Livestock

An uncertainty analysis was undertaken for the *livestock* subsectors, addressing both CH_4 and N_2O emissions. Uncertainty distributions were developed for the inputs and the relationships used in the inventory. Where possible, uncertainties were based on quantitative analysis of probability distributions. Nevertheless, many of the distributions remain based on expert judgement. For many biological variables there are limits to the likely minimum and maximum values, and these constrain the distributions. For example, feed intakes have maximum values that are defined by the physiology of the livestock and the characteristics of the feed. Minimum values of feed intake relate to productivity and survival below which the industry wouldn't attempt to operate.

The estimated uncertainty in *enteric fermentation* emissions ranged from –5.1% to +5.9% (Table A.7.7) while the uncertainty in the *manure management* emissions was in the order of 10%. For total CO_2-e emissions from *livestock* the uncertainty was estimated to be –5.3% to +6.1%. The uncertainty in the reported cattle numbers was the most significant contributor to the overall uncertainty.

Recent measurements of methane emissions from sheep on high-quality pastures and cattle on grain diets in Australia show that the inventory procedure produces accurate estimates of methane emission rates. However, further work is needed to reduce uncertainties relating to feed intakes, methane emissions from sheep on low-quality pasture, methane emissions from beef cattle, and emissions from manure under a range of conditions.

Table A.7.7: Relative uncertainty in emission estimates for the livestock subsector [(a)]

Greenhouse gas source and sink categories	Uncertainty (%)	
	CH_4	N_2O
A. Enteric fermentation	–5.1 to +5.9	
B. Manure management	–9.8 to +11.1	–10.1 to +10.6

Note: a) Uncertainty reported at 95% confidence limits estimated using Monte Carlo analysis.

Other Agriculture

Estimates of uncertainties in the emissions for the *other agriculture* subsectors were determined using a Latin Hypercube analysis (Table A.7.8). Ideally, the probability distributions of the input variables would be determined by statistical analysis of real data. However, in the current analysis, suitable data sets were not available and the probability distributions were defined using expert judgement. The uncertainty in emission factors and associated parameters were determined from surveys of the published international literature, with emphasis on local Australian measurements. All variables are considered to be independent except fuel load and burning efficiency, which were positively correlated. The activity data with the greatest uncertainties are the areas of savanna fires. These are collated from a large and dispersed number of state government organisations with a wide range of data quality protocols.

There is large relative uncertainty in the emission estimates from all subcategories, including approximately –45 to +55% for methane in the *field burning of residues* subsector and –32% to +52% for nitrous oxide from *agricultural soils*. By way of comparison, estimates presented in the IPCC *Good Practice* guidelines indicate uncertainties of up to +55% and +500% for these sectors respectively as being likely to be typical. Significantly, in all subsectors, most of this uncertainty was derived from the uncertainties in emission factors and associated parameters. Uncertainty in the activity data was a relatively minor contributor to overall uncertainty. Partly this is a result of using three-year averages of annual activity data. The effect of averaging is to significantly reduce the sensitivity of the emissions estimates to uncertainty in the value for any individual year. In most cases, the uncertainty ranges are distributed asymmetrically around the estimates because, while emission factors usually have well constrained minima, their maxima are generally unconstrained.

Table A.7.8: Relative uncertainty in emission estimates for other agriculture subsectors [(a)]

Greenhouse gas source and sink categories	Uncertainty (%)	
	CH_4	N_2O
4. AGRICULTURE		
C. Rice cultivation	–19 to 22	
1. Irrigated	–19 to 22	
D. Agricultural soils		**–32 to 52**
1. Direct soil emissions		–30 to 42
2. Animal production		–49 to 120
3. Indirect		–61 to 107
E. Prescribed burning of savannas	**–52 to 112**	**–55 to 115**
F. Field Burning of agricultural residues	**–45 to 55**	**–43 to 50**
1. Cereals	–49 to 60	–47 to 59
2. Pulse	–59 to 85	–59 to 92
3. Tuber and root	NO	NO
4. Sugar cane	–45 to 60	–48 to 63
5. Other	–57 to 96	–57 to 99

Note: a) Uncertainty reported at 95% confidence limits estimated using Latin Hypercube

Land Use, Land Use Change and Forestry

Australia's National Carbon Accounting System (NCAS) uses Tier 3 methods (ecosystem model) of emissions estimation and an Approach 3 (full spatial enumeration) method of representing land (IPCC 2003). Unlike the Tier 1 and Tier 2 methods, Tier 3 uses complex modelling to estimate emissions in a way that fully represents both annual and spatial variability. Tier 3 and Approach 3 methods were chosen because the causes of most emissions in Australia (forest conversion) are from rare events (a small fraction of the forest estate). Tier 3 methods allow more complex forms of sensitivity and uncertainty analysis, and in concert with verification activities give an ability to identify any potential bias.

The verification processes focus on the detailed checking of land areas and modelled emissions estimates. That is, the testing of the NCAS results is typically against actual measures that have a 'certain' outcome. The benefits of verification by direct measurement are, first, the detailed data derived can be used to determine the model and land area estimation performances in general (e.g., by region, soil type, vegetation type) and in detail, for example, by carbon pool (e.g., litter, fast turnover soil organic matter). Second, having actual measures allows for continuous improvement whereby the verification data can subsequently be used to enhance calibration, which is then tested again in subsequent verification. This ensures a growing base of data for model calibration while also ensuring that calibration and verification data remain independent.

Extensive independent verification programs of the land cover change and plantation mapping via remote sensing techniques have been continuously applied throughout the time-series updates. The methods applied to verification of the land cover change results are published in the NCAS Technical Reports (Lowell et al., 2003 and Jones et al., 2004) and in peer review literature (Lowell et al., 2005). This program initially relied on verification against historic air photographs, and more recently, by using very high resolution satellite data (1m). The verification of the plantations mapping (MBAC Consulting *in prep*.) was based on on-site field inspection. This alternative approach was used because it was able to provide a definite date of planting (from signage or company records) and could accurately provide parameters such as species, stocking rate, condition etc. that could not be derived with certainty from remote techniques. This program was based on several hundred sites throughout Australia, selected to be representative of geographic regions, plantation types and plantation ages.

The direct measurement of forest biomass is rare, and as destructive sampling is required, no time-series growth data based on whole mass measurement is available. However, through the use of allometric equations from measurable forest stand parameters of basal area, height etc. it is possible to model total stand biomass. As these measures are widely used in forest inventory, there is a wealth of industry data available as both single point in time and time-series (permanent plot) measurements against which growth and biomass estimates have been verified. In addition, research site data comparisons and select whole-stand mass measurements have been applied. The benefits of comparisons with research data has been that additional to commonly available stand biomass estimates are data on site conditions and management. Because of the cost and logistical difficulty in actually measuring total stand biomass, the approach taken was to destructively sample and weigh forest plots of a single species across a productivity gradient (Ximines et al., 2005). This approach could then test both the biomass predictions and replication of the gradient in forest productivity and carrying capacity by model estimates.

Much like the verification activities for forest biomass, a tiered approach was applied to the verification of modelled soil carbon change estimates. Most geographically widespread and representative data were taken from paired site samples, before and after land use change. The change in total soil organic carbon was compared to modelled estimates. Soil fractionations were also completed to test the model performance in predicting turnover in various soil carbon pools. Wherever possible, models were also compared to research site data (Skjemstad and Spouncer 2002). This again had the benefit of multiple pool, time-series measurements for comparison, along with the recorded impacts of detailed site condition and management.

The methods of uncertainty analysis described by the IPCC Good Practice Guidance 2003 are typically designed for Tier 1 and Tier 2 emissions factor based approaches. More complex methods for dealing with potential error propagation and inter-correlation of parameter uncertainties needs to be applied to the process model forms of inventory used in Tier 3. However, the fundamental approach of using *Monte Carlo* forms of analysis for both sensitivity and uncertainty analysis remains relevant and are applied.

The sensitivity and uncertainty analysis of the NCAS are used to determine:

- that the best estimate (most likely outcome) is not subject to bias;
- the parameter sensitivity, in order to understand the drivers of uncertainty and guide improvement programs and verification priorities; and
- to determine the probability distribution of possible outcomes.

The sensitivity and uncertainty analyses undertaken are described in detail in each of the methods Appendices 7.B, 7.C and 7.D. To enable these analyses a *Monte Carlo* analysis capability has been integrated into the modelling framework and is routinely applied.

Uncertainty analyses using *Monte Carlo* techniques are also supplemented by the determination of accuracies of spatial data through verification programs. Verification can also be used to identify if there is any potential bias in the spatial inputs to the emissions modelling.

Table A.7.9: Estimation of uncertainties in components of the land use change and forestry subsectors (UNFCCC accounting)

Subsector	Uncertainty Level
Forest land remaining forest (CO_2, CH_4, N_2O)	±30, -45 +77,-53 +93
Grassland conversion (CO_2, CH_4, N_2O)	±10, 20
Cropland conversion (CO_2, CH_4, N_2O)	±10, 20

Waste

Estimates for uncertainty for emissions from solid waste disposal were estimated by Burnbank Consulting. The full implications of non-linearities in the solid waste methodology are still to be satisfactorily explored, however, and further work into the solid waste estimates are likely in future.

Table A.7.10: Relative uncertainty in emission estimates for key waste subsectors

Greenhouse gas source and sink categories	Uncertainty (%)				
	CH_4	N_2O	NO_x	CO	NMVOC
6. Waste					
A. Solid waste disposal on land [(a)]	± 3.25%	NA	NA	NA	NA
B. Wastewater	± 50%				
C. Incineration	NA				

Source: a) Burnbank Consulting 2006

Table A.7.11: Specific distributions, parameters and results – Solid Waste

Variable	Distribution and parameters	2sd	M-2sd	M+2sd	2sd/M	M-/2.5 perc	M+/97.5 perc
Emission Generated / 2004 – ACT		0.70	12.85	14.26	5.19%	1.00	1.00
Emission Generated / 2004 – NSW		16.55	277.85	310.95	5.62%	1.00	1.00
Emission Generated / 2004 – NT		0.26	4.63	5.14	5.26%	1.00	1.00
Emission Generated / 2004 – QLD		7.84	163.61	179.30	4.57%	1.00	1.00
Emission Generated / 2004 – SA		4.92	45.95	55.79	9.68%	1.00	1.00
Emission Generated / 2004 – TAS		1.72	15.75	19.19	9.84%	1.00	1.01
Emission Generated / 2004 – VIC		16.57	163.14	196.29	9.22%	1.00	1.00
Emission Generated / 2004 – WA		8.94	78.13	96.01	10.27%	1.00	1.00
Emissions Generated – Australia		26.59	792.84	846.03	3.25%	1.00	1.00
DOCfood	Normal (0.15,0.05*0.15)	0.01	0.13	0.16	10.00%	1.00	1.00
DOCpaper&text / DOCpaper&text	Normal (0.4,0.05*0.4)	0.04	0.36	0.44	10.00%	1.00	1.00
DOgGarden / DOgGarden	Normal (0.17,0.05*0.17)	0.02	0.15	0.19	10.00%	1.00	1.00
DOCwood / DOCwood	Normal (0.43,0.05*0.43)	0.04	0.39	0.47	10.00%	1.00	1.00
Standard Mix – MSW- food	Triang (0.15,0.21,0.27)	0.05	0.16	0.26	23.33%	0.99	1.01
Standard Mix – MSW-p&t / Standard Mix – MSW-p&t	Triang (0.07,0.11,0.15)	0.03	0.08	0.14	29.69%	0.98	1.01
Standard Mix – MSW-gg / Standard Mix – MSW-gg	Triang (0.14,0.19,0.24)	0.04	0.15	0.23	21.49%	0.99	1.01
Standard Mix – MSW-wood / Standard Mix – MSW-wood	Triang (0.02,0.03,0.04)	0.01	0.02	0.04	27.22%	0.98	1.01
Standard Mix – MSW-other / Standard Mix – MSW-other	Triang (0.38,0.46,0.54)	0.07	0.39	0.53	14.20%	0.99	1.01
DDOC	Normal(0.5,0.1*0.5)	0.10	0.40	0.60	20.00%	1.00	1.00
Half-life	Triang(3,4,6)	1.25	3.09	5.58	28.78%	0.94	0.99
Half-life	Triang(10,12,14)	1.63	10.37	13.63	13.61%	0.99	1.01

Variable	Distribution and parameters	2sd	M-2sd	M+2sd	2sd/M	M-/2.5 perc	M+/97.5 perc
Half-life	Triang(6,7,9)	1.25	6.09	8.58	17.01%	0.97	1.00
Half-life	Triang(17,23,35)	7.48	17.52	32.48	29.93%	0.94	0.99
Time Delay	Normal(7,0.28*7)	3.92	3.08	10.92	55.99%	0.98	1.01
Half-life	Triang(3,4,6)	1.25	3.09	5.58	28.78%	0.94	0.99
Half-life	Triang(10,12,14)	1.63	10.37	13.63	13.61%	0.99	1.01
Half-life	Triang(6,7,9)	1.25	6.09	8.58	17.01%	0.97	1.00
Half-life	Triang(17,23,35)	7.48	17.52	32.48	29.93%	0.94	0.99
Time Delay	Normal(7,0.28*7)	3.92	3.08	10.92	56.00%	0.98	1.01
Half-life	Triang(1,2,4)	1.25	1.09	3.58	53.45%	0.85	0.99
Half-life	Triang(8,10,12)	1.63	8.37	11.63	16.33%	0.99	1.01
Half-life	Triang(3,4,5)	0.82	3.18	4.82	20.41%	0.99	1.01
Half-life	Triang(14,20,23)	3.74	15.26	22.74	19.69%	1.01	1.03
Time Delay	Normal(7,0.28*7)	3.92	3.08	10.92	55.99%	0.98	1.01
Half-life	Triang(1,2,4)	1.25	1.09	3.58	53.45%	0.85	0.99
Half-life	Triang(8,10,12)	1.63	8.37	11.63	16.33%	0.99	1.01
Half-life	Triang(3,4,5)	0.82	3.18	4.82	20.41%	0.99	1.01
Half-life	Triang(14,20,23)	3.74	15.26	22.74	19.69%	1.01	1.03
Time Delay	Normal(7,0.28*7)	3.92	3.08	10.92	56.00%	0.98	1.01
Half-life	Triang(9,12,14)	2.05	9.61	13.72	17.61%	1.00	1.02
Half-life	Triang(14,17,23)	3.74	14.26	21.74	20.79%	0.96	1.00
Half-life	Triang(12,14,17)	2.05	12.28	16.39	14.34%	0.98	1.00
Half-life	Triang(23,35,69)	19.48	22.85	61.82	46.02%	0.86	0.99
Time Delay	Normal(7,0.28*7)	3.92	3.08	10.92	55.99%	0.98	1.01
Half-life	Triang(9,12,14)	2.05	9.61	13.72	17.61%	1.00	1.02
Half-life	Triang(14,17,23)	3.74	14.26	21.74	20.79%	0.96	1.00
Half-life	Triang(12,14,17)	2.05	12.28	16.39	14.34%	0.98	1.00
Half-life	Triang(23,35,69)	19.48	22.85	61.82	46.02%	0.86	0.99
Time Delay	Normal(7,0.28*7)	3.92	3.08	10.92	56.00%	0.98	1.01
Half-life	Triang(9,12,14)	2.05	9.61	13.72	17.61%	1.00	1.02
Half-life	Triang(14,17,23)	3.74	14.26	21.74	20.79%	0.96	1.00
Half-life	Triang(12,14,17)	2.05	12.28	16.39	14.34%	0.98	1.00
Half-life	Triang(23,35,69)	19.48	22.85	61.82	46.02%	0.86	0.99
Time Delay	Normal(7,0.28*7)	3.92	3.08	10.92	55.99%	0.98	1.01
Half-life	Triang(9,12,14)	2.05	9.61	13.72	17.61%	1.00	1.02
Half-life	Triang(14,17,23)	3.74	14.26	21.74	20.79%	0.96	1.00
Half-life	Triang(12,14,17)	2.05	12.28	16.39	14.34%	0.98	1.00
Half-life	Triang(23,35,69)	19.48	22.85	61.82	46.02%	0.86	0.99
Time Delay	Normal(7,0.28*7)	3.92	3.08	10.92	55.99%	0.98	1.01

Source: Burnbank Consulting

Annex 8: Description of Australia's National Registry

The description of Australia's national registry follows the reporting guidance set down in Decision 15/CMP.1, part II (Reporting of supplementary information under Article 7, paragraph 1, E. National registries) under the Kyoto Protocol.

Name and contact information of the registry administrator designated by the Party to maintain the national registry

Shaun Calvert
Registry Administrator
Emissions Trading Division
Department of Climate Change
GPO Box 854
CANBERRA ACT 2601
Tel: +61 2 6275 9689
Email: shaun.calvert@climatechange.gov.au

Names of any other party with which the party cooperates by maintaining their respective registries in a consolidated system

The Australian National Registry is not operated in a consolidated system with any other party's registry.

A description of the database structure and capacity of the national registry

The following is an extract from the Software Specifications for the Australian National Registry – Please note that the AUKPNR refers to the Australian National Registry.

SQL Server Database

The AUKPNR (Australian Kyoto Protocol National Registry) database is a Microsoft SQL Server 2005 database. The vast majority of the system's business logic is contained in stored procedures, views, and functions contained in the database instance. The AUKPNR has a complex system of metadata used to control many aspects of the system's configuration. Much of this metadata can be managed through the Registry Management Application (RMA) tool, from a desktop with network access to the database hosting environment.

SQL Server 2005 Reporting Services

SQL Server 2005 Reporting Services (SSRS) runs on the IIS Web Server (described below) and is configured with data sources that point to the AUKPNR SQL Server 2005 database. SSRS provides reporting functionality to the AUKPNR web application. The report content for the web application reports is controlled through metadata, which is managed through the Registry Management Application (RMA) tool, from a desktop with network access to the database hosting environment.

In addition to the AUKPNR web application reports, SSRS hosts two administrative reports that are available through the RMA. These are the CPR Level report and the Kyoto report for submission to the UN. The CPR Level report allows the Registry Administrator to see the status of the registry with respect to the required commitment period reserve. The commitment period reserve is the minimum quantity of Kyoto units that the registry must hold at any given time in order to limit the scope of non-compliance. The Kyoto report provides automatic generation of the required annual reports for Kyoto parties (COP 10). The report is generated using the standard electronic format (SEF) of submission under Article 7.1 of the Kyoto Protocol. SSRS also provides an ad-hoc reporting capability intended for administrators that is accessible through the RMA tool.

IIS Web Server

The AUKPNR is primarily accessed through a web application. The web server used is Microsoft IIS, which communicates with the ColdFusion 8 application server.

ColdFusion MX 8 Application Server

The AUKPNR web application is developed in ColdFusion 8. The files comprising the AUKPNR ColdFusion application are distributed as a file tree. The ColdFusion application server runs as a service on the designated machine also hosting the IIS web server.

Hardware Specifications

The AUKPNR application will be deployed to the web hosting environment provided by AussieHQ. It is expected that each instance (production, standby, dev/test, etc.) of the AUKPNR application will be deployed in a clustered Microsoft SQL 2005 environment where each node meets the Microsoft recommended specifications of a 1 GHz Pentium III-compatible processor or higher and 1 GB or more of RAM. If deployed in an Active/Active cluster each node must be able to provide full failover of another node's SQL instance. Hardware which is to provide load balancing for the web application must support sticky sessions. Each web server must meet the recommended specification of a 1 GHz Pentium III-compatible processor and have 1.5 GB or more of RAM. The web servers will be used to run IIS, ColdFusion, and the ITL related web services.

Software Specifications

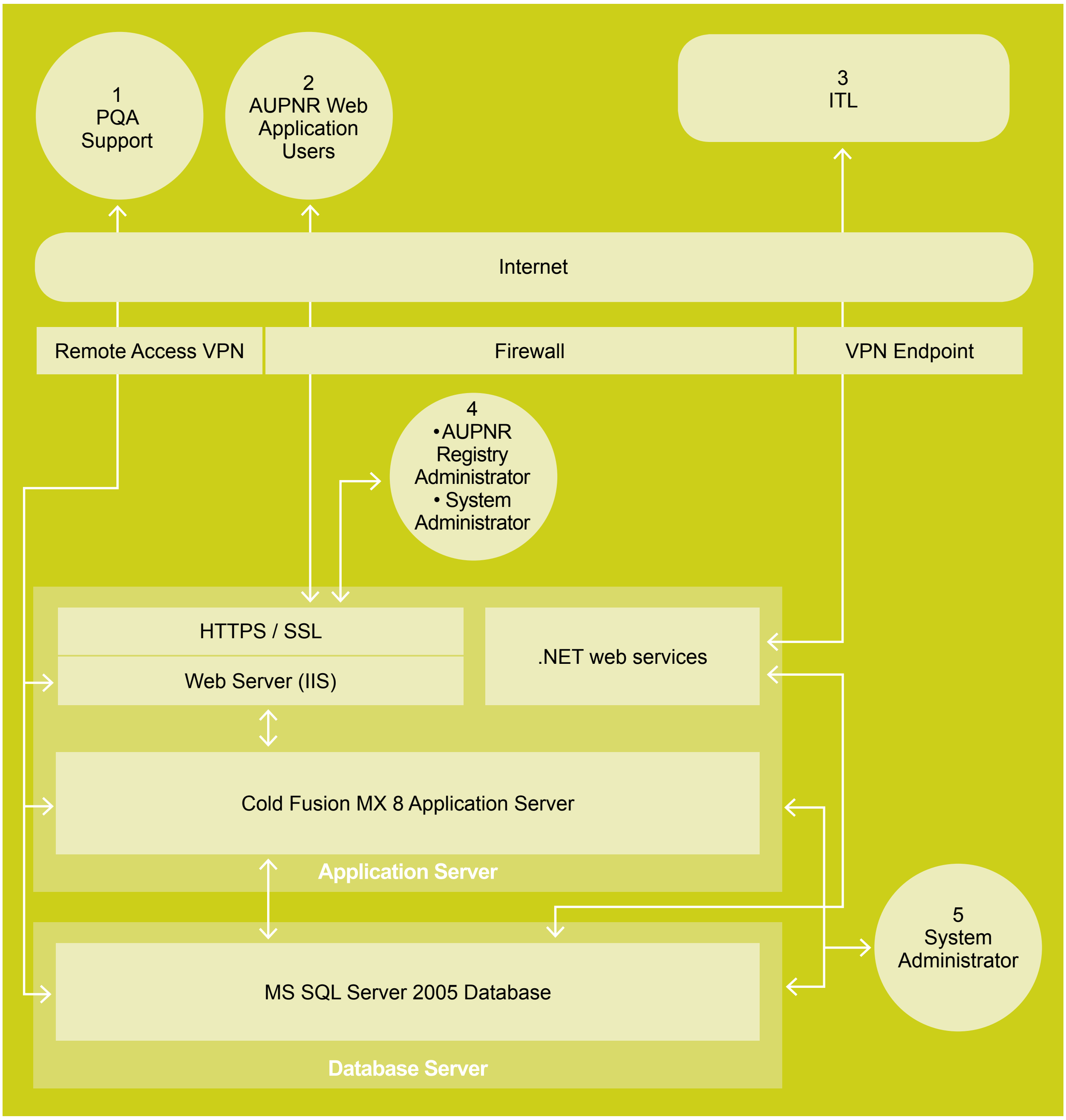
The AUKPNR consists of the following software components.

- Internet Information Services (IIS) 6.0 or higher
- ColdFusion 8
- SQL Server 2005
- SQL Server 2005 Reporting Services
- Microsoft Messaging Queue components
- NET 2.0 Framework
- NET Web Services (C#)
- NET ITLListenerService (C#)
- Registry Management Application (RMA)

Communications with the UNFCCC International Transaction log are managed by software components deployed in IIS.

Network Specifications

Figure A.8.1: AUKPNR Logical Network Topology (Production Environment)



A description of how the national registry conforms to the technical standards for the purpose of ensuring the accurate, transparent and efficient exchange of data between national registries, the clean development registry and the independent transaction log, including (i) to (vi) below

The Australian National Registry system contains the functionality to perform issuance, conversion, external transfer, (voluntary) cancellation, retirement and Reconciliation processes using XML messages and web-services as specified in V1.1 of the UN DES document.

In addition, it also contains: 24 Hour Clean-up, Transaction Status enquiry, Time Synchronisation, Data Logging requirements (including, Transaction Log, Reconciliation Log, Internal Audit Log and Message Archive) and the different identifier formats as specified in the UN DES document.

(i) A description of the formats used in the national registry for account numbers, serial numbers for ERUs, CERs, AAUs, and RMUs, including project identifiers and transaction numbers

The formats used in the Australian National Registry are as specified in the DES 1.1 Annex F — Definition of identifiers.

(ii) A list, and the electronic format, of the information transmitted electronically when transferring ERUs, CERs, AAUs, and/or RMUs to other registries

The formats used in the Australian National Registry to transmit information to other registries are specified in the DES 1.1.

(iii) A list, and the electronic format, of the information transmitted electronically when acquiring ERUs, CERs, AAUs, and/or RMUs from other national registries or the CDM registry

The formats used in the Australian National Registry to acknowledge the messages transmitted to other registries are specified in the DES 1.1.

(iv) A list, and the electronic format, of the information transmitted electronically from the national registry to the independent transaction log when issuing, transferring, acquiring, cancelling and retiring ERUs, CERs, AAUs, and/or RMUs

Information will be transmitted to the ITL in the message formats specified in the UN DES Version 1.1.

(v) An explanation of the procedures employed in the national registry to prevent discrepancies in the issuance, transfer, acquisition, cancellation and retirement of ERUs, CERs, AAUs, and/or RMUs

In order to minimise discrepancies between the Australian National Registry and the ITL , the following approach has been adopted:

- Communications between the registry and the ITL are via web-services using XML messages — as specified in the DES 1.1. These web services, XML message format and the processing sequence are checked by the registry to ensure the compliance with DES 1.1;
- The registry validates data entries against the formats of information as specified in Annex F of the DES 1.1;
- The registry implements internal controls in accordance with the checks performed by the ITL — as documented in Annex E of the DES 1.1.
- All units that are involved in a transaction shall be earmarked internally within the registry; thereby preventing the units from being involved in another transaction until a response has been received from the ITL and the current transaction has been completed;
- The web service that sends the message to the ITL for processing will ensure that a message received acknowledgement is received from the ITL before completing the submission of the message. Where no acknowledgement message has been received following a number of retries, the web-service would terminate the submission and roll back any changes made to the unit blocks that were involved;
- Where a 24 hour clean-up message is received from the ITL, the existing web service would rolling back any pending transactions and the units that were involved, thereby preventing any discrepancies in the unit blocks between the registry and the ITL;
- Finally, if an unforeseen failure were to occur, the data discrepancies between our registry and the ITL can be corrected via a manual intervention function within our registry. Following this, reconciliation will be performed to validate that the data is in sync between the registry and the ITL. If a discrepancy reoccurs in the registry, the following measures will be applied:

  Identification, and registration of the discrepancy;

  – Identification of the source of the discrepancy (DES, registry specifications, erroneous programming code);

ANNEXES

– Elaboration of a resolution plan and testing plan;

– Correction and testing of the software;

– Release and deployment of the corrected software.

(vi) An overview of the security measures employed in the national registry to deter unauthorised manipulations and minimize operator error

For the Australian National Registry the following security measures have been implemented. In addition the Department of Climate Change is undertaking an external security review of the Registry to ascertain key security risks and to ensure compliance with the Australian Government Authentication Framework (AGAF).

Identification and Authentication

Access to the registry is allowed via a personal username and password – allocated as apart of a Registration process performed by the Department5 of Climate Change.

Access control

Users of the AUKPNR are divided into three security groups. These groups control the access and security at the application level. A user's login information is assigned to a user group, which determines what the user can and cannot do within the system.

The Registry supports the following user groups:

System Administrator

The System Administrator group has global authority throughout the Registry. This user is responsible not only for the day-to-day functionality of the system, but also for administrative support. This may include user management, managing and setting batch jobs, and reviewing audit and transaction logs. This person is responsible for maintaining the technical environment of the Australian National Registry, including all hardware, software, and network concerns. This includes scheduling regular data backups and restoring data in the event of a system.

Program Manager/Australian National Registry Administrator

The registry administrator, or program manager role, represents the person or persons responsible for all policy-based operations of the registry. This person will have access to all functionality that can be provided through the Registry interfaces, but will not have direct access to the database tables and the web application server. Should the need arise to access these resources, the registry administrator must coordinate with the system administrator. The registry administrator is responsible for such policy-based activities as account creation, approval of forwarding instructions, monitoring notifications and messages logs, and coordinating with the ITL for reconciliations.

Industry User/Account Holders

Provisions are made for account holders to have access to the registry web application. The Registry provides the capability to create users with restricted levels of access by which users would only be permitted to access data relevant to their own holdings and activities. These permissions can be configured using the system administration functions.

Access protection

In order to prevent operator errors, our registry software incorporates validations on all user inputs to ensure that only valid details are submitted for processing; The registry displays confirmation of user input to help the user to spot any errors that had been made and implements an internal approval process (input of relevant password details) for secondary approval for relevant operations before submitting the details to the ITL for processing.

A list of the information publicly accessible through the user interface to the national registry

The following Public Reports are available through the user interface – no logon procedures are required to view these reports:

- A list of all Accounts held within the National Registry.
- A list of all unit transactions made in the past Calendar years.
- A list of all JI projects – including details of such projects.

A summary report of total unit holdings and transactions for the past calendar years.

An explanation of how to access information through the user interface of the national registry

Access to the Australian National Registry will be available through the internet – and will have 2 main components: – Access to Public Information (through a "tab" on the Web application), or designated Users can Logon to the system using their allocated Usernames and Passwords.

Measures to safeguard, maintain and recover data in the event of a disaster

The servers (main and backup sites) that host the Australian National Registry are in physically secure data centres fitted with secure access control systems. All data centres are fitted with smoke detection and automatic fire suppression systems. Anti-virus software upgrades are downloaded and installed autonomously on to the servers as soon as they are released.

A full backup of each database and an hourly transaction log backup during business hours takes place every day with the back-up media being held at an off site third party secure storage facility. The database content will also be replicated at a minimum of 30 minute intervals to a secondary data centre location when the clustering environment is implemented. This will serve as the hosting platform for Disaster Recovery.

In the event of a disaster a decision will be taken (between the Department of Climate Change and the IT contract supplier) to invoke disaster recovery. This will involve:

- Stopping all transactions to the main platform.
- Ensuring that the committed transactions are replicated to the DR site.
- Switching all external interaction with the main site over to the secondary location.

The IT contract supplier is committed to resuming the service for the Department operators within 8 hours of the decision being made.

Results of previous test procedures

Australia's independent assessment report is available from the UNFCCC website http://unfccc.int/resource/docs/2008/iar/aus01.pdf.

Annex 9: Glossary

Activity	A process that generates greenhouse gas emissions or uptake. In some sectors it refers to the level of production or manufacture for a given process or category.
Afforestation	The direct human-induced conversion of land that has not been forested land for a period of at least 50 years to forested land through planting, seeding and/or human-induced promotion of natural seed sources.
Automotive Diesel Oil (ADO)	A middle distillate petroleum product used as a fuel in high-speed diesel engines. It is mostly consumed in the road and rail transport sectors and agriculture, mining and construction sectors.
Anaerobic	A process relying on bacteria that can live without oxygen.
Anthropogenic	Resulting from human activities. In the inventory, *anthropogenic emissions* are distinguished from *natural emissions*.
Bagasse	The fibrous residue of the sugar cane milling process which is used as a fuel in sugar mills.
Briquettes	A composition fuel manufactured from brown coal, which is crushed, dried and moulded under high pressure without the addition of binders.
Clinker	An intermediate product from which cement is made.
Coke	The solid product obtained from the carbonisation of suitable types of coal at high temperature. It is low in moisture and volatile matter and is mainly used in the iron and steel industry as an energy source and chemical agent. Semi-coke or coke obtained by carbonisation at low temperatures is included in this category.
Deforestation	The direct human-induced conversion of forested land to non-forested land.
Dolomite	A naturally occurring mineral ($CaCO_3$.mg CO_3) which can be used to produce lime, iron and steel.
Emission Factor	The quantity of greenhouse gases emitted per unit of some specified activity.
Emission Intensity	The total emissions divided by the total energy content of the fuels or the total energy used in a sector. The overall emissions intensity of coal used in Australia, for example, is determined by the quantity and emission factors for each of the many types and grades of coal used.
Enteric Fermentation	The process in animals by which gases, including methane, are produced as a by-product of microbial fermentation associated with digestion of feed.
Feedlot	A confined yard area with watering and feeding facilities where livestock (mainly beef cattle) are completely handfed for the purpose of production. It does not include the feeding or penning of cattle for weaning, dipping or similar husbandry purposes or for drought or other emergency feeding, or at a slaughtering place or in recognised saleyards.
Feedstocks	Products derived from crude oil and destined for further processing in the refining industry, other than blending. Products include those imported for refinery intake and those returned from the petrochemical industry to the refining industry, such as naphtha.
Flaring	The process of combusting unwanted or excess gases at a crude oil or gas production site, a gas processing plant or an oil refinery.
Forest	Parties are required to select single minimum values for land area, tree crown cover and tree height. The NCAS when assessing Australia's land use change emissions uses a criteria of 20% tree crown cover, 2 metre minimum tree height, and a minimum of 0.2 hectares in land area for inclusion. These minimum criteria are within the ranges outlined in the Marrakech Accords.
Fuel Oil	Covers all residual (heavy) fuel oils including those obtained by blending.

Fugitive Emissions	Generally deliberate but not fully controlled emissions that typically result from leaks, including those from pump seals, pipe flanges and valve stems. Fugitive emissions also include methane emitted from coal mine seams. During petroleum storage tank filling, venting loss of vapour is a fugitive emission.
Global Warming Potential (GWP)	Represents the relative warming effect of a unit mass of a gas compared with the same mass of CO_2 over a specific period. Multiplying the actual amount of gas emitted by the GWP gives the CO_2-equivalent emissions.
Greenhouse Gases	Gases that contribute to global warming, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) and sulphur hexafluoride (SF_6). In addition, the photochemically important gases—NMVOCs, oxides of nitrogen (NO_x) and carbon monoxide (CO)—are also considered. NMVOC, NO_x and CO are not direct greenhouse gases. However, they contribute indirectly to the greenhouse effect by influencing the rate at which ozone and other greenhouse gases are produced and destroyed in the atmosphere.
Hydrofluorocarbons (HFCs)	Used as substitutes for chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs).
Industrial Diesel Fuel (IDF)	A petroleum product primarily consumed in the rail and water transport sectors.
Intergovernmental Panel on Climate Change (IPCC)	The international body responsible for assessing the state of knowledge about climate change. The IPCC increases international awareness of climate change science and provides guidance to the international community on issues related to climate change response.
Key Category	The IPCC *Good Practice* report (IPCC 2000) introduces the concept of key categories for prioritising the inventory development process. A key category has a significant influence on a country's total inventory of direct greenhouse gases in terms of absolute level of emissions, the trend in emissions, or both. The tier 1 key category analysis identifies categories that contribute to 95% of the total emissions or 95% of the trend of the inventory in absolute terms. Tier 2 analysis identified categories that contribute to 90% of total uncertainty in the inventory.
Kyoto Protocol	The Kyoto Protocol to the convention on climate change was developed through the UNFCCC negotiating process. The protocol was negotiated in Kyoto, Japan, in 1997. It sets binding greenhouse gas emissions targets for UNFCCC developed country parties that ratify the agreement.
Liquefied Petroleum Gas (LPG)	A light hydrocarbon fraction of the paraffin series. It occurs naturally, associated with crude oil and natural gas in many oil and gas deposits, and is also produced in the course of petroleum refinery processes. LPG consists of propane (C_3H_8) and butane (C_4H_{10}), or a mixture of the two. In Australia, LPG as marketed contains more propane than butane.
Lubricants	Hydrocarbons that are rich in paraffin and not used as fuels. They are obtained by vacuum distillation of oil residues.
Military Transport	Includes all activity by military land vehicles, aircraft and ships.
National Carbon Accounting System	An integrated suite of models that estimate emissions from biomass, litter and soil carbon in a geographic information system framework with the support of resource inventories, field studies and remote sensing to assess land cover change.
Natural Gas	Consists primarily of methane (around 9%, with traces of other gaseous hydrocarbons, as well as nitrogen and carbon dioxide) occurring naturally in underground deposits. As a transport fuel it is generally used in compressed or liquefied form.

Navigation	All civilian (non-military) marine transport of passengers and freight. Domestic marine transport consists of coastal shipping (freight and cruises), interstate and urban ferry services, commercial fishing, and small pleasure craft movements. International shipping using marine bunker fuel purchased in Australia is reported but not included in the national inventory emissions total.
NMVOC	Non-methane volatile organic compounds such as alkanes, alkenes and alkynes, aromatic compounds and carbonyls that are gases at standard temperature and pressure (i.e. Boiling points below 200°C) and normally 10 or less carbon atoms per molecule; excludes chlorofluorocarbons (CFCs).
PFC	Perfluorocarbons, chemical compounds containing carbon and fluorine atoms only (e.g. CF_4 and C_2F_6).
Prescribed Burning	The intentional burning of forests to reduce the amount of combustible material present and thereby reduce the risk of wildfires. In Australia this is known as 'fuel reduction burning'.
Process Emission	The gas released as a result of chemical or physical transformation of materials from one form to another.
Reference approach	A 'top–down' tier 1 IPCC methodology for estimating CO_2 emissions from fuel combustion activities (1.a).
Reforestation	The direct human-induced conversion of non-forested land to forested land through planting, seeding and/or human-induced promotion of natural seed sources, on land that was forested but that has been converted to non-forested land. For the first commitment period, reforestation activities will be limited to reforestation occurring on those lands that did not contain forest 31 December 1989.
Savanna	A grassland ecosystem with associated woody shrub and/or tree overstorey, the latter with projective foliage cover comprising less than 30% of the area. The IPCC category of 'savanna' is extended to include all non-agricultural grassland ecosystem types that experience burning in Australia.
Sink	Any process or activity that removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas from the atmosphere. It includes chemical transformations in the atmosphere and uptake of the gases from the atmosphere by the underlying land and ocean surfaces.
Solid Waste	Waste from various activities; includes *municipal solid waste* (waste from domestic premises and council activities largely associated with servicing residential areas; such as street sweepings, street tree lopping, parks and gardens and litter bins), *commercial and industrial waste*, and *building and demolition waste*.
Solvent	An organic liquid used for cleaning or to dissolve materials.
Source	Any process or activity that releases a greenhouse gas, an aerosol or a precursor of a greenhouse gas into the atmosphere.
Tier	The IPCC methods for estimating emissions and removals are divided into 'tiers' encompassing different levels of activity and technology detail. Tier 1 methods are generally very simple (activity multiplied by default emissions factor) and require less data and expertise than the most complicated tier 3 methods. Tier 2 and 3 methods generally require more detailed country-specific information on things such as technology type or livestock characteristics. The concept of tiers is also used to describe different levels of key source analysis, uncertainty analysis, and quality assurance and quality control activities.
Town Gas	Includes all manufactured gases that are typically reticulated to consumers, including synthetic natural gas, reformed natural gas, tempered LPG, and tempered natural gas.

Uncertainty	Uncertainty is a parameter associated with the result of measurement that characterises the dispersion of values that could be reasonably attributed to the measured quantity (e.g. The sample variance or coefficient of variation). In general inventory terms, uncertainty refers to the lack of certainty (in inventory components) resulting from any causal factor such as unidentified sources and sinks, lack of transparency etc.
United Nations Framework Convention on Climate Change (UNFCCC)	Entered into force in 1994. Parties to the convention have agreed to work towards achieving the ultimate aim of stabilising 'greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'.
Venting	The process of releasing gas into the atmosphere without combustion. This may be done either at the production site or at the refinery or stripping plants. It is done to dispose of non-commercial gas or to relieve system pressure.

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