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Australian National Greenhouse Accounts

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6.1 Emission trends

The net emissions from the *land use, land use change and forestry* (LULUCF) sector were -5.63 Mt CO_2-e in 2013.

Table 6.1 Land Use, Land Use Change and Forestry net CO_2-e emissions, 2013

Greenhouse gas source and sink categories	CO_2-e emission (Gg)			
	CO_2	CH_4	N_2O	Total
4 Land use, land use change and forestry	-7,425	1,525	1,941	-3,959
A. Forest land	-38,738	542	322	-37,873
A.1 Forest land remaining forest land	-25,799	508	125	-25,166
A.2 Land converted to forest land	-12,932	27	198	-12,707
B. Cropland	1,318	106	46	1,470
B.1 Cropland remaining cropland	-2,216	-	-	-2,216
B.2 Land converted to cropland	3,534	106	46	3,686
C. Grassland	33,836	876	1,573	36,286
C.1 Grassland remaining grassland	-2,685	IE	1,113	-1,572
C.2 Land converted to grassland	36,521	876	460	37,857
D. Wetlands	NE	NE	NE	0
E. Settlements	NE	NE	NE	0
F. Other land	NO,NA	NO,NA	NO,NA	0
G. Harvested wood products	-3,842	-	-	-3,842

Notes: NE = not estimated (voluntary reporting categories), IE = included elsewhere (reported in the agriculture sector), NA = not applicable, NO = not occurring.

Forest land (4A) comprises emissions and removals from plantations, harvested native forests and other native forests. Emissions from *fuelwood consumption* and biomass burning in forests (*controlled burning* and *wildfire*) are also included as are the removals associated with post fire recovery. The *forest land* category is estimated to have constituted a net sink of 37.9 Mt CO_2-e in 2013.

Cropland (4B) comprises emissions and removals from cropland remaining c*ropland and forest land converted to cropland*. The *cropland* subsector is estimated to have constituted a net source of 1.5 Mt CO_2-e in 2013.

Grassland (4C) comprises emissions and removals from *grassland remaining grassland* and *forest land converted to grassland*. The *grassland* subsector is estimated to have constituted a net source of 36.3 Mt CO_2-e in 2013.

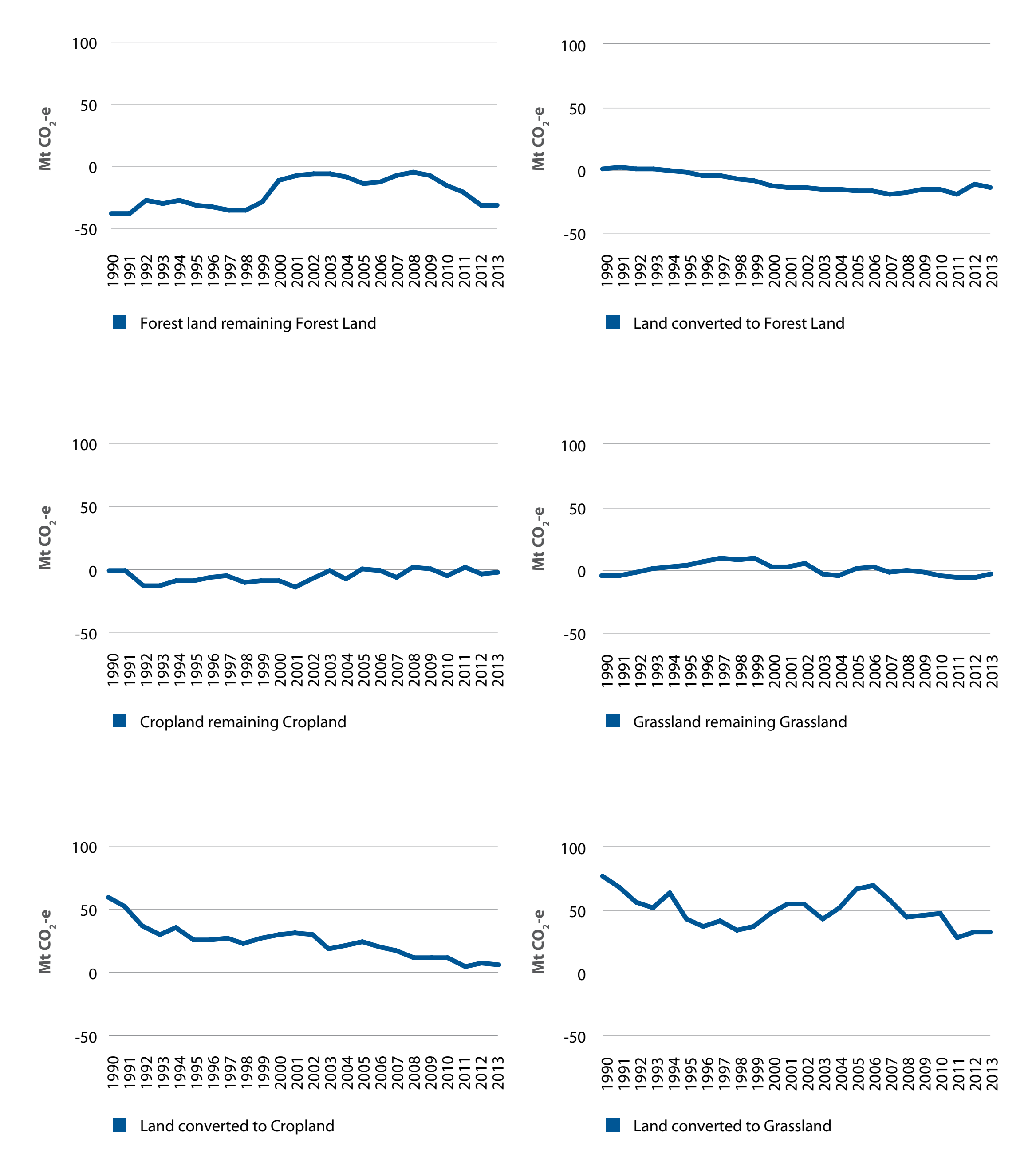
Forest land converted to cropland and *forest land converted to grassland* were a net source of 41.5 Mt CO_2-e in 2013.

Harvested wood products are not reported in the *forest land* category and carbon stocks are transferred to 4G *harvested wood products*. As the reporting tables do not account for transfers of carbon stocks between forests and harvested wood products, this leads to an apparent, but not real, emission from *forest land* and a 3.8 Mt CO_2 'sink' in *harvested wood products*.

By 2013, the net *LULUCF* emissions had decreased from 103.3 Mt CO_2-e in 1990 to -4.0 Mt CO_2-e in 2013 (Figure 6.1).

The underlying trend of declining emissions from *LULUCF* since 1990 has been mainly driven by the decline in emissions from *forest land converted to cropland and grassland* (Figure 6.1). Change in *LULUCF* emissions from year-to-year are affected by other factors, principally natural disturbances such as wildfire and climate.

Figure 6.1 Net CO_2-e emissions from Land Use, Land Use Change and Forestry, by sub-sector, 1990–2013

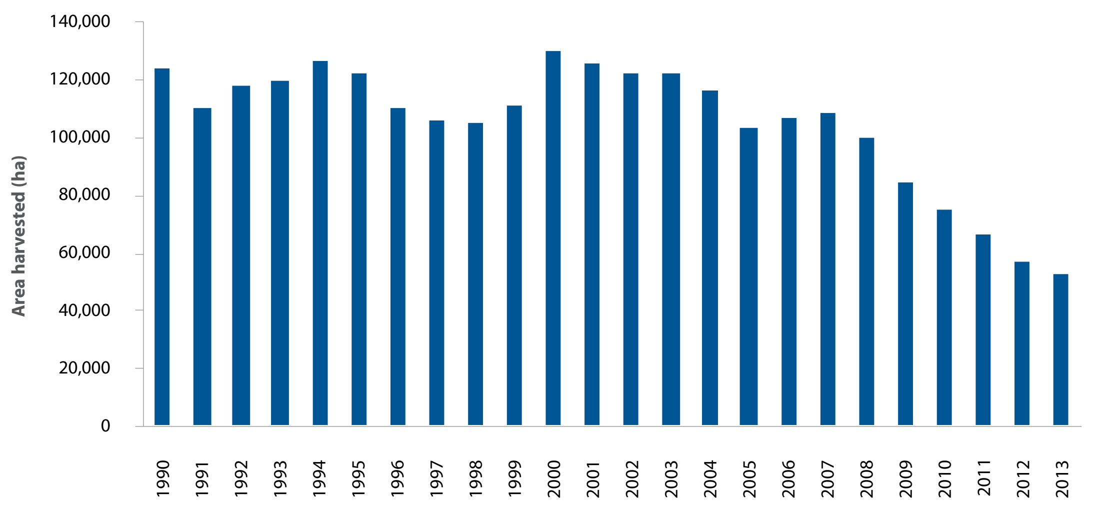


Forest land

Forest land (4A) was a net sink of 27.4 Mt CO_2-e in 1990 compared to a net sink of 37.9 Mt CO_2-e in 2013, a difference of -10.5 Mt CO_2-e. Within *forest land forest land remaining forest land* was a net sink of 28.9 Mt CO_2-e in 1990 compared to a net sink of 25.2 Mt CO_2-e in 2013, while the emissions from *land converted to forest land* decreased from a net source of 1.4 Mt CO_2-e in 1990 to a net sink of 13.1 Mt CO_2-e in 2013.

On average, since 1990, *forest land* has been accumulating carbon stocks of approximately 6 Mt of carbon each year (equivalent to a sink of approximately 22 Mt CO_2 per year, see Figure 6.1). A contributing factor to the accumulation of carbon in forest land over recent years has been the decline of the area harvested in Australia's native forests (Figure 6.2).

Figure 6.2 Area harvested in native forests since 1990



The key drivers of variation in *forest land* outcomes are annual harvest areas, the age classes of the forests, prescribed burning, climate and wildfires.

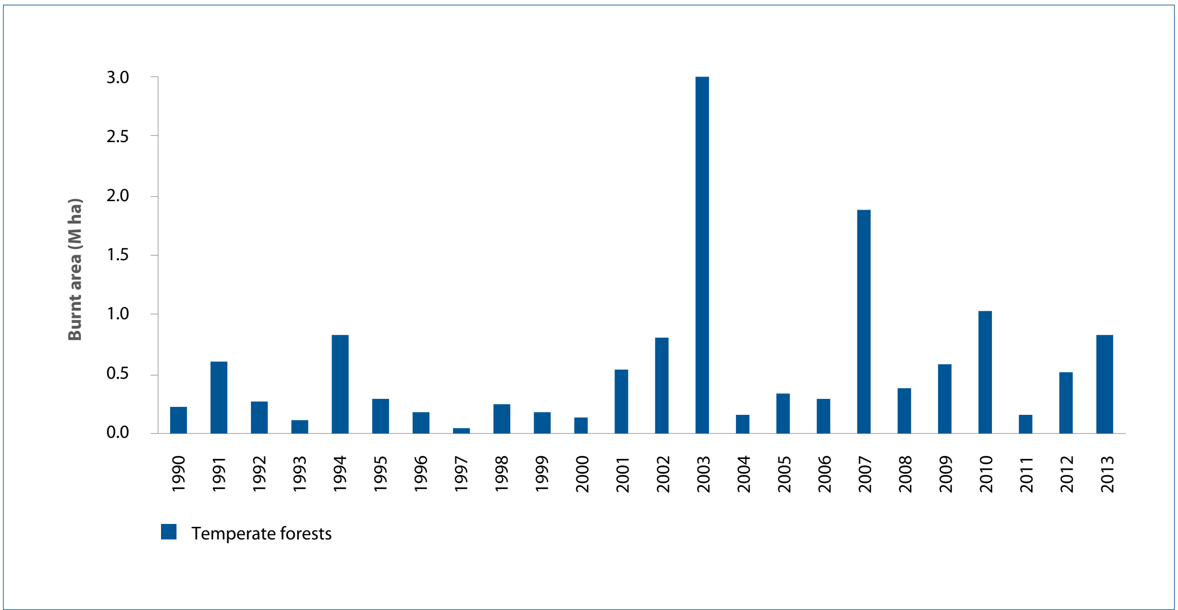
Harvesting in Australia's native forests, including Multiple Use Forests and private native forests, is the key driver of human induced emissions and removals in these forests. Over recent years, harvesting in the native forest sector has reached historically low levels (Figure 6.2). This decline has been associated with changes in supply factors such as increasing supply from plantations (particularly those established after 1990) and demand factors, including the international price of harvested wood products and the value of the Australian dollar, as well as shifts in demand patterns, especially between Japan and China. As the Australian dollar has depreciated since its highs during 2011-2012, this trend may be reversed. Trade data for the year ending June 2014 show a 33% rise in the value of hardwood woodchip exports from the preceding year due to increased volumes, despite prices continuing to fall (ABARES 2014).

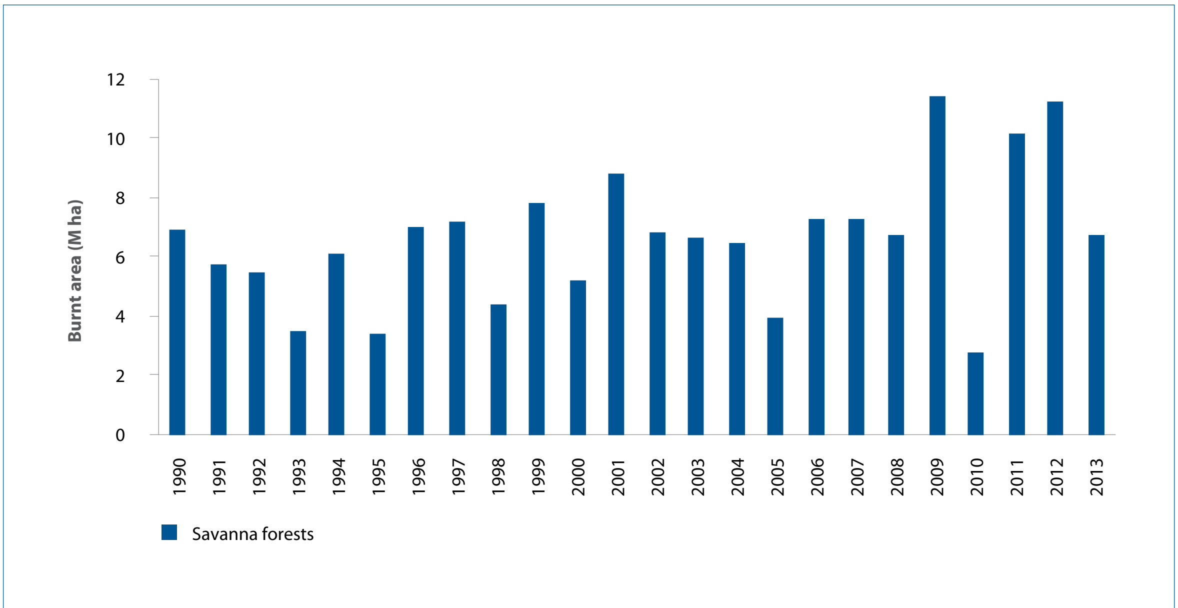
Wildfires are the largest cause of variability in emissions from *forest land remaining forest land*. Wildfires occur annually across Australia's 107 million hectares of forests with the area burnt varying considerably from year to year (Figure 6.3).

The area burnt in forests growing in savanna regions of northern and central Australia are consistently higher than the area burnt in temperate regions of southern and eastern Australia (Figure 6.3). Net emissions due to wildfire in the wet/dry tropics of northern Australia tend to be lower than in temperate forests due to the frequency of fires and the rapid regrowth of vegetation following wildfire.

In 2013 the total national area affected by wildfire was estimated to be 5.7 M ha, which is the lowest area affected by wildfire since 2010 (Figure 6.3). Emissions due to wildfire in 2013 were 12.4 Mt CO_2-e in temperate forests and 3.06 Mt CO_2-e in savanna forests. A moving average over five years is applied to wildfire data for the purpose of emissions reporting.

Figure 6.3 Annual area of forests burned by wildfire, A savanna forests, B temperate region forests 1990 – 2013





Cropland remaining cropland

Cropland remaining cropland (4.B.1) is estimated to be a net sink of 2.2 Mt CO_2-e in 2013. Since 1990, there has been no significant trend in emissions (Figure 6.4), with minor variations driven by fluctuations in climatic conditions and shifts in management practices.

Figure 6.4 Net CO_2-e emissions from *cropland remaining cropland*, 1990 - 2013

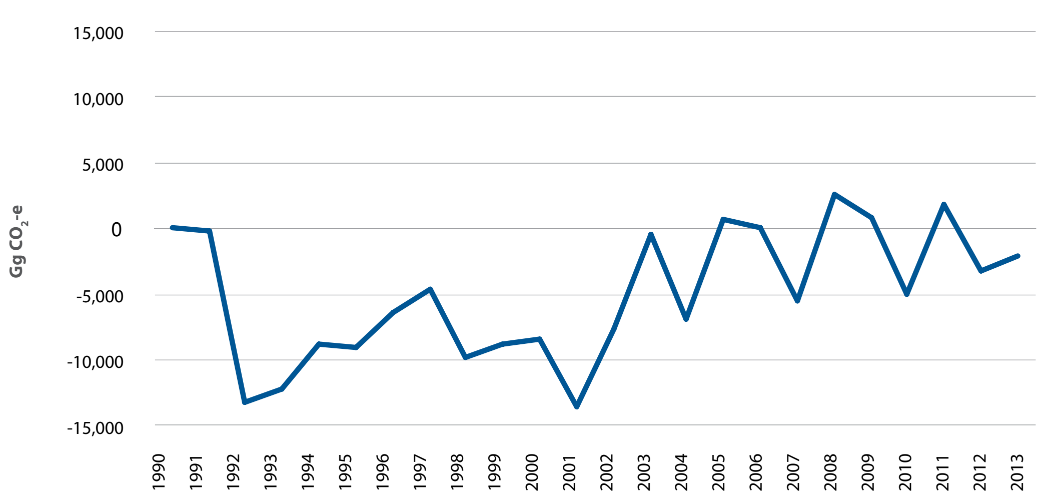


Table 6.2 Net emissions and removals from cropland remaining cropland by sub-division, 1990-2013 (Gg)

Year	Soil carbon	Perennial Woody Crops (biomass)	Total
1990	0	-69	-69
2000	-8,413	-50	-8,463
2005	777	-162	616
2006	152	-175	-23
2007	-5,575	36	-5,539
2008	2,663	-122	2,541
2009	863	-152	711
2010	-4,745	-282	-5,027
2011	2,160	-363	1,797
2012	-3,170	-109	-3,279
2013	-2,310	94	-2,216

Grassland remaining grassland

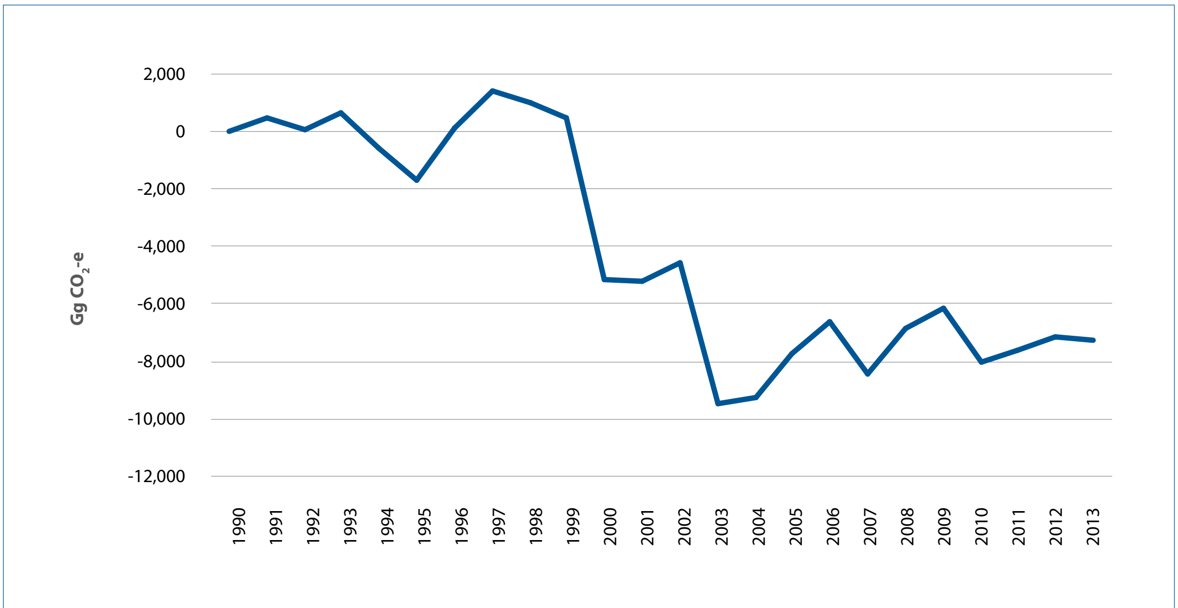
As with *cropland remaining cropland*, there has been no significant longer term trend in emissions discernible for *grassland remaining grassland* (4C1).

Changes in carbon stocks in *grassland remaining grassland* are largely affected by changes in land management practices, natural disturbances and climate. These factors determine the amount of live biomass and dead organic matter (DOM) as well as the amount of residues, root and manure inputs to soil carbon. The results are reported in three components to reflect the three elements of the emission estimation:

- herbaceous grassland (soil carbon);
- changes in shrubland extent; and
- fire.

In the reported estimates for herbaceous grasslands, there has been no significant trend in emissions (Table 6.3). In the arid and semi-arid regions of central Australia, however, soil carbon stocks under natural grassland have also reached a steady-state.

Figure 6.5 Net CO_2-e emissions from *grassland remaining grassland*, 1990-2013



Woody shrubs are a key component of grassland ecosystems in semi-arid and arid regions of central Australia. Emission and removals on these shrublands are driven by fire, land management and transitions between shrubs and grasses. These processes are driven by climate as well as anthropogenic activities. The trend in emissions on these lands is primarily the result of natural variability.

Table 6.3 Net emissions and removals from grassland remaining grassland, by sub-category 1990-2013 (Gg)

Year	Herbaceous grasslands	Perennial woody biomass		All
	Soil Carbon	*Transitions*	*Fire*	
1990	3,068	-1,150	-2,801	-883
2000	-3,375	-842	8,381	4,164
2005	-6,413	-702	9,119	2,004
2006	-5,527	-638	9,642	3,477
2007	-7,256	-683	7,363	-576
2008	-6,101	-527	6,788	160
2009	-5,193	-289	4,722	-759
2010	-4,945	-183	3,796	-1,332
2011	-6,386	-193	2,583	-3,995
2012	-6,859	-248	1,644	-5,462
2013	-6,174	-385	4,987	-1,572

Forest land converted to cropland and grassland

In 2013 total emissions from *forest land converted to cropland* and *forest land converted to grassland* were 69.4% (94.3 Mt CO_2-e) lower than in 1990. This transition from forest to non-forest land use results in an immediate loss of carbon as trees are cleared and burnt, as well as ongoing loss of soil carbon as it decays to a new equilibrium stock level.

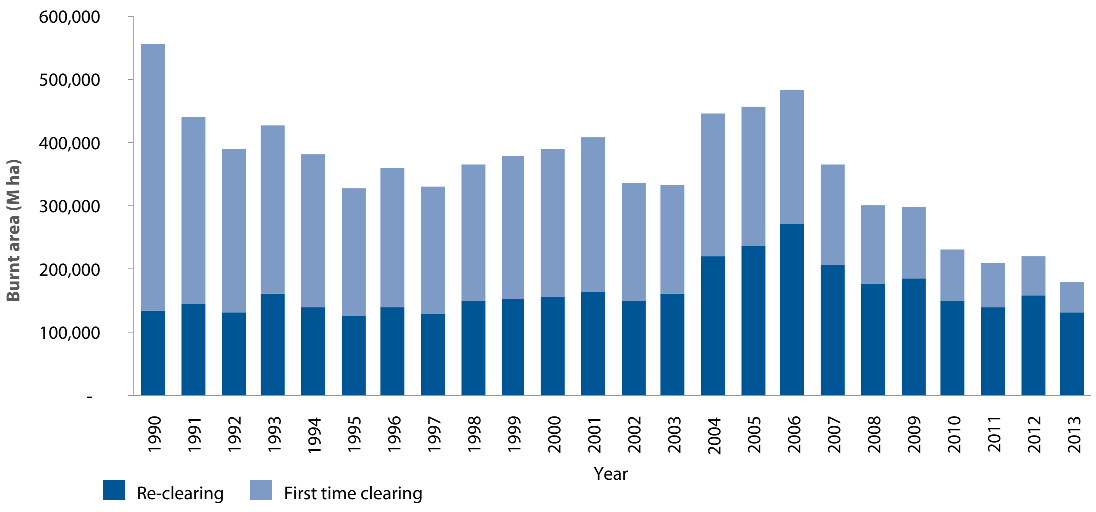
The management of native vegetation and the majority of forest conversion processes in Australia are governed by the *Native Vegetation Framework,* which is an intergovernmental agreement among all levels of Australian government under the Council of Australian Governments (COAG).

Individual jurisdictions implement the national *Native Vegetation Framework* commitments in accordance with their own individual circumstances and land management practices and legislative frameworks.

Examples of administrative processes include compliance with regional ecosystem plans established under legislation, individually negotiated property management plans or additional approval processes / permit processes for clearing. Permits for conversion of all forests to grasslands for agriculture are required in the Northern Territory, Western Australia, Victoria, South Australia and Tasmania, with minor exceptions. In Queensland and in New South Wales, the processes are more complex.

First-time clearing of mature forest is now restricted by government regulation in many areas. Figure 6.6 illustrates the trend in land clearing in Australia between 1990 and 2013 and shows the contribution of first-time clearing of mature forest and re-clearing of forest cover that has re-grown on previously cleared land. The relative stability of the rate of re-clearing (Figure 6.6) indicates an ongoing and cyclical need of land managers to re-clear certain areas on the fringe of agricultural regions where seed from adjacent forests has supported forest regeneration.

Figure 6.6 First-time forest clearing and re-clearing in Australia, 1990-2013, as used for Australia's greenhouse accounts.



Within this national *Native Vegetation Framework*, economic considerations remain important drivers of the demand for forest conversion to alternative uses.

Most land cleared in Australia is used for cattle grazing or for crop production but also for settlements and mining. For farmers and other landowners, economic considerations are an important driver of land clearing. When the prices of agricultural products, for example beef, are high, landowners have a strong incentive to clear land and expand production.

Although economic conditions are also a factor, the effects of the more restrictive policy changes implemented in 2007 may be seen in the drop in first-time clearing, from 2007 onwards (Figure 6.6). In addition, the current decline may also reflect land managers bringing forward decisions to clear land in the period 2004 and 2006 - the period between the announcement of new policies and before they came into force.

This recent shift in the balance between first time clearing and re-clearing (Figure 6.6) also contributes to the ongoing decrease in emissions from *forest land converted to cropland* and *grassland*. Where land is re-cleared the biomass stock at clearing will be significantly less than the initial biomass of first time clearing. For the purpose of the tier 2 forest conversion model (see Appendix 6.H) it is assumed that the biomass of recleared forests is 32% of the mature forest biomass.

6.2 Source Category Description and Methodology

6.2.1 National Circumstances

Australia has a land area of 769 million hectares containing unique land, water, vegetation and biodiversity resources. Australia is a dry continent where rainfall is highly variable and floods and droughts are a common feature. There are a number of distinct climatic zones, with summer dominant rainfall in the tropics/subtropics in the north, Mediterranean climates in the south, arid and semi-arid regions in the centre, and areas of high rainfall on the coastal fringes and in the ranges of the east (Figure 6.7 and Figure 6.8).

Australia has a diversity of soil types ranging from old, highly weathered and infertile, to younger, more fertile soils derived from volcanic rocks and alluvium. Approximately 50% are dominated by sandy surface soil horizons, 37% are dominated by loam and sandy clay loams in the surface horizon and 13% are dominated by light to medium clay textured soil in the surface horizon. Most of these soils have low levels of nitrogen, phosphorus and other nutrients.

The areas of the continent under different land uses are shown in Figure 6.9. Significant agricultural activities include wool, beef, wheat, cotton and sugar production. Australia is also an exporter of dairy produce, fruit, rice and flowers. Australia's forest resources consist of native forests (primarily dominated by *Eucalyptus* species), which are used for wood production, recreation and conservation, and plantations of native (primarily *Eucalyptus* species) and exotic species (primarily *Pinus* species).

Croplands are generally located along a broad inland fringe across the southern and eastern areas of Australia, with the highest yields commonly obtained in the south west and 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; wheat, sugarcane, sorghum and cotton production dominate.

The majority of *grassland* areas occur in inland Australia and are 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 to extensive rangeland systems in the semi-arid and arid regions of Australia. Native or naturalised pastures are the major pasture type, occupying approximately 17 per cent of Australia's land area with sown and fertilised pastures occupying only 4 per cent of the land area. 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. Irrigated pastures represent about 1 per cent of all pastures and are generally confined to the dairy and feedlot industries.

Figure 6.7 Average annual rainfall 1970-2013

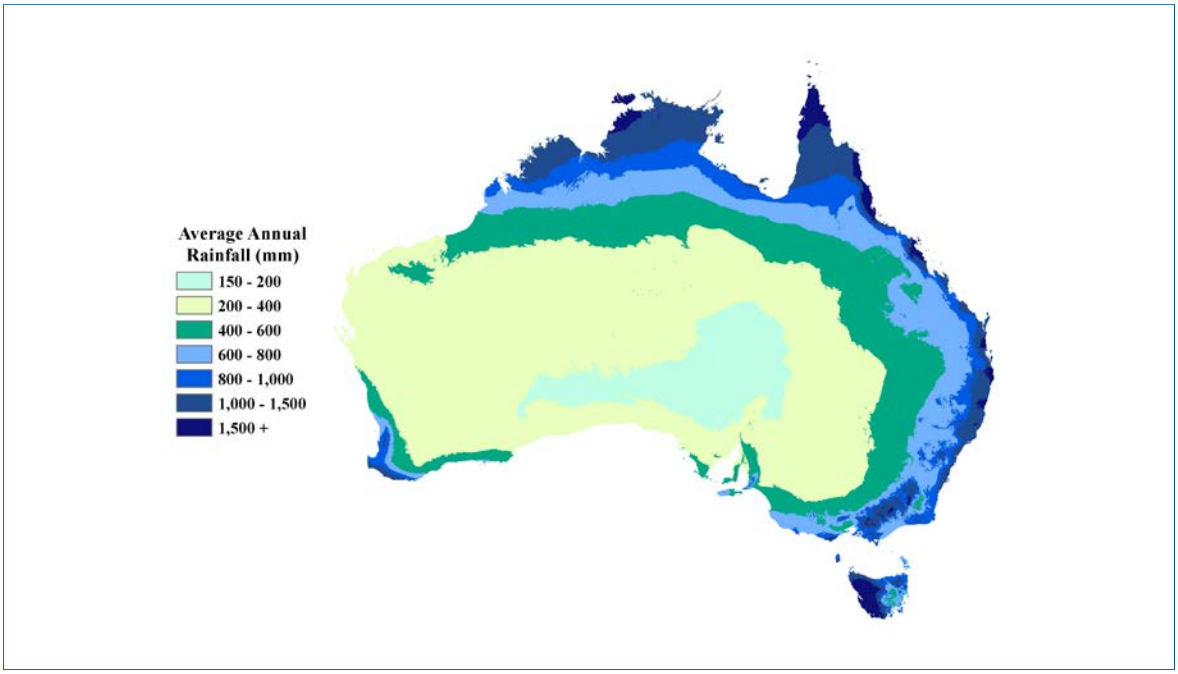


Figure 6.8 Average annual temperature 1970-2013

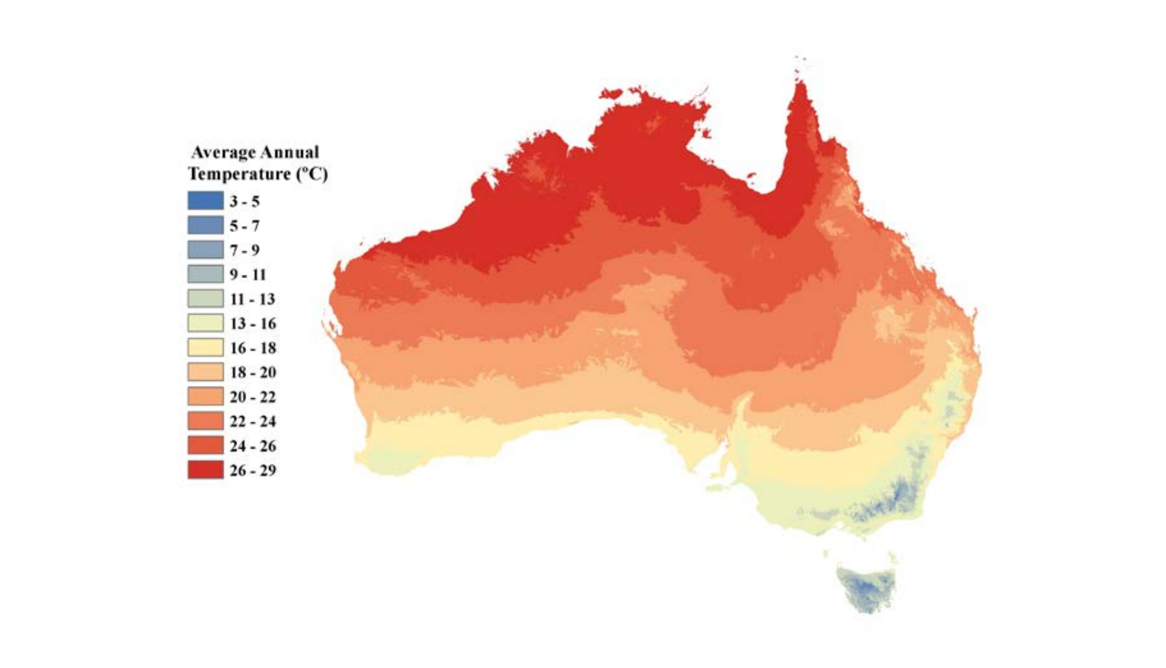
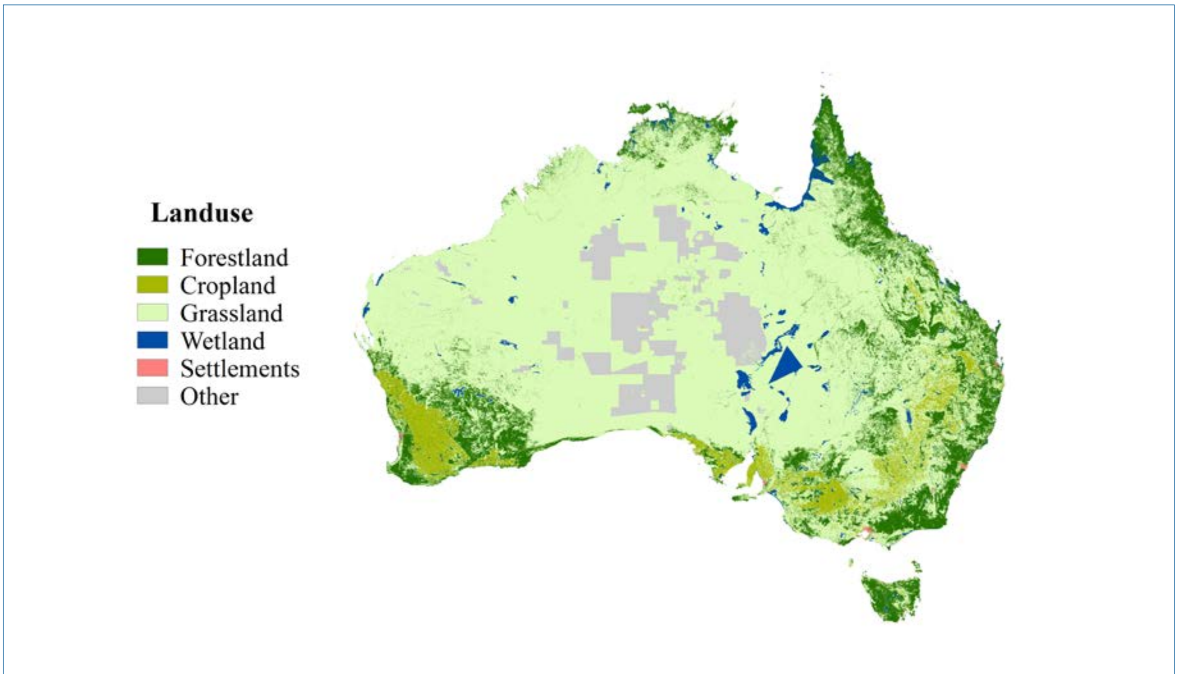


Figure 6.9 Land use in Australia 2013



6.2.2 Methodology

Land use and management activities influence a variety of ecosystem processes that affect greenhouse gas fluxes. The focus of reporting for the *LULUCF* sector is the estimation of emissions and removals of carbon dioxide (CO_2) from these activities. Carbon dioxide fluxes between the atmosphere and managed land systems are primarily controlled by uptake via 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).

Predominantly country specific methodologies and Tier 3 models (Table 6.4) are used for *LULUCF*. The methods used in the reporting of the *LULUCF* categories of the inventory are described in detail in Appendices 6.A to 6.I.

Table 6.4 Summary of methodologies and emission factors – *LULUCF* sector

Greenhouse Gas Source And Sink	CO_2		CH_4		N_2O		NO_x, CO and NMVOC	
	Method applied	EF	Method applied	EF	Method applied	EF	Method applied	EF
4. Land Use, Land Use Change and Forestry								
A. Forest Land								
1. Forest land remaining Forest land								
Harvested Native Forests	T2	M						
Other Native Forests	T2	CS						
Pre-1990 Plantations	T2	M						
Fuelwood consumed	T2	CS						
4(V) Biomass Burning – 4.A.1.			CS	CS	CS	CS	CS	CS
2. Land converted to Forest land	T2, T3	M						
B. Cropland								
1. Cropland remaining Cropland	T3	M						
2. Land converted to Cropland	T3	M						
4(III) Disturbance associated with land conversion					T2	CS		
4(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						
4 (V) Biomass Burning - 4.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						

Greenhouse Gas Source And Sink	CO_2		CH_4		N_2O		NO_x, CO and NMVOC	
	Method applied	EF	Method applied	EF	Method applied	EF	Method applied	EF
G. Harvested wood products								
Harvested Wood Products	T3	M						
4(I) Direct nitrous oxide (N2O) emissions from nitrogen (N) inputs to managed soils					IE	IE		
4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils	NE	NE	NE	NE	NE	NE		
4(III) Direct nitrous oxide (N2O) emissions from nitrogen (N) mineralization/immobilization associated with loss/gain of soil organic matter resulting from change of land use or management of mineral soils					T2	CS		
4(IV) Indirect nitrous oxide (N2O) emissions from managed soils					T2, CS	D		
4(V) Biomass burning	T2	CS	CS	CS	CS	CS	CS	CS
H. Other								

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,

Australia's land sector inventory system integrates spatially referenced data with an empirically constrained, mass balance, carbon cycling ecosystem model (*FullCAM*) to estimate carbon stock changes and greenhouse gas emissions (including all carbon pools, gases, lands and land use activities). The system supports Tier 3, Approach 3 spatial enumeration of emissions and removals calculations for the following sub-categories:

- *forest land converted to cropland*
- *forest land converted to grassland*;
- *grassland converted to forest land*; and
- the agricultural system components of *cropland remaining cropland* and *grassland remaining grassland*.

Spatial enumeration is achieved through the use of a time-series (since 1972) of Landsat satellite data which is used to determine change in forest extent at a fine spatial disaggregation. The forest cover change information is coupled together with spatially referenced databases of climate and land management practices which allows a comprehensive quantification of emissions (see Appendices 6.A and 6.B).

The other principal reporting elements, *forest land remaining forest land, cropland remaining cropland (woody horticulture)* and *grassland remaining grassland* (*perennial woody*), are reported using a combination of Tier 2 and 3 methods.

FullCAM can also be configured to operate in a Tier 3, Approach 2 mode where spatially explicit data are unavailable. In this configuration, known as the 'Estate' module, *FullCAM* uses age-based growth data to estimate living biomass and dead organic matter (DOM) from both turnover and harvest residue. The 'Estate' module of *FullCAM* is used to scale regional models of carbon stock change by the areas of each forest type(see Richards and Evans (2000a)).

6.3 Representation of Lands

Land representation must be consistent over time and land units must be represented in only one category in order to meet the criteria for good practice established in the IPCC (2006).

6.3.1 Land Classifications

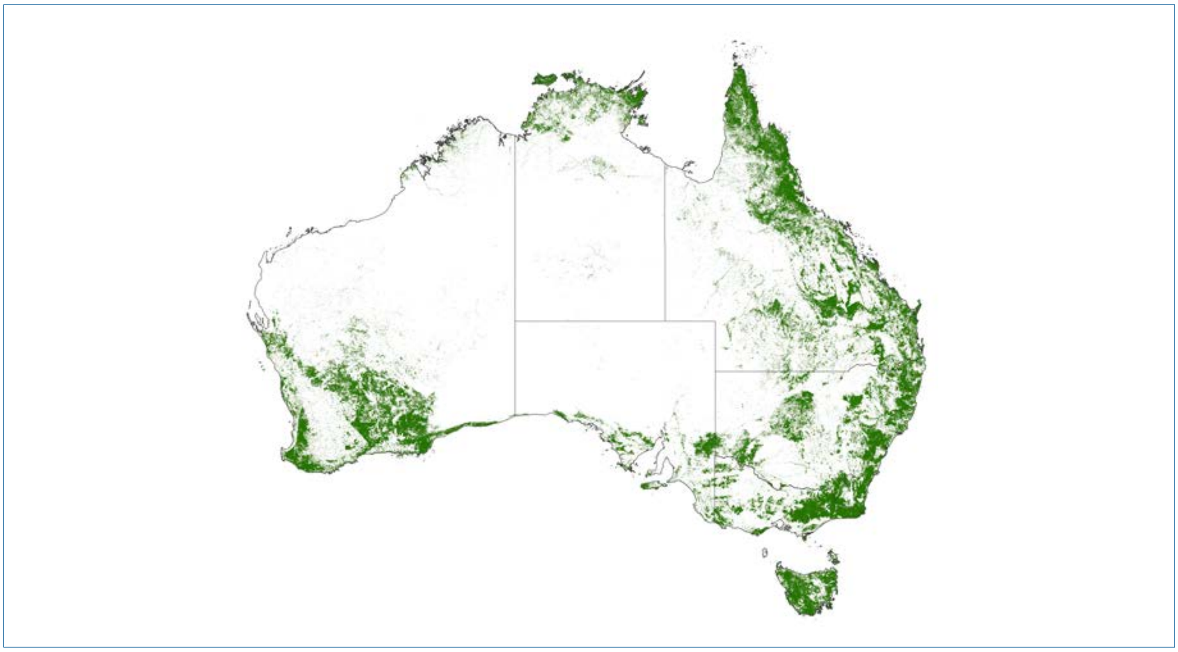
Forest land includes all lands with a tree height of at least 2 metres and crown canopy cover of 20 per cent or more (Figure 6. 10) and lands with systems with a woody biomass vegetation structure that currently fall below but which, *in situ,* could potentially[1] reach the threshold values of the definition of *forest land*. Young natural stands and all plantations which have yet to reach a crown density of 20 per cent or tree height of 2 metres are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of either human intervention, such as harvesting, or natural causes, but which are expected to revert to forest.

Forest land does not include woody horticulture which meets the forest threshold parameters; this land is classified as croplands.

The forest cover definition is consistent with the definition used in Australia's National Forest Inventory that has been used for reporting to the Food and Agriculture Organisation and Montreal Process. Australia has adopted a minimum forest area of 0.2 ha.

Forest use is typically evident by human 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.

Figure 6. 10 Forest extent in Australia 2013

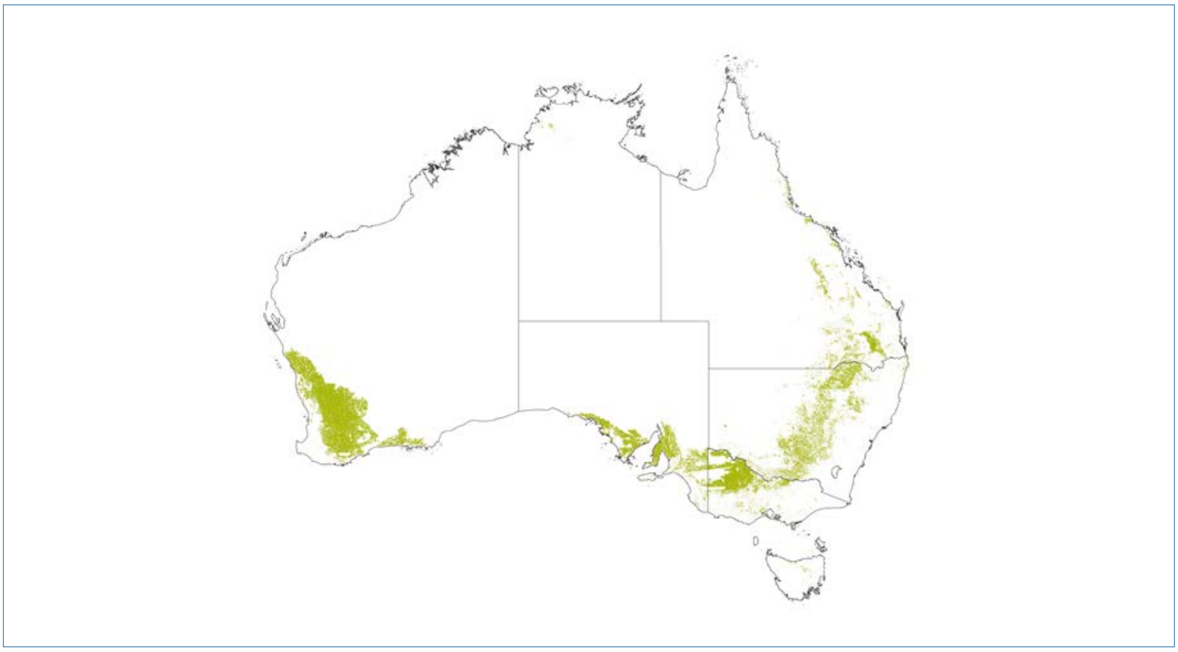


1 This potential is evidenced from the Landsat series that the land had previously supported forest.

Cropland includes all land that is used for continuous cropping and those lands managed as crop-pasture (grassland) rotations (Figure 6. 11) (ABARES, 2014).

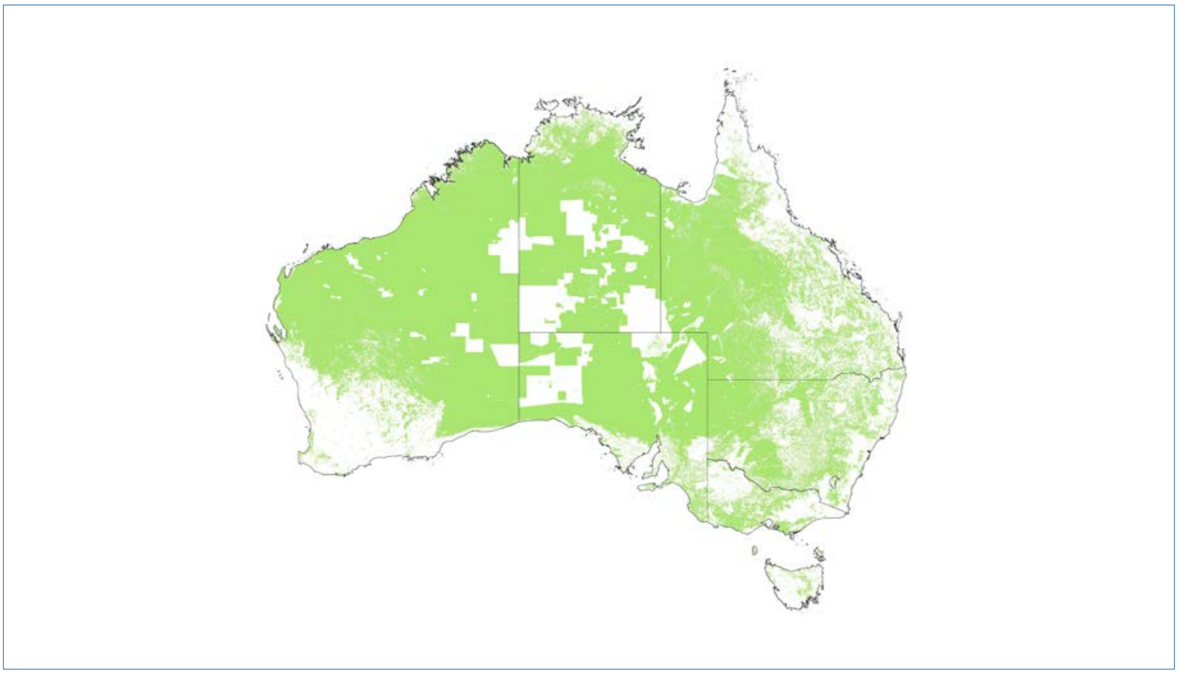
Non-CO_2 emissions from *cropland remaining cropl*and are reported in the Chapter 4 *agriculture* sector.

Figure 6. 11 *Cropland remaining cropland* distribution in Australia 2013



The *grassland* category represents a diverse range of climate, management and vegetation cover (Figure 6. 12) (ABARES, 2014). The *grassland* category also includes sub-forest forms of woody vegetation (shrubs).

Figure 6. 12 *Grassland remaining grassland* distribution in Australia 2013



Settlements include areas of residential and industrial infrastructure, including cities and towns, and transport networks. The area of the *settlements* land use classification is based on the latest information sourced from the ABARES catchments scale land use data (Version 5, 2014), and includes additional land use classes such as manufacturing and industry, commercial services, transport and communications including airports etc. Land areas that meet the definition of forest land are reported under the *forest land* category.

Wetlands include areas of perennial lakes, reservoirs, swamps and major water course areas derived from the Australian Hydrological Geospatial Fabric (AHGF) data published by the Australian Bureau of Meteorology, and all existing wetlands as defined in the Directory of Important Wetlands in Australia (DIWA) dataset published by the Department of the Environment. Land areas that meet the definition of forest land, such as mangroves, are reported under the *forest land* category.

The *other land* category includes bare soil, rock and other land areas that do not fall into any of the other five categories according to ABARES' catchment scale land use map of Australia (version 5).

Where a direct human-induced removal of forest cover and land use change has been identified, these lands are classified and reported as *forest converted to grassland* or *forest land converted to cropland*. The allocation of forest conversion areas to *cropland* or *grassland* is designated by the relative frequency of the management practices within the particular ABS Statistical Local Areas and soil type in which it occurred.

Where there has been direct human-induced conversion from grass to forest these lands are classified and reported as *land converted to forest*. The encroachment of woody vegetation onto *grassland* with no clear human-induced cause is classified as *land converted to forest land* or *grassland remaining grassland*, depending on whether the vegetation meets the criteria for *forest land*.

In cases where there is a temporary change in forest cover, due to a forest harvest or fire, the land remains in the *forest land* category unless a subsequent land use change is identified.

The permanent conversion of *forest land* to other land uses is distinguished from a temporary removal or loss of forest cover. Changes in forest cover due to natural events (e.g. fire, drought) or changes that occur within land tenures where it is expected that the land will revert to forest (e.g. harvested forest, national park) are monitored for a period of time, depending upon the type of forest land use (2.6.2.1 of IPCC 2014). In the absence of land use change, areas without forest cover that have entered the monitoring system continue to be classified as "forest" provided that the time since forest cover loss is shorter than the number of years within which tree establishment is expected. After that time period, lands that have lost forest cover due to direct human-induced actions, have undergone land use change, and failed to regenerate are classified as converted to the appropriate non-forest land use classification.

6.3.2 Land monitoring systems

Australia uses approaches two and three as described in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* to monitor land use, land use change and forestry.

The principal monitoring system is a remote sensing programme used to identify forest lands and changes in forest cover.

The remote sensing programme is implemented by the Department of the Environment. The system monitors national forest cover on an annual basis using Landsat satellite data (collected by MSS, TM, ETM+ and OLI sensors). The time series of national maps of forest cover extends across 23 time epochs from 1972 to 2014 and has been assembled on an annual basis since 2004. These maps are able to detect fine scale changes in forest cover at a 25 m by 25 m resolution.

Within the *forest land remaining forest land*, data on areas of forest management are drawn from Australia's National Forest and Wood Protection Statistics (ABARES 2014), Australia's State of the Forests Report (ABARES 2008) and Lucas *et al.* (1997).

Supplementary spatial information from the Land Use Mapping programme of Australia's Bureau of Agricultural Resource Economics and Sciences (ABARES, 2014) is used to identify land areas in the *cropland remaining cropland*, *grassland remaining grassland, wetlands, settlements*, and *other land* categories.

Identified changes in forest area from the remote sensing programme are assessed through a series of automated analytical tools and are quality controlled through inspection by trained operators to determine if these changes are due to human activity and are followed by land use change (e.g. forest clearing for agriculture, mining or urban development). The full details of the remote sensing and attribution analysis are provided in Appendix 6.A.

Once classified as a *Forest conversion* event, land remains in the conversion category for 50 years. This period of time reflects the long term impacts of conversion on carbon dynamics in Australian systems. After 50 years, the lands will be moved into the "land remaining" sub-categories. Archives of satellite data currently support only 42 years of conversion monitoring so that additional methods and data sources are used to identify amounts of land subject to conversion prior to 1972 (see Appendix 6.A).

6.3.3 Land representation matrix

Areas of forest cover change are supported by spatially referenced databases of land management information held by the Department of Environment. Reconciliations are performed 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.

The representation of land areas for Australia for 1990-2013 is reported in Table 6.5.

Table 6.5 Land representation matrix (start of 1990 to end of 2013)

Land Use	1990[b]	2013	Net Change
	(Mha)	(Mha)	(Mha)
Forest Land Total	111.2	107.0	-4.2
Forest land remaining Forest Land	110.8	103.4	-7.4
Grassland Converted to Forest land	0.3	3.5	3.2
Grassland Total	540.7	544.3	3.6
Grassland remaining Grassland	531.9	528.7	-3.2
Forest Land converted to Grassland	8.8	15.6	6.8
Cropland Total	36.0	36.6	0.6
Cropland remaining Cropland	35.0	35.0	0.0
Forest Land converted to Cropland	1.0	1.6	0.6
Wetlands Total	19.3	19.3	0.0
Settlements Total	1.1	1.1	0.0
Other Lands	60.7	60.7	0.0
Total Land Area	769.0	769.0	0.0

a) Total area does not include external territories

b) The land areas for 1990 in this table are the land areas at the start of 1990. The net change is therefore the change in land area including change that occurred in 1990 through to 2013 inclusive.

Table 6.6 Land area in IPCC land use classifications 1990-2013

Year	4.A.1 Forest land remaining Forest land	4.A.2 Land converted to forest land	4.B.1 Cropland remaining cropland	4.B.2 Land converted to cropland	4.C.1 Grassland remaining grassland	4.C.2 Land converted to grassland	4.D.1 Wetlands remaining wetlands	4.E.1 Settlements remaining settlements	4.F.1 Other land remaining other land	Total
1990	110.82	0.33	35.02	1.00	531.89	8.79	19.33	1.13	60.70	769.00
1991	110.40	0.49	35.02	1.03	531.73	9.18	19.33	1.13	60.70	769.00
1992	110.04	0.60	35.02	1.05	531.62	9.51	19.33	1.13	60.70	769.00
1993	109.64	0.72	35.02	1.08	531.51	9.88	19.33	1.13	60.70	769.00
1994	109.29	0.83	35.02	1.10	531.39	10.22	19.33	1.13	60.70	769.00
1995	108.98	0.93	35.02	1.11	531.29	10.51	19.33	1.13	60.70	769.00
1996	108.65	1.04	35.02	1.12	531.19	10.83	19.33	1.13	60.70	769.00
1997	108.35	1.14	35.02	1.14	531.08	11.12	19.33	1.13	60.70	769.00
1998	108.02	1.24	35.02	1.16	530.99	11.43	19.33	1.13	60.70	769.00
1999	107.67	1.34	35.02	1.20	530.88	11.74	19.33	1.13	60.70	769.00
2000	107.32	1.47	35.02	1.23	530.75	12.05	19.33	1.13	60.70	769.00
2001	106.95	1.62	35.02	1.27	530.61	12.38	19.33	1.13	60.70	769.00
2002	106.65	1.75	35.02	1.30	530.48	12.66	19.33	1.13	60.70	769.00
2003	106.35	1.88	35.02	1.33	530.34	12.93	19.33	1.13	60.70	769.00
2004	105.95	2.06	35.02	1.37	530.16	13.28	19.33	1.13	60.70	769.00
2005	105.56	2.21	35.02	1.40	530.02	13.65	19.33	1.13	60.70	769.00
2006	105.15	2.34	35.02	1.44	529.89	14.02	19.33	1.13	60.70	769.00
2007	104.82	2.52	35.02	1.47	529.71	14.31	19.33	1.13	60.70	769.00
2008	104.55	2.72	35.02	1.50	529.51	14.55	19.33	1.13	60.70	769.00
2009	104.28	2.90	35.02	1.52	529.32	14.80	19.33	1.13	60.70	769.00
2010	104.06	3.12	35.02	1.54	529.10	15.00	19.33	1.13	60.70	769.00
2011	103.84	3.39	35.02	1.57	528.84	15.19	19.33	1.13	60.70	769.00
2012	103.63	3.53	35.02	1.58	528.70	15.40	19.33	1.13	60.70	769.00
2013	103.42	3.55	35.02	1.60	528.68	15.58	19.33	1.13	60.70	769.00

6.4 Source Category 4A.1 Forest Land Remaining Forest Land

There are four broad sub-divisions to *forest land remaining forest land*: harvested native forests, plantations, other native forests and fuelwood consumed. These are treated as independent sub-divisions and emissions estimates are modelled independently.

6.4.1 Harvested Native Forests

Harvested native forests are those forests comprised of endemic species arising from natural regrowth (including old forests). Various silvicultural techniques may be applied to initiate and promote particular growth characteristics. The areas included in this sub-division are those subject to harvest, those regrowing from prior harvest for which age class (harvest record) data are available, and those considered available for harvest in 1990.

In Australia, many areas that were historically harvested are no longer available for harvest; they have been withdrawn from commercial use due to changes in policy, such as new codes of practice, and transfer to conservation and recreation reserves. For continuity, the removal of carbon dioxide, due to recovery from former harvesting, continues to be reported in this category, even if the lands have moved to a reserve status. As a result, the land areas of the various forest classifications do not change with time. The areas of each forest type are shown in Table 6.5.

6.4.1.1 Methodology

The emissions and removals from *harvested native forests* are estimated using the non-spatially explicit Estate modelling capability of *FullCAM*. Consistent with the treatment of mineral soils in *forest land remaining forest land* in the IPCC Good Practice Guidance (IPCC, 2006), a Tier 1 method is applied for soil carbon. This method assumes that soil organic carbon in mineral soils is stable when averaged over the *harvested native forest* estate through time. Any losses due to harvesting are compensated by uptake in areas recovering from previous harvesting. Over time, the balance between losses from harvesting and gains from recovering areas has shifted towards the recovering areas.

Harvested wood products are not reported in this category and carbon stocks are transferred to category *4G Other - harvested wood products*.

Estimating Changes in Living Biomass

The annual change in living biomass in harvested native forests is the net result of uptake due to forest growth (above and belowground as determined from the growth models) and losses due to forest harvesting. Losses occur with the removal of forest products (transferred to *4G Other - harvested wood products*) and movement of residue material (including belowground biomass) to dead organic matter (DOM).

The growth rates of *harvested native forests* (t C ha^{-1} yr^{-1}) are modelled based on the broad forest types and age classes reported by Lucas *et al.* (1997) (Table 6.7). The initial carbon stock in 1990 is estimated using *FullCAM* which is configured using the area of each forest type and age class in Table 6.7. *FullCAM* is then configured to model biomass increments based on the growth rates reported in Table 6.8. Forests of unknown age, or those which contain two or more age classes, were assumed to be 70 years old in 1990, to ensure that all forest areas were assigned to an age-based growth curve.

The growth rate of rainforests was assumed to be constant at 0.58 t C ha^{-1} yr^{-1} as per Lucas *et al.* (1997). The growth rate of Medium sparse Eucalypt forests, Cypress pine forests and 'Other' forests is also assumed to be constant, based upon the data in Lucas *et al.* (1997) (Table 6.8).

Post-harvest growth is modelled according to the type of harvest that took place. Areas subject to clearfell harvest regrow from age zero. Areas subject to partial harvest continue to grow at the same rate as they were growing prior to the harvest (i.e., there is no thinning effect at the stand level, either positive or negative, on the rate of biomass accumulation despite the reduction in stem numbers).

Table 6.7 Areas by forest type and age classes in 1990 (ha).

Forest Type	Establishment 1-10 yrs	Juvenile 11-30 yrs	Immature 31-100 yrs	Mature 100-200 yrs	Senescent > 200 yrs	Forests of unknown age ([a])	Two Aged	Three or More Aged	Total
Rainforests				1,332,882					1,332,882
Tall Dense Eucalypt Forests	73,919	151,025	371,586	462,067	364,000	1,015,024	183,000	614,077	3,234,698
Medium Dense Eucalypt Forests	23,058	154,619	274,340	1,311,540	266,000	2,625,710	433,000	1,616,923	6,705,190
Medium Sparse Eucalypt Forests					546,000	433,869		1,049,383	2,029,252
Cypress pine Forests						66,848		228,083	294,931
Other Forests						1,064,653		224,134	1,288,787
Totals	96,977	305,644	645,926	3,106,489	1,176,000	5,206,104	616,000	3,732,600	14,885,740

(a) The unknown and mixed age classes were assumed to have an average age of 70 years

Table 6.8 Aboveground growth rates by forest type and age class (t C ha^{-1} yr^{-1})

Forest Type	Establishment 1-10 yrs	Juvenile 11-30 yrs	Immature 31-100 yrs	Mature 100-200 yrs	Senescent > 200 yrs
Rainforests	-	-	-	0.58	0
Tall Dense Eucalypt Forests	6.44	4.41	2.23	0.74	0
Medium Dense Eucalypt Forests	4.24	2.80	0.99	0.18	0
Medium Sparse Eucalypt Forests	0.24	0.24	0.24	0.24	0
Cypress pine Forests	0.25	0.25	0.25	0.25	0
Other Forests	0.23	0.23	0.23	0.23	0

Partitioning of biomass to tree components

The ratios used to partition biomass to the different tree components (Table 6.9) are drawn from a synthesis of available data compiled by Snowdon *et al.* (2000) and the results of Ximenes and Gardner (2005) and Ximenes *et al.* (2005).

Table 6.9 Partitioning of biomass to each of the tree components

Forest Type	Fraction of biomass allocated to:					
	Stems	Branches	Bark	Leaves	Coarse roots	Fine roots
Rainforest	0.60	0.08	0.09	0.03	0.17	0.03
Tall Dense Eucalypt Forest	0.55	0.12	0.10	0.03	0.17	0.03
Medium Dense Eucalypt Forest	0.50	0.15	0.12	0.03	0.17	0.03
Medium Sparse Eucalypt Forest	0.47	0.15	0.12	0.03	0.20	0.03
Cypress pine Forest	0.47	0.15	0.12	0.03	0.20	0.03
Other forest	0.47	0.15	0.12	0.03	0.20	0.03

Carbon Fraction of Biomass

The carbon fractions of the tree components (Table 6.10) are based on studies of Australian vegetation (Gifford, 2000a and 2000b).

Table 6.10 Carbon Fraction of biomass for each tree component based on Gifford (2000a and 2000b)

Tree component	% Carbon
Stems	52
Branches	47
Bark	49
Leaves	52
Coarse roots	49
Fine roots	46

Forest Harvest

The amount of carbon removed as products in a harvest is dependent upon age class, forest type and the type of harvest.

The area of *harvested native forests* harvested in each broad forest type and age class was derived from roundwood log volumes removals for each state (ABARES, 2014a) using a historical relationship between roundwood removals and harvest area data collated by state agencies (Table 6.11).

Table 6.11 Estimated total area of native forest harvested

Year	Area harvested (ha)
1990	124,612
1995	123,079
2000	130,581
2005	103,470
2006	107,455
2007	108,479
2008	99,906
2009	84,747
2010	75,061
2011	66,812
2012	57,188
2013	52,590

The broad silvicultural systems applicable to each state are reported in Table 6.12. Information on the forest type and silviculture method applied also varied in the level of detail available. Where the information was not explicitly reported, it was inferred from the best available information, including information within the state agency reporting, publications from state agencies (e.g., Forestry Tasmania, 2008; FPA, 2007; Forests NSW, 2008; Vic Forests, 2008) and from Raison and Squire (2008). It was assumed that no harvesting occurred in the Establishment (1-10 years) and Juvenile (11-30 years) phases as these are generally too young to produce forest products in Australia's native forests.

Most states began phasing out logging of rainforests in the 1980s, and for the most part, logging was entirely phased out prior to 1990 (Raison and Squire, 2008). It was not possible to separate cold temperate rainforest logging from logging in wet temperate eucalypt forests in Tasmania. The harvested area for rainforests in Tasmania was therefore modelled as tall and medium dense eucalypt forests, which are closest to cold temperate rainforests spatially and in successional sequence (Hickey, 1994).

Table 6.12 Broad silvicultural systems used in the *harvested native forests* model

Forest type	Silviculture	% of trees harvested	Post harvest management
Tall dense eucalypt forest	Clearfell with pulpwood	100%	Regeneration burn
	Clearfell without pulpwood	100%	Regeneration burn
	Partial harvest with pulpwood	35-50%	Slash left on-site
	Partial harvest without pulpwood	25%	Slash left on-site
Medium dense eucalypt forest	Clearfell with pulpwood	100%	Regeneration burn
	Clearfell without pulpwood	100%	Regeneration burn
	Partial harvest with pulpwood	35-75%	Slash left on-site
	Partial harvest without pulpwood	40%	Slash left on-site
Medium sparse eucalypt forest	Partial harvest without pulpwood	30%	Slash left on-site
Callitris forest	Partial harvest without pulpwood	40%	Slash left on-site

Once harvested, in the model, the removal of products at harvest is assumed to result in a transfer of carbon to the *harvested wood products* modelling (see section 6.13.1) (based on production statistics).

Estimating Changes in Debris

The annual change in DOM in harvested native forests is the net result of additions from turnover and losses due to decay. This is due to harvesting and losses caused by decomposition of both natural accumulation and harvest residue, and burning of residues as part of some silvicultural systems.

Losses from the DOM pool are accounted as emissions in the year in which they occur due to the ongoing decay and management of residue from harvesting in previous years. A Tier 1 approach is currently used for soil carbon, assuming a balance between losses due to harvest and re-accumulation following harvest.

The initial amount of forest debris for each forest type and age class combination is based upon model simulations, cross checked with published estimates of debris in Australian forests. For each forest type, a clearfell event was simulated using initial debris levels. This simulation was then run to equilibrium over 200 years. The final debris pools from this simulation were then used as the initial conditions for a final simulation. The results of the final simulation were used to define the initial debris for each age class for each respective forest type. This method produced debris quantities that are comparable with published estimates of debris in Australian forests (e.g., Woldendorp and Keenan, 2005, Hingston *et al.* 1981).

The turnover rates applied for each plant component in the model are shown in Table 6.13. There is limited information on decomposition rates in the *harvested native forests* of Australia. The decomposition rates for the different debris pools were drawn from the best available information including Mackensen *et al.* (2003), Mackensen and Bauhaus (1999), O'Connell (1997) and Paul and Polglase (2004a). The rates used are shown in Table 6.14.

Table 6.13 Turnover for tree components

Tree component	Turnover $year^{-1}$
Branches	0.05
Bark	0.07
Leaves	0.5
Coarse Roots	0.1
Fine Roots	0.85

Table 6.14 Decomposition rates for debris pools used in the *harvested native forests* model.

Debris component	Breakdown yr^{-1}	
	Decomposable	Resistant
Deadwood	0.05	0.05
Bark litter	0.50	0.50
Leaf litter	0.80	0.80
Coarse dead roots	0.40	0.10
Fine dead roots	1.00	1.00

The amount of residue produced by a harvest is also dependent upon the harvest type, forest age and forest type. Information on the production of harvest residue by broad forest type, harvest type and forest age was sourced from Raison and Squire, 2008 and studies of residue production (Ximenes and Gardner, 2005, Ximenes *et al.* 2005).

6.4.2 Plantations

Plantations included within *forest land remaining forest land* are commercial plantations (hardwood and softwood) established in Australia up to the end of 1989. Softwood plantations make up the vast majority of these pre-1990 plantations with hardwood plantations (primarily eucalypt species) making up only a minor part of the plantation estate. Until the mid-1960s, most new areas of softwood plantation were derived from clearing of native forest or scrublands. In later years, some of the hardwood plantations were also established after clearing native forest (Snowdon and James, 2008). By the mid-1980s, clearing of native forests for the establishment of plantations had ceased in most states, and most new plantations were established on farmland.

6.4.2.1 Methodology

The emissions and removals from *plantations* are estimated using *FullCAM* operating in Estate mode. In this mode, *FullCAM* implements tree yield formula (TYF) method of tree production and uses location specific climate and site data, combined with region specific silvicultural practices. The carbon pools considered for *plantations* include above and belowground biomass, DOM and soil.

The areas of *plantations* have been drawn from Australia's National Forest Inventory. The National Forest Inventory makes no distinction between native forest conversions to plantations, second rotation plantations and other non-forest land uses converted to forests. As historic Australian forest inventory data on plantation establishment does not separate new forest establishment from second rotation forests (Jaakko Pöyry Consulting, 2000), it is not currently possible to separate *plantations* from *forest land remaining forest land*. Post-1990 this separation is made possible through the plantation mapping using Landsat data as described in Appendix 6.A.

Harvested wood products are not reported in this category. Carbon stocks removed as products are reported under 4.G *Harvested wood products*.

Estimating Changes in Living Biomass

For the *plantations* category, tree growth is modelled using the tree yield formula embedded into the *FullCAM* code. A full description of the *FullCAM* modelling system is provided in Appendix 6.A and 6.D (see also Waterworth *et al,* 2007; Waterworth and Richards, 2008).

For the *plantations*, 34 *FullCAM* models representing the key species and management practices within each National Plantation Inventory region were developed. Plantations are modelled using *FullCAM* operating in Estate mode, from the time of establishment taking into account the plantation type, management, site and climate conditions to estimate emissions and removals.

The plantation management database incorporated in the FullCAM modelling system contains information on tree species characteristics including forest growth model parameters, carbon allocation to tree components over time, biomass carbon percentages, basic wood density, turnover rates for each tree component, decay and product use data. These data allow *FullCAM* to model forest growth for any point based on the site and climate data.

FullCAM is parameterised to allocate biomass to different plant parts, depending upon species and age of the forest. *FullCAM* calculates the partitioning using an empirical approach derived from expansion factors reported in Snowdon *et al.* (2000) and Mokany *et al.* (2006). This method allows allocation to vary between sites and species within set ranges based on age, site productivity and level of stand development.

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.

Studies of the carbon fractions of above and below ground biomass components for Australian vegetation were used to provide the parameters for the carbon fractions of tree components in the model (Gifford, 2000a and 2000b). Carbon fractions were examined for a range of species and growing conditions, which provided a range for the carbon fractions with a recommended estimate. 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. The carbon contents are listed in Table 6.17.

Estimating Changes in Debris

The amount of carbon moved from living biomass to the DOM pools due to forest harvesting is determined in the model by the age, type of harvest and species characteristics. The turnover rate of leaves and fine roots affects both the amount of fine litter on the forest floor, and subsequently, most of the contribution to soil carbon. The tree component turnover rates applied in the model were guided by work by Paul *et al.* (2004b). The tree component turnover rates are shown in Table 6.15.

Decomposition rates determine the rates of loss of carbon back to the atmosphere as the debris breaks down. The rates of decomposition applied in the model have been guided by the work of Mackensen and Bauhus (1999). Table 6.16 shows the decomposition rates applied. The balance of these two factors determines the amount of debris on site, excluding the effects of management.

Table 6.15 Tree component annual turnover rates

Tree Component	Softwood Turnover yr^{-1}	Hardwood Turnover yr^{-1}
Branches	0.03	0.05
Bark	0.05	0.07
Leaves	0.3	0.5
Coarse Roots	0.07	0.1
Fine Roots	0.8	0.85

Table 6.16 Debris decomposition rates

Debris 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

Table 6.17 Plantation types, wood densities, carbon contents and management regimes

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
South Australia	Eucalyptus plantations	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% thinning @ 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

Region(s)	Species	Density	CC% Leaf	CC% Branch	CC% Wood	CC% Bark	CC% Fine Roots	CC% Coarse Roots	Regime Description
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

Estimating Changes in Soil Carbon

Soil carbon is estimated using FullCAM operating in estate mode with a recent soil carbon map (Appendix 6.E) as the base input data. FullCAM simulates changes in soil carbon using Roth-C soil carbon model. Roth-C model computes turnover of organic carbon in soils, taking into account clay content, temperature, moisture content, plant material inputs and plant cover.

Activity data

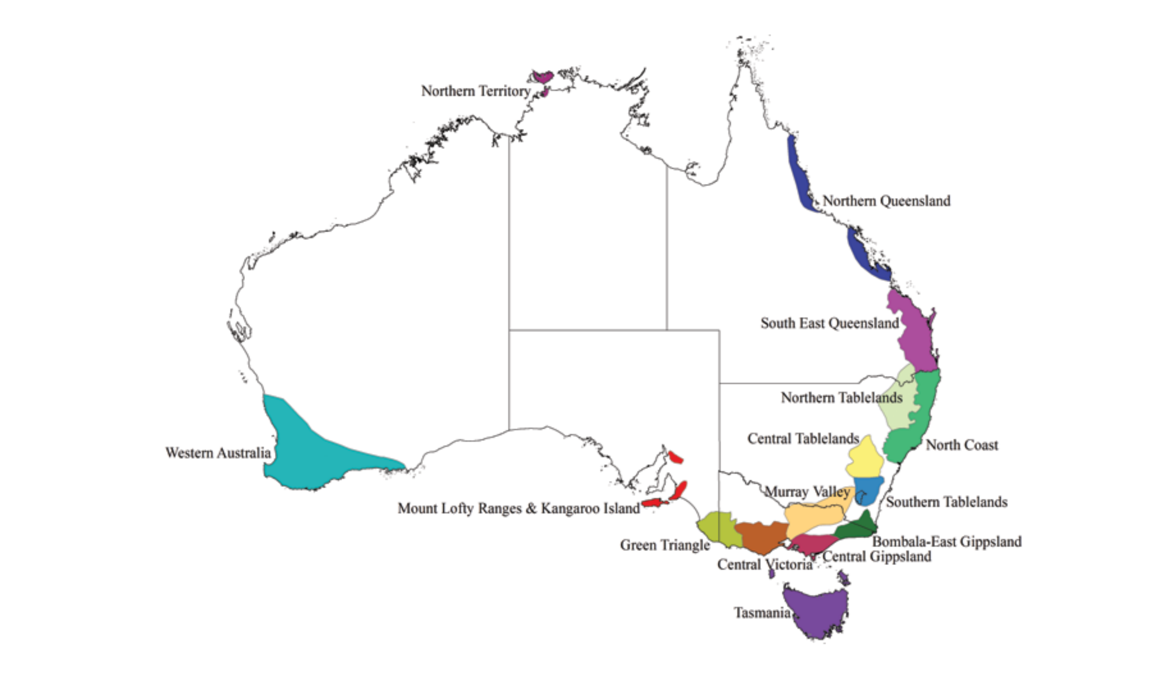
Activity data for *plantations* is sourced from the National Plantation Inventory (NPI) (Table 6.18). The plantation area data is reported on the basis of the 14 NPI regions (Figure 6.13). Three broad classes of forest are defined - Short Rotation Hardwood (SRH), Long Rotation Hardwood (LRH) and Softwood (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).

Allocations of the SRH, LRH and SW classes are made to the region and species specific plantation models as described by Turner and James (2002).

Table 6.18 Areas of land converted to plantation from 1940-1989

Year	Area (ha)	Year	Area (ha)
1940	386	1965	15,684
1941	587	1966	18,017
1942	788	1967	20,351
1943	989	1968	22,689
1944	1,191	1969	25,014
1945	1,099	1970	27,352
1946	1,346	1971	28,520
1947	1,593	1972	29,687
1948	1,840	1973	30,854
1949	2,087	1974	32,021
1950	2,415	1975	32,119
1951	2,498	1976	32,281
1952	2,581	1977	32,605
1953	2,664	1978	32,281
1954	2,747	1979	32,119
1955	2,743	1980	29,489
1956	2,828	1981	27,853
1957	2,913	1982	24,581
1958	2,998	1983	27,853
1959	3,083	1984	29,489
1960	6,311	1985	31,125
1961	8,651	1986	32,761
1962	10,991	1987	34,397
1963	13,331	1988	36,033
1964	15,671	1989	37,669

Figure 6.13 The National Plantation Inventory regions



6.5.3 Other Native Forests

Other native forests include those forests that are comprised of endemic species, which are not *harvested native forests* or *plantations.* The *other native forests* sub-division includes protected areas (such as Wilderness areas and National Parks) not previously subject to harvesting and areas of extensive forests and woodlands.

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 natural disturbance and recovery patterns over time; and
- not expected to exhibit consistent trends toward either emissions or removals over the longer term, but will be highly variable over shorter time periods.

The major components of the estimated net emissions comprise estimates for the following activities and disturbances:

- prescribed burning of temperate forests;
- wildfire in temperate forests; and
- prescribed burning and wildfire in savanna forests.

6.5.3.1 Methodology

Temperate forests

Prescribed burning includes managed fires that aim to reduce debris loads in *other native forests* and is typically low intensity, removing only 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. It is rare in Australian native systems for a fire to be 'stand-replacing'. However, even in instances where this does occur, 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 caused by 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* and the emissions of non-CO_2 gases is based on the areas burnt (Figure 6.3), and parameters and input data such as fuel loads. It is assumed that the debris mass recovers within five years following the wildfire.

The burnt area activity data for wildfires is sourced from Landgate based on burnt area as detected using the AVHRR sensor. In the previous submission wildfire burnt areas were compiled by CSIRO based on state agency reporting. Prescribed burning activity data are sourced from CSIRO based on reporting by state agencies.

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

$$M_{jk} = A_{jk} * FL_{jk} * Z_{jk} * 10^{-3} \qquad (4.A.1\_1)$$

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 6.19 and 6.20),

Z_{jk} = burning efficiency (Table 6.21).

Annual CO_2 emissions are calculated as:

$$E_{ijk} = M_{jk} * CC_{jk} * C_i \qquad (4.A.1\_2))$$

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 6.22),

C_i = 3.67 factor to convert from elemental mass of gas species *i* to molecular mass.

Annual CO_2 removals are calculated as:

$$R_{ijk} = \Sigma(M_{jk} * CC_{jk)\,/\,t} * C_i \qquad (4.A.1\_3))$$

Where: R_{ijk} = annual removals of CO_2 following biomass burning *(Gg),*

ΣM_{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 6.22),

C_i = 3.67, factor to convert from elemental mass of gas species *i* to molecular mass.

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

$$E_{ijk} = M_{jk} \times CC_{jk} \times EF_{ijk} \times C_i \qquad (4.A.1\_4))$$

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 6.22),

EF_{ij} = emission factor for gas *i* from vegetation (Table 6.23),

C_i = factor to convert from elemental mass of gas species *i* to molecular mass (Table 6.24), and total annual emissions for NO_x and N_2O are:

$$E_{ijk} = M_{jk} \times CC_{jk} \times NC_{jk} \times Ei_{jk} \times C_i \quad (4.A.1\_5))$$

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 6.22)

NC_{jk} = nitrogen to carbon ratio in biomass (Table 6.22)

EF_{ijk} = emission factor for gas *i* from vegetation (Table 6.23)

C_i = factor to convert from elemental mass of gas species *i* to molecular mass (Table 6.24)

Table 6.19 Fuel load for Prescribed Burning of Temperate Forest in Australia (Mg dry matter ha^{-1})

State	ACT[(a)]	NSW[(a)]	NT[(a)]	Qld[(a)]	SA[(b)]	Tas[(b)]	Vic[(a)]	WA[(a)]
	FL_{jk} (Mg ha^{-1})							
Load	17.6	18.2	4.1	9.7	9.6	20.0	17.9	12.0

(a) State agencies, (b) Tolhurst (1994)

Table 6.20 Fuel load for Temperate Wildfires in Australia (Mg dry matter ha^{-1})

State	ACT[(a)]	NSW[(a)]	NT[(a)]	Qld[(a)]	SA[(b)]	Tas[(b)]	Vic[(a)]	WA[(a)]
	FL_{jk} (Mg ha^{-1})							
Load	35.2	36.4	7.2	19.4	19.2	40.0	35.8	33.4

(a) State agencies, (b) Tolhurst (1994)

Table 6.21 Burning efficiencies for Prescribed Burning and Wildfires in Australia

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

Tolhurst (1994)

Table 6.22 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

(a) Hurst *et al.* (1994a,b)

Table 6.23 Mean emissions 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

Hurst *et al.* (1996) mean of 4 Australian temperate forest fires.

Table 6.24 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

Slash Burning

The CO_2 emissions associated with slash burning in h*arvested native forests* are estimated by *FullCAM*. The mass of carbon burnt annually (FC_{jk}) is taken directly from *FullCAM* and is used to estimate the CO_2 and non-CO_2 gas emissions associated with slash burning.

There are no direct measurements of trace gas emissions from slash burning 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:

$$E_{ijk} = FC_{jk} * EF_{ijk} * C_i \quad (4.A.1\_6))$$

and for total annual emissions for NO_x and N_2O are:

$$E_{ijk} = FC_{jk} * NC_{jk} * EFi_{jk} * C_i \quad (4.A.1\_7))$$

Where: FC_{jk} = annual fuel carbon burnt in slash burning (obtained from *FullCAM*) (Gg),

EF_{ijk} = emission factor for gas *i* from vegetation (Table 6.23),

NC_{jk} = nitrogen to carbon ratio in biomass (Table 6.22)

C_i = factor to convert from elemental mass of gas species *i* to molecular mass (Table 6.24).

For the purpose of ensuring that the inventory reports *anthropogenic* emissions, the guidance of the natural disturbance provision (IPCC 2014, section 2.3.9) was applied to the estimation of reported emissions due to wildfire in temperate region forests. The IPCC default method for the estimation of the background level and margin was applied to wildfire emissions over the calibration period of 2000-2012, consistent with the method used for Forest Management lands (see Chapter 11). The parameters estimated were: background level 19.04 Mt CO_2-e and margin 22.19 Mt CO_2-e. The application of the natural disturbance provision resulted in the exclusion of emissions and removals on two occasions: in 2003 and 2007 which rank highest and second highest in terms of burnt area in the time series (Figure 6.3). Events such as these are closely linked to variations in climate on a decadal scale and both of these events occur within the period of the 'millennium drought'.

A five year moving average was applied to the resulting estimates to enable long term trends in emissions to be more clearly presented. The raw emissions and emissions following the application of the moving average are shown in Table 6.25.

Savanna forests

The CO_2 emissions and removals associated with the burning and subsequent regrowth of savannas that are classified as *forest land* are reported under 4(V.A.1) *forest land remaining forest land*. Non-CO_2 emissions are reported under 3.E *prescribed burning of savannas* in the *agriculture* sector. Savanna fires occur on lands classified as *forest remaining forest*, *forest converted to grassland* and *grassland remaining grassland*.

Emissions and removals of carbon dioxide are estimated for the coarse and heavy fuel size classes for savanna woodlands. For some vegetation and fuel classes (savanna grasslands, temperate grasslands and the fine and shrub fuels for savanna woodlands) the carbon lost during the fire recovers within a year so there is not net change in carbon stocks.

The CO_2 emissions from savanna burning are estimated from the mass of fuel burnt (M_{ijklmt} Gg) as calculated in Equation 4E_3 (section 5.7) and the carbon content of the fuel:

$$E = \Sigma_i \Sigma_j \Sigma_l \Sigma_m \Sigma_t (M_{ijklm,t} \times CC_{jm} \times C_g) \quad (4.A.1\_8))$$

Where:

$M_{ijklm,t}$ = mass of course and heavy fuels burnt (Gg) (see section 5.7)

CC_{jm} = carbon content (Appendix Table 5.K.7);

C_g = elemental to molecular mass conversion factor (44/12)

The CO_2 removals are estimated as the growth increment on land that is burnt in the inventory year and the regrowth increment on lands that were burnt in previous years. The growth increment on burnt lands ($MAB_{ijklm,t}$ Gg DM) is calculated as the difference in the fuel load at the time of burning (t) and the fuel load in the previous year (t-1):

$$MAB_{ijklm,t} = AB_{ijkl,t} \times (FL_{ijkm,t} - FL_{ijkm,t-1}) \times 10\text{-}3 \quad (4.A.1\_9))$$

The growth increment on previously burnt lands ($MNB_{ijkm,t}$ Gg DM) is calculated as:

$$MNB_{ijkm,t} = ANB_{ijk,t} \times (FL_{ijkm,t} - FL_{ijkm,t-1}) \times 10^{-3} \quad (4.A.1\_10))$$

The CO_2 removals are:

$$R = \Sigma_i \Sigma_j \Sigma_l \Sigma_m \Sigma_t ((MAB_{ijklmt} \times CC_{jm}) + (MNB_{ijkmt} \times CC_{jm}))) \times C_g \times -1 \quad (4.A.1\_11)$$

Where:

$AB_{ijkl,t}$ = area of savanna woodland burnt (ha)

$ANB_{ijkl,t}$ = area of savanna woodland burnt in previous years (1-11 years since last burnt) (ha)

$FL_{ijkm,t}$ = fuel load (t DM) as calculated in equation 3E_2 (section 5.7)

CC_{jm} = carbon content (Appendix Table 5.K.7);

C_g = elemental to molecular mass conversion factor (44/12)

Net CO_2 emissions/removals are calculated as:

$$\text{Net } CO_2 = E + R \quad (4.A.1\_12)$$

The emissions and removals from this source are highly variable (i.e moving from a net source to a net sink from year to year) largely reflecting variations in climatic conditions (Meyer 2004). This means that the 'signal' of the impact of human activities, including mitigation measures, on emissions and removals in this category are not discernible against the 'noise' of the climate driven variability. Through the Carbon Farming Initiative and future Emission Reduction Fund projects the Australian Governments is supporting mitigation activities to reduce emissions from savanna burning. To reduce the extent to which the climate variability is captured, estimates are reported as five year averages. The five year period was selected as it allows the underlying trends in the annual data to become apparent (i.e. emissions rising to a peak in 2001 but no discernible trend between 1996-2012) and it is consistent with suggested periodic measurement time-frames for the estimation of stock changes.

6.5.3.2 Emission estimates

Emissions in the Other Native forests classification are presented in Table 6.25.

Table 6.25 Biomass burning emissions in the *forest land remaining forest land* classification

	Emissions (Mt CO_2)				
Year	Temperate forest wildfire (raw – data not counted in total)	Temperate forest wildfire (five year moving average)	Prescribed burning (temperate forests)	Savanna forest prescribed burning and wildfire	Total
1990	-4,508	-4,917	838	1,636	-2,442
2000	-2,395	6,600	840	1,597	9,038
2005	-46	5,629	764.5	2,115	8,508
2006	-2,965	3,607	615.2	1,979	6,202
2007	19,039	7,904	636.7	3,256	11,797
2008	8,929	13,231	727.7	2,851	16,810
2009	14,562	11,939	687.1	2,777	15,403
2010	26,592	8,020	707.3	3,490	12,217
2011	-9,428	8,707	571.7	2,953	12,232
2012	-556	794	491.0	1,674	2,959
2013	12,367	4,568	618.6	3,057	8,244

6.5.4 Fuelwood Consumed

Emissions of CO_2 from the consumption of *fuelwood* are estimated using data on the residential and industrial consumption of wood and wood-waste obtained from DIS (formerly BREE). Emissions from the use of log processing residues, typically consumed to support the energy needs of the timber and paper industry, are included under the transfers from live biomass into the wood products pool. This ensures there is no double counting between this and the collections of firewood from DOM for the residential and industrial sectors.

There is no double counting of *Fuelwood consumed* between the LULUCF and Energy sectors as emissions from biomass consumption are provided as an information item but are not reported as emissions in the Energy sector.

6.5.5 Uncertainties and Time Series Consistency

Uncertainties for the *forest land remaining forest land* sub-category are estimated to be ±30% for CO_2. The majority of this uncertainty is due to the *other native forests* sub-division. Uncertainty in the *plantations* is expected to be less than 10 per cent. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to methodology.

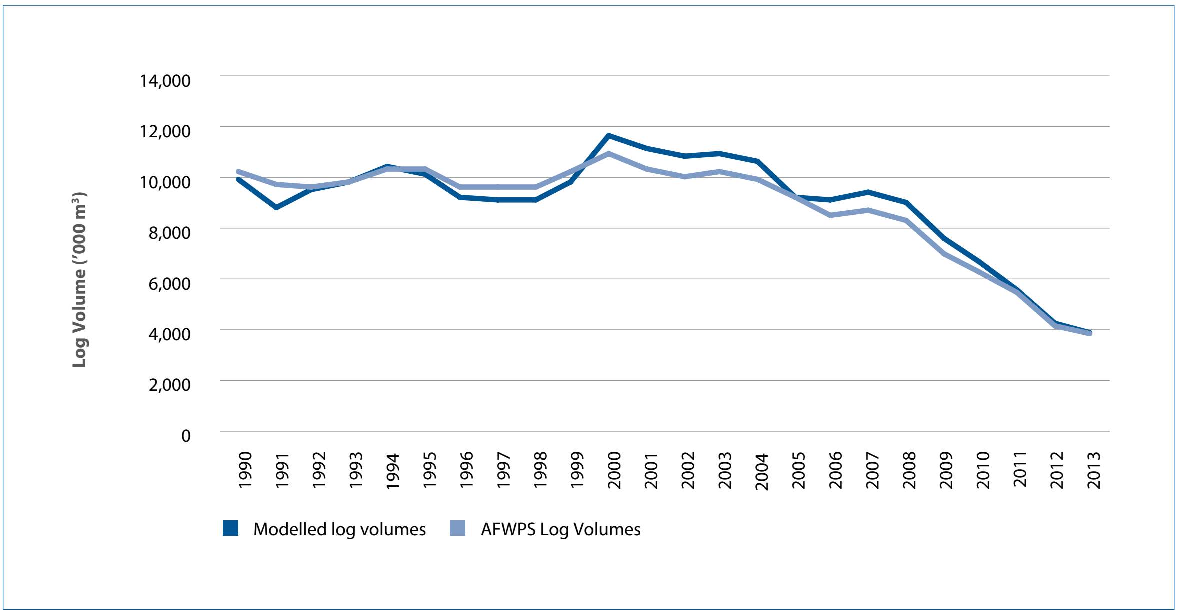
6.5.6 Source Specific QA/QC

6.5.6.1 Harvested Native Forests

Data on native forest harvesting is derived from roundwood log volumes removals for each state (ABARES, 2014a) using a historical relationship between roundwood removals and harvest area data collated by state agencies. Roundwood log volumes are published in the biannual Australian Forest and Wood Products Statistics report (ABARES, 2014a), a comprehensive dataset relating to Australia's forestry sector, including time series data on forest and wood products resources, production, consumption, trade and employment. Historical harvest area data was obtained from a combination of annual reports of Australian State agencies, financial statements, and spatial harvest area data. These data sets have been subject to review processes and financial auditing. Data on stem to whole tree conversions, carbon contents and wood densities are within the ranges published in Gifford, 2000a; Gifford, 2000b; Ilic *et al.* 2000; and Snowdon *et al.* 2000. The estimated slash produced by forest harvesting is in line with independent studies of slash production from forest harvesting for major Australian harvested forests (Snowdon *et al.* 2000; Ximenes *et al.* 2008a).

The *harvested native forests* model was verified by comparing the log volume, calculated using the harvested native forest model used for emissions estimation with national statistics of round wood production in native forest, recalculated by calendar year instead of financial year as published (ABARES, 2014a) (Figure 6. 14). The log volume from the *harvested native forest* model was estimated by converting the carbon removed from forests as forest products in to stem volume, assuming a stemwood carbon percentage of 52% and average wood basic density of 750 kg m-3. The modelled log volumes closely track the published statistics over time.

Figure 6.14 Estimated net removals in Harvested Native Forests, new Tier 2 model compared to the former model used in previous inventories



6.5.6.2 Plantations

Biomass (including the effects of ongoing management) and soil carbon are estimated using FullCAM operating in estate mode (Tier 2). It comprises of 34 models implementing tree yield formula.

The calibration and validation of the *FullCAM* model, along with the associated quality assurance and quality control programme are described in Appendix 6.B. An independent review of the models used to estimate emissions and removals in the *Plantations* category was undertaken by CSIRO in 2001.

6.5.7 Recalculations Since the 2012 Inventory

Harvested native forests

The *Harvested Native Forests* classification within the *forest land remaining forest land* sub-category has been updated as part of the refinements to the methodology and activity data necessitated by new reporting requirements for Forest Management under the Kyoto Protocol. The refinements include the use of new activity data on forest harvesting, and associated methodological refinements enabled by the new, nationally consistent time series of activity data.

Revised activity data on the volume of roundwood removals in each state (ABARES, 2014a) was used to calculate the area of native forest harvested each year, based on a state-specific 'productivity' conversion factor from volume to hectares. The impact of using the new activity data is a small increase in emissions (i.e. reduced net sink) which is consistent with an increase in harvesting in 2012 of 5,684 ha using the new data, although on average since 2000 the new activity data results in an annual harvesting reduction of 279 ha (or -0.002%).

Other refinements were made to the estimation of emissions from the *Harvested Native Forests* classification. The method of historical extrapolation has also been improved to maintain consistency of age class, forest type and silvicultural treatment with the activity data commencing in 1990. This has allowed the model to reach a steady state prior to 1990 so that emissions estimates better reflect variations in the harvesting data. As a result of this pre-1990 model run-in, there are also fewer modelled CO_2e removals (i.e. a smaller carbon sink) from *Harvested Native Forests*, equivalent to 4.97 Mt CO_2e per year on average since 2000.

Other native forests

The principal change concerns the implementation of a revised approach to the estimation and reporting of anthropogenic emissions and removals from forest fires. The Department of the Environment has chosen to implement an estimation and reporting framework consistent with that applied to Forest Management forests under the Kyoto Protocol. This change is designed to make the UNFCCC national inventory more comparable, more accurate and representative of long term net emission trends, and more policy-relevant and useful. Over the period 1990 to 2013 the effect of applying the five year moving average was to reduce average annual emissions from 4,893 Gg CO_2-e to 4,225 Gg CO_2-e – the small reduction due to an end point issue with a high raw emissions value in 2012.

Additional revisions are due to the implementation of a spatial monitoring system consistent with Australia's definition of forest. The new system tracks land where forest cover temporarily falls below the 20 per cent threshold due to natural events (e.g. fire, forest dieback) or which occurs within a land tenure where the area is expected to revert to forest (for example, a harvested forest or national park) (see section 6.4.1). A change in land use is deemed to occur when the monitored grasslands have failed to revert to forest after the specified monitoring period. Otherwise no change in land classification occurs.

Under the implemented monitoring system, ephemeral gains or losses of forest cover are not identified as a change in land classification. While all gains and losses of forest cover are monitored on an ongoing basis, only permanent gains or losses are used to generate estimates of reported net emissions.

Australia has also implemented a new monitoring system for wildfire activity based on the AVHRR sensor. This new method is described in chapter 11.6.4.

Previously, an estimate for sequestration from 'woody thickening' of forests was reported (-12.2 Mt CO_2-e per year, in all years). In this inventory, the assumption of 'woody thickening' has been discarded and replaced by estimates of the effects of changes in identifiable management actions - in particular, fire management - and where there is an observable activity data in the form of woody encroachment/changes in sparse woody extent.

For the *plantations* sub-category refinements include the implementation of the tree yield formula method for estimating tree growth. Changes in soil carbon are also estimated with *FullCAM* using Roth-C soil carbon model, a recent soil carbon map (Appendix 6.E) as the base input and location specific climate and site data. As a result of this the total annual carbon change, during 1990-2013, shows greater variation compared to variations in the previous submission, reflecting variability in climate data and site productivity over the years. The annual carbon stock change, during 1990-2013, in soil also varied from year to year whereas it increased gradually and consistently, in the previous submission.

Table 6.26 Forest land remaining forest land: recalculation of total CO_2-e emissions (Gg), 1990-2012

Year	2014 submission	2015 submission	Change	
	(Gg CO_2)	(Gg CO_2)	(Gg CO_2)	(%)
1990	-43,732	-28,948	14,784	34
2000	-48,626	-2,550	46,076	95
2001	-17,463	1,141	18,604	107
2002	1,820	1,446	-374	-21
2003	160,849	2,649	-158,200	-98
2004	-81,169	721	81,890	101
2005	-79,628	-5,837	73,791	93
2006	-87,133	-4,720	82,414	95
2007	-10,214	993	11,207	110
2008	-80,479	4,446	84,926	106
2009	-38,726	147	38,872	100
2010	-28,087	-8,203	19,884	71
2011	-82,062	-12,898	69,164	84
2012	-18,888	-25,420	-6,532	-35

As shown in Table 6.26 emissions in the forest land remaining forest land classification have been revised up throughout the time-series except for epochs of extreme fire activity (n.b. 2002 and 2003) and the year 2012. The general upward revision of reported emissions estimates has resulted from a number of factors. These include:

- The application of the rules of the natural disturbances provision (IPCC 2014a) which has resulted in the removal of extremely high and low emission estimates from the reported time-series.
- The application of a five-year moving average to the reported emissions estimates. Over the period 1990-2012 the *forest land remaining forest land* classification has generally been a moderate sink of emissions. The application of the five-year moving average to the reported estimates has moved the reported estimates closer to a neutral emissions state due to the effects of extreme emission events associated with wildfires on the calculation of the five year average of emissions.

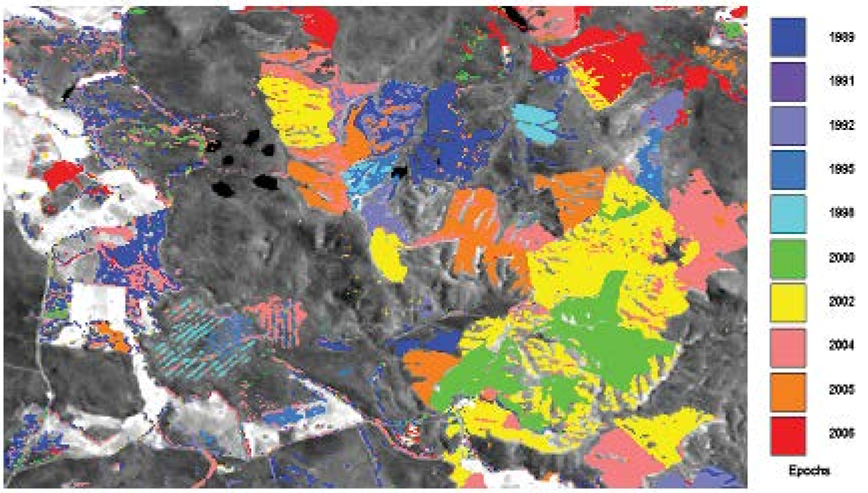
The recalculations shown in Table 6.26 are also affected by the exclusion of the estimated sink due to woody thickening and ephemeral changes in forest cover. A new monitoring system has also been implemented in order to monitor for wildfires. The new system is based on the AVHRR sensor (see chapter 11.6.4).

6.5.8 Source Specific Planned Improvements

Harvest Native Forests and Plantations

The Department of the Environment is continuing to develop capacity to have comprehensive use of Tier 3, Approach 3 modelling in the future for the *plantations* and *harvested native forests* sub-categories. A preliminary map showing the distribution of pre-1990 plantations has been developed which will be updated further based on remote sensing and other ancillary information.

Figure 6.15 An example of harvested area detection using Australia's time-series remote sensing data. Coloured areas represent detected harvest areas in a particular epoch



Savanna Forest Biomass Burning

Further analysis of the savanna woodland fuel accumulation curves is currently underway. Once the analysis is complete the accumulation curves used in the inventory method will be reviewed and revised where necessary.

6.6 Source Category 4A.2 Land Converted to Forest Land

6.6.1 Grassland converted to Forest Land

Grassland converted to forest land contains forest established on land that was previously non-forest. These conversions include plantations and the regeneration of natural seed sources.

6.6.1.1 Methodology

The emissions and removals from *Grassland converted to forest land* are estimated using the spatially explicit (Approach 3) and the non-spatially explicit (Approach 2) capabilities of the Tier 3 *FullCAM* modelling system. The regeneration of forests from natural seed sources is modelled using the Approach 2 system while forest establishment by planting is modelled using the Approach 3 system. A full description of the modelling system is provided in Appendix 6.B and 6.D, and Waterworth *et al*, 2007; Waterworth and Richards, 2008.

Reporting includes carbon in living biomass, dead organic matter (DOM) and soil pools.

The areas of *grassland converted to forest land* are drawn from remotely sensed data as per the methods described in Appendix 6.A. The time-series of Landsat satellite data (25 m) is analysed to provide the previous vegetation cover, area, time of establishment and, if applicable, type of plantation (Caccetta and Chia, 2004).

Each individual 25 m × 25 m pixel identified as being a *plantation* is modelled through time from the time of establishment. Each 25 × 25 m model takes into account the age, plantation type, management and site conditions to estimate emissions and removals.

Estimating Changes in Living Biomass

Forest Growth

The estimation of net emissions from land converted to forest through regeneration of natural seed sources is estimated using FullCAM operated in Approach 2 mode (Appendix 6.B and 6.D). The model is parameterised to model the growth of native forest vegetation from seed.

To estimate plantation growth the native forest regrowth model (Appendix 6.B and 6.D) is supplemented to include functions that represent Type 1 and Type 2 growth responses (Snowdon and Waring, 1984) and the impact of using non-endemic species (Appendix 6.F). Type 1 management practices advance or retard stand development (effectively age) but do not increase underlying site productivity over the life of the rotation (e.g. weed control at establishment). Type 2 treatments increase (or decrease) a site's carrying capacity in the longer term (e.g. phosphorus application).

Stem to Whole Tree Mass Conversions

FullCAM calculates belowground biomass (roots) using an empirical approach derived from expansion factors reported in Snowdon *et al.* (2000) and Mokany *et al.* (2006). This method allows allocation to vary between sites and species within set ranges based on age, site productivity and level of stand development.

Carbon Contents

Studies of the carbon fractions of above and below ground biomass components for Australian vegetation were used to provide the parameters for the carbon fractions of tree components in the model (Table 6.27, Gifford, 2000a and 2000b).

Table 6.27 Percent carbon of tree components – *land converted to forest land*

Tree Component	Hardwood carbon content %	Softwood carbon content %	Other (environmental plantings) carbon content %
Stems	50.0	51.0	50.0
Branches	46.8	51.4	46.8
Bark	48.7	53.3	48.7
Leaves	52.9	51.1	52.9
Coarse roots	49.2	50.4	49.2
Fine roots	46.1	48.4	46.1

Forest management practices

The Tier 3, Approach 3 modelling system is supported by a comprehensive database of the plantation management practices used in Australia since 1970 (Waterworth and Richards, 2008). The plantation management database contains information on management practices for each tree species within each region. The range of possible management actions is shown in Table 6.28. The management regimes are assigned frequencies within each region to enable time series management regimes to be developed for each plantation pixel through time (Table 6.29) (Waterworth and Richards, 2008).

Table 6.28 Management actions, the *FullCAM* events used to represent them and the choices available through parameterisation of the *FullCAM* event

Management action	*FullCAM* event type	Effect in model	Standard event options
Mechanical weed control	Plough (agriculture)	Moves herbaceous species carbon to debris, mulch and soil	Spot Strip Broadcast
Chemical weed control	Herbicide event (agriculture)	Kills herbaceous species cover, moving it to debris	Spot application Strip application Broadcast application
Chopper roll	Chopper roll (forest)	Transfers woody debris to faster decaying 'chopped wood' pool	Chopper roll
Management fires	Forest fire (forest)	Transfers carbon from trees to debris and atmosphere, and debris to the atmosphere or soil pools.	Prescribed burn Broadcast burn Windrow and burn
Wildfire[1]	Forest fire (forest)	Transfers carbon from trees to debris and atmosphere, and debris to the atmosphere or soil pools.	Trees killed Trees not killed
Grazing	Graze (agriculture)	Removes aboveground herbaceous species mass and varies root slough	Normal Heavy
Plant trees	Plant trees (forest)	Establishes trees on a site	Different initial masses depending on stocking
Cultivation	Plough (agricultural)	Moves herbaceous species carbon to debris, mulch and soil	Spot cultivation Strip cultivation Broadcast cultivation
Forest thin and harvest and pruning	Forest thin (forest)	Moves tree components to products or debris, debris to bioenergy	Varies by time, species and region.
Fertiliser application[2]	Type 1 or 2 event (forest)	Varies tree growth based on the type and intensity of fertilisation (see Snowdon, 2002).	Normal N fertilisation Applied to any treatment that affects tree growth
Fertiliser application[3]	Fertiliser application (forest and agriculture)	Adds N to the mineral N pool	Different levels of N addition (kg ha^{-1})

Source: Waterworth and Richards (2008)

1 Although not a management practice, wildfire events allow for the future spatial modelling of their effect on carbon stocks. See the discussion for more details.

2 *FullCAM* only requires kg N ha^{-1} when using the nitrogen cycling model capacity.

3 Applies only when using the nitrogen cycling model capacity.

Table 6.29 Plantation Management Database - Time series management regime

Year	Day	Species	Management action	*FullCAM* event
0	152	Agricultural species	Cultivation: Strip plow	Plow
0	166	Agricultural species	Weed control initial: Blanket herbicide	Herbicide
0	196	Pinus radiata	Plant trees: seedlings normal stocking	Plant trees
0	196	NA	Forest percentage -> determined by tree yield formula	Forest percentage Change
0	196	Pinus radiata	Weed control - Standard (All 1980-present)	Type 1 Forest Treatment
0	196	Pinus radiata	Starter fertiliser - normal	Type 1 Forest Treatment
1	196	Agricultural species	Weed control post planting: Strip herbicide	Herbicide
10	196	Pinus radiata	Thin 1 (SthnTbl ACT 1978-1996)	Forest Thin
10	196	Pinus radiata	Fertilisation: Mid-rotation (Medium)	Type 1 Forest Treatment
10	197	Pinus radiata	Prune (Selective 33%)	Forest Thin
20	196	Pinus radiata	Thin 2 (SthnTbl ACT 1978-1996)	Forest Thin
20	196	Pinus radiata	Fertilisation: Mid-rotation (Medium)	Type 1 Forest Treatment
30	196	Pinus radiata	Thin 3 (SthnTbl ACT 1987-1996)	Forest Thin
40	196	Pinus radiata	Thin clearing Pa (SthnTbl ACT 1987-1996)	Forest Thin

The species table contains information on tree species characteristics including forest growth model parameters, carbon allocation to tree components over time, biomass carbon percentages, basic wood density, turnover rates for each tree component, decay and product use data. These data allow *FullCAM* to model forest growth for any point based on the site and climate data using the methods described previously.

Estimating Changes in Debris

Turnover and Decomposition Rates

The turnover rate of leaves and fine roots (Table 6.30) affects both the amount of fine litter on the forest floor and subsequently most of the contribution to soil carbon. The tree component turnover rates applied in the model were guided by work by Paul *et al.* (2004).

Decomposition rates determine the rates of loss of carbon back to the atmosphere as the debris breaks down. The balance of these two factors determines the amount of debris on site, excluding the effects of management. The amount of carbon moved from living biomass to the DOM pools due to forest harvesting is determined in the model by the age, type of harvest and species characteristics.

Table 6.30 Tree component annual turnover rates

Tree Component	Softwood Turnover yr^{-1}	Hardwood Turnover yr^{-1}
Branches	0.03	0.05
Bark	0.05	0.07
Leaves	0.3	0.5
Coarse Roots	0.07	0.1
Fine Roots	0.8	0.85

The rates of decomposition applied in the model have been guided by the work of Mackensen and Bauhus (1999). Table 6.25 shows the decomposition rates applied.

Table 6.31 Debris decomposition rates

Litter Component	Breakdown Rate yr^{-1}
Deadwood	0.1
Bark Litter	0.5
Leaf Litter	1.0
Coarse Dead Roots	0.4
Fine Dead Roots	1.0

Estimating Changes in Soil Carbon

Soil carbon is estimated using the fully spatially explicit approach described in Appendix 6.B and Appendix 6.E, with a recent soil carbon map as the base input data for modelling post-1990 *plantations*.

Activity data

The activity data for the *land converted to forest land* classification is drawn from the remote sensing programme (see Appendix 6.A) (Table 6.32).

Table 6.32 Cumulative area of *land converted to forest land* 1990-2013

Year	Area (ha)
1990	330,252
1995	933,942
2000	1,473,802
2005	2,207,667
2010	3,120,621
2011	3,390,026
2012	3,528,674
2013	3,545,465

6.6.2 Uncertainties and Time Series Consistency

Uncertainty in the *land converted to forest land* sub-categories is expected to be less than 12%. Further details are provided in Annex 2. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to methodology.

6.6.3 Source Specific QA/QC

The calibration and validation of the *FullCAM* model, along with the associated quality assurance and quality control programme are fully described in Appendices 6.B and 6.F.

To conduct quality control of the Tier 3, Approach 3 model, a series of Tier 2 models based on 48 plot files drawn from within the *FullCAM* modelling framework were selected. The Tier 2 models are parameterised with site average climate (rainfall, temperature and open pan evaporation) and forest productivity data. The selected plot files are representative of the most common species and management regimes within each state and National Plantation Inventory (NPI) region (Figure 6.13).

The area of each type of forest (hardwood, softwood and native planting) in each region was determined from the land sector remote sensing programme. As *FullCAM* is used for both the Tier 2 and Tier 3 models, the model inter- comparison primarily represents a test of the:

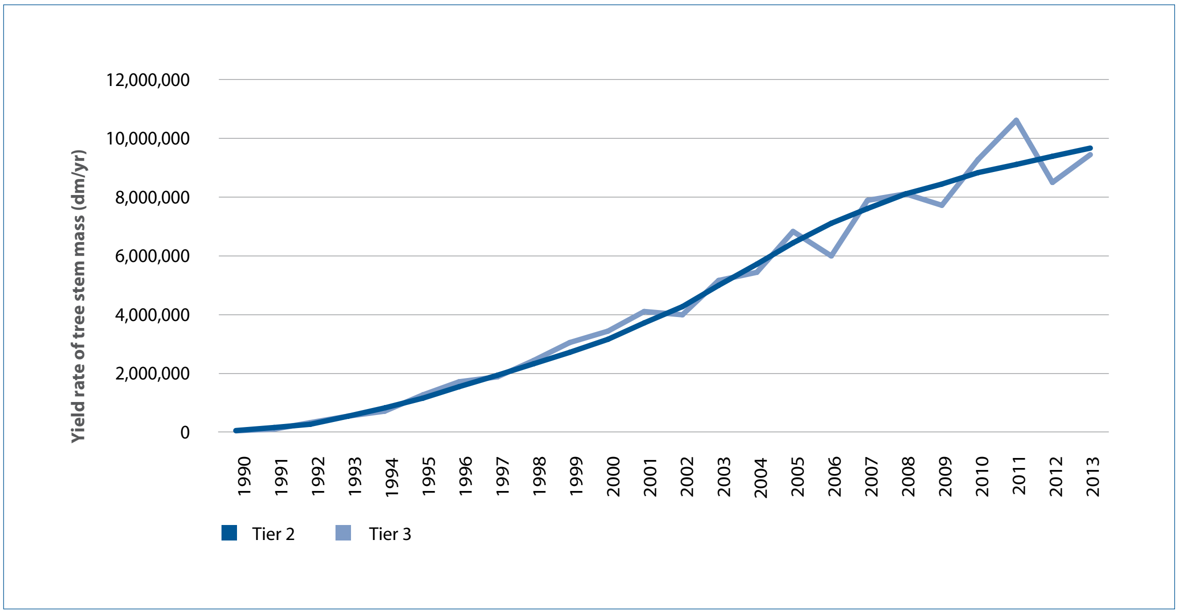
1. Approach 3 component of Australia's inventory method for *grassland converted to forest land*; and
2. The use of annually updated, spatially explicit climate and forest productivity data (Tier 3) as compared to site average data (Tier 2).

The Tier 2 and Tier 3 models are largely in agreement from 1990 through to 2013 (Figure 6.16). The key difference between the two models is the variability in the Tier 3 outputs compared to the invariable results from the Tier 2 models.

A comparison of the yield rate of tree stem mass (Figure 6.16) showed a close agreement between the two models. The Tier 3 model results are more variable, reflecting the ability of the Tier 3 model to represent the effects of spatial and temporal variability in climatic variables on plant growth.

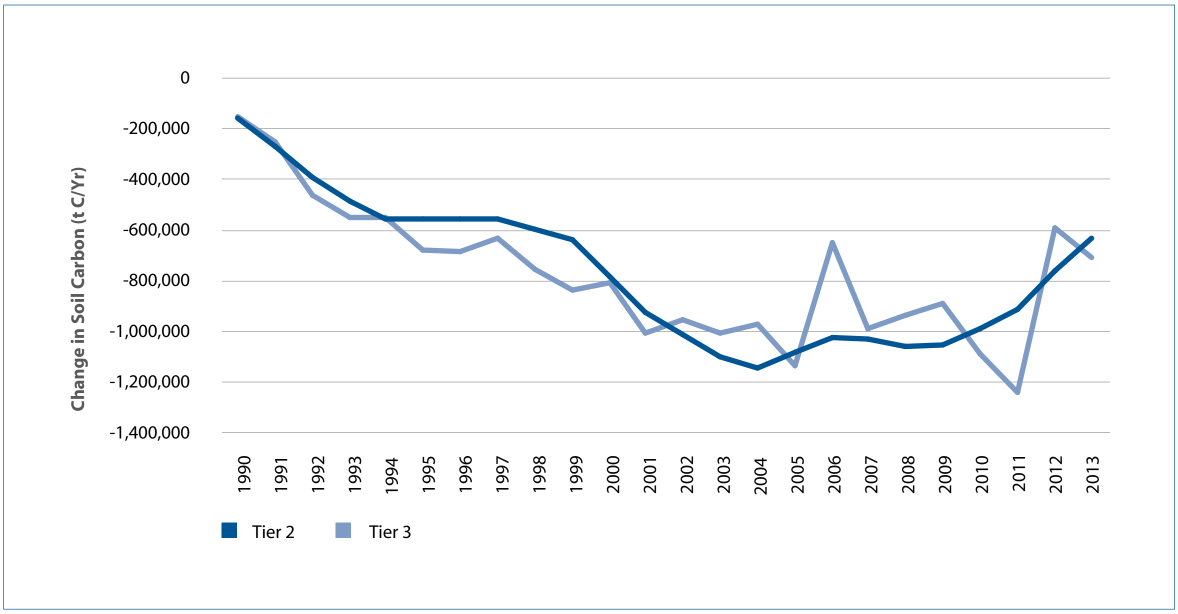
Over the period 2010-2012, the Tier 3 yield rate of stem mass increased and decreased relative to the Tier 2 models (Figure 6.16). These variations were due to conditions for plant growth being close to optimal in 2011 and then becoming less optimal in 2012. By 2013 conditions for plant growth within the post 1990 plantation estate has returned to approximately average. The variability in plant growth in the Tier 3 model is driven by the spatially and temporally explicitly Forest Productivity Index (Appendix 6.C), which is a parameter of the Tree Yield Formula (Appendix 6.B) within the FullCAM model framework. As a result of this deterioration in conditions for plant growth, net emissions in the *grassland converted to forest land* classification increased by 7.9 Mt CO_2-e between 2011 and 2012 (Figure 6.16).

Figure 6.16 Yield rate of tree stem mass (dm t/yr) output from Tier 2 and Tier 3 methodology, 1990-2013



The results of the Tier 3 soil carbon model (Figure 6.17) were also compared to the results of the Tier 2 model based on the same 46 plot files described earlier in this section. The comparison shows that the trend is similar but that emissions estimated from the Tier 3 model are more variable due to the effects of spatial variability in soil and climatic conditions and better representation of the effects of previous land use on initial soil carbon stocks.

Figure 6.17 Soil carbon (t C/yr) output from Tier 2 and Tier 3 methodology, 1990-2013



6.6.4 Recalculations Since the 2012 Inventory

Improvements and updates made to estimates of emissions and removals in the *land converted to forest land* sub-category included:

- implementation of a new baseline map of organic carbon in Australian soil (Appendix 6.E.);
- implementation of a clay surface from the Australian three-dimensional soil grid (Appendix 6.E);
- recalibration of soil decomposition rates (Appendix 6.B);
- the inclusion of *land converted to forest land* in the period 1972-1989 into the Land converted to forest land classification; and
- the inclusion of land converted to forest due to human induced promotion of natural seed sources since 1990.

The inclusion of Land converted to forest pre-1990 added 0.196 million hectares of land and increased the net sink in 2013 by 0.26 Mt CO_2-e. The inclusion of human induced promotion of natural seed sources since 1990 added approximately 2.18 million hectares of land and increased the net sink in 2013 by 3.15 Mt CO_2-e.

Table 6.33 *Land converted to forest land*: recalculation of total CO_2-e emissions (Gg), 1990-2012

Year	2014 submission	2015 submission	Change	
	(Gg CO_2)	(Gg CO_2)	(Gg CO_2)	(%)
1990	-91.42	1,553	1,645	-1,799%
2000	-11,012	-10,610	402	-3.6%
2005	-15,426	-13,850	1,576	-10.2%
2006	-13,471	-13,647	-176	1.3%
2007	-17,202	-17,325	-123	0.7%
2008	-16,792	-15,450	1,342	-8.0%
2009	-15,251	-12,605	2,646	-17.4%
2010	-16,649	-13,790	2,860	-17.2%
2011	-19,393	-17,696	1,697	-8.8%
2012	-11,526	-10,002	1,524	-13.2%

6.6.5 Source Specific Planned Improvements

Currently the human induced promotion of natural seed sources is modelled using the Approach 2 FullCAM system while the remaining components modelled using the Approach 3 system. A project is underway to investigate the use of the Approach 3 FullCAM system for the purpose of modelling emissions and removals on these lands. If this project is successful, the existing Approach 2 system used to model the human induced promotion of natural seed sources will then be used for the purpose of QC, as with the other components of the *land converted to forest land* classification (e.g. see Figure 6.17).

6.7 Source Category 4B2 and 4C2 – Forest Conversion

6.7.1 Forest Land Converted to Cropland and Grassland

When the land use subsequent to a forest conversion contains a cropping activity, associated emissions are reported under *forest land converted to cropland*. 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*. Lands which are managed under a crop-pasture rotation are reported under *forest land converted to cropland*.

Some forest regrowth and re-clearing of woody regrowth in grasslands is continuously reported under *forest land converted to grassland*. Land that was cleared since 1972 but which regrew to forest by 1990 and has remained as forest since is classified as *land converted to forest land*. Land which was cleared since 1972 and was not forest in 1990 which subsequently regrew to become forest remains in the *forest land converted to grassland* classification.

6.7.1.1 Methodology

The areas of forest conversion are identified and allocated to the *cropland* and *grassland* sub-categories as described in section 6.4. Emissions and removals from *forest land converted to cropland* and *grassland* are estimated using the Approach 3, Tier 3 *FullCAM* as described in Appendix 6.B. The reporting includes all carbon pools (living biomass, dead organic matter (DOM) and soil). 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 6.34.

N_2O emissions from disturbance associated with land-use conversion to cropland and *grassland* are estimated using the methods described in section 6.16.1. Other non-CO_2 emissions that are not related to biomass burning from these lands are reported in the *agriculture* sector.

Table 6.34 *FullCAM* configuration used for the *forest land converted to cropland* and *grassland* sub-categories

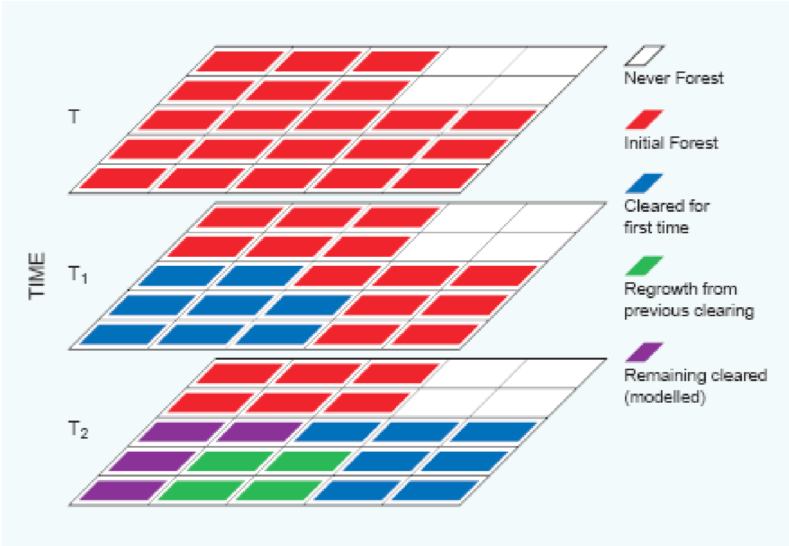
Component	Forest	Agriculture
Living biomass	*CAMFor* – Forest Productivity Index and Tree Yield Formula	*CAMAg* – Crop yield tables
Dead organic matter	*CAMFor*	*CAMAg*
Soil carbon	*Roth-C*	*Roth-C*
Offsite products	NA	NA

Entry of lands into forest land converted to cropland and grassland sub-categories

The fundamental analytic unit of Tier 3, Approach 3 land sector reporting in Australia is the land cover change pixel (25 m × 25 m) derived from the satellite remote sensing programme. Beginning in 1972, land clearing events are detected through the remote sensing programme. The first time a land clearing event is detected for a pixel, 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. Therefore, in any given year, there will be three classes of forest pixels represented as shown in Figure 6.18.

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 undergone a land clearing event in the current year (T_1, blue). The pixel now triggers the initiation of *FullCAM* for the quantification of emissions. *FullCAM* calculates the emissions and removals on that pixel from the moment that the pixel becomes active and the tracking continues each year into the future (T_2, purple and green). These active pixels may remain cleared (purple) or may temporarily regrow some forest cover as part of a cyclic clearing/re-clearing management system (green).

Figure 6.18 Diagrammatic representation of the spatially explicit approach used to estimate the forest land conversion sub-categories



Modelling emissions and removals

Once lands enter the conversion category through a land clearing event, based on activity data, *FullCAM:*

- randomly allocates date of clearing between the two dates of satellite images;
- obtains site, climate, management and initial assumed biomass (see Appendices 6.B to 6.E) data for that pixel from a series of spatial grids and databases);
- begins to model changes in living biomass, debris and soil carbon pools associated with the change in forest cover; and
- sums the estimates for each pixel each year to estimate the emission/removals.

Where the forest has regrown after clearing (as identified from the remote sensing), *FullCAM* begins to regrow the forest. Where this regrowth is subsequently re-cleared, the biomass at re-clearing is based on actual age (through identification of time since regrowth).

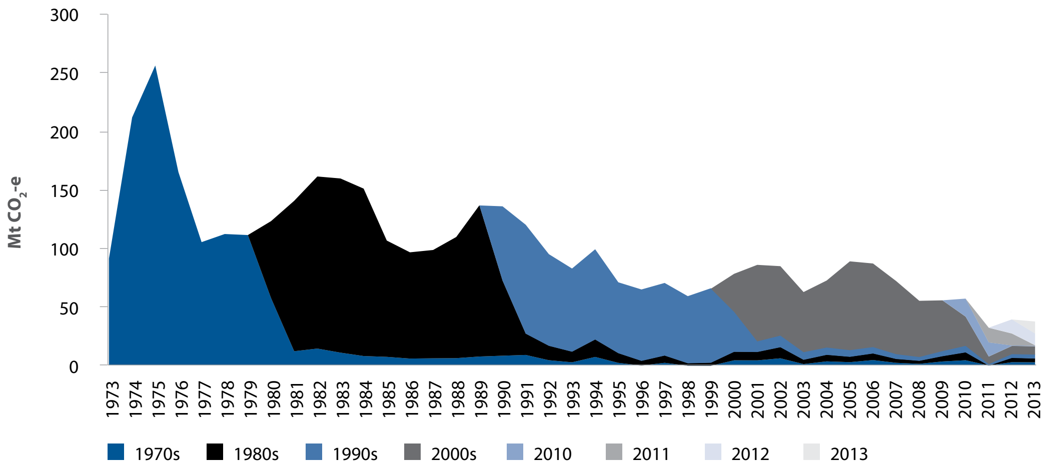
Estimating lagged emissions

Lagged emissions are emissions in any given year that result from a land clearing event in previous years. These lagged emissions are associated with the decay of DOM and soil carbon. As land remains in the conversion category for 50 years from the time of the initial clearing event, any lagged emissions are reported in the years subsequent to the clearing event.

The lagged emissions profile in Figure 6.19 shows that the greatest impact of lagged emissions on overall emissions estimates occurs within the first two years following a land clearing event (n.b. 2012 and 2013).

After 50 years, these forest conversion lands and their associated emissions/removals will be reallocated to the land remaining sub-categories.

Figure 6.19 Tier 3 FullCAM outputs for *forest land converted to cropland and grassland* showing emissions due to past clearing



Estimating Changes in Biomass

The initial forest biomass and subsequent forest re-growth is estimated using the approaches outlined in Appendices 6.B to 6.D and the parameters described below. The parameters needed to model the subsequent crop and pasture are detailed in Appendix 6.B.

Wood Basic Density

The wood basic density information used for the back calculation of wood volume was drawn from Ilic *et al.* (2000), a national compendium of wood basic density information. The data of Ilic *et al.* (2000) are presented on a species basis. The wood basic density assigned to each forest type (Table 6.35) is an approximate average of the values for species typically represented in each class.

Table 6.35 Wood basic density values for the major vegetation group (MVG) classes

MVG Class	Wood Density (Basic) (kg dry matter m)
Rainforest and Vine Thickets	500
Eucalypt Tall Open Forest	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 Shrubland	940
Heath	900
Chenopod Shrub, Samphire Shrub and Forbland	900
Unclassified Native Vegetation	780

Tree Partitioning

The partitioning of mass to different tree components has limited effect on the carbon modelling for forest conversion, but robust data are required for model accuracy. A number of studies have been completed 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.

The most important attribute in partitioning is the ratio of belowground biomass to aboveground biomass (the root:shoot ratio). There is also a need to apportion materials to different decomposition pools from aboveground components. The partitioning ratios used (Table 6.36) are largely taken from the synthesis of data compiled by Snowdon *et al.* (2000).

Table 6.36 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 Woodland	0.42	0.15	0.10	0.02	0.25	0.06
Callitris Forest and Woodland	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 Woodland	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 woodland/ grassland	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 Shrubland	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 Shrubland	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

The carbon content of various tree components (Table 6.37) are drawn from an analysis of a range of species across a range of environments by Gifford (2000a, 2000b).

Table 6.37 Carbon content of tree components – *forest conversion categories*

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

Estimating Changes in Debris

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 *forest land converted to grassland* categories except for areas under trees that are part of the regrowth cycle. Litterfall (leaf), branch and bark shed and root turnover have been determined from available literature. The rates applied are in Table 6.38. These draw heavily on the rates determined by Paul *et al.* (2002b) in a model calibration study.

Table 6.38 Tree component turnover rates

Tree Component	Turnover rate yr^{-1}
Leaf	0.50
Branch	0.05
Bark	0.07
Coarse Roots	0.10
Fine Roots	0.85

Initialisation of the forest litter stock in the model (coarse woody debris and fine litter) draws upon work by Murphy *et al.* 2002; Griffin *et al.* 2002; Harms and Dalal, 2003; Harms *et al.* 2005 and Mackensen and Bauhus, 1999). Sites used in these studies were widespread throughout the areas primarily cleared for agricultural purposes. Additional data were drawn from literature where available. The values used are shown in Table 6.39. Debris mass is converted to carbon assuming a carbon fraction of 0.45.

Table 6.39 Initial forest litter values (t dry matter ha^{-1})

Major Vegetation Group (MVG) Class	Decomposable Fine Decay	Resistant Fine Decay	Decomposable Coarse Decay	Resistant Coarse Decay	Decomposable Leaf Decay	Resistant Leaf decay	Decomposable 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 Forest	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

Major Vegetation Group (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
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 Shrubland	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

Forest Residue Management

The principal methods of land cover change for forest conversion involve the extraction of root material (e.g., tree pulling) to allow for subsequent cultivation for pasture and cropping.

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. *FullCAM* 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 %, leaving 2 % of all biomass unaffected by burning. Further residue is left to decompose following incomplete combustion, with combustion efficiencies set at 90 % for deadwood, 95 % for bark, 95 % for leaf litter, 80 % for coarse dead roots and 70 % for fine roots.

Litter decomposition rates have been extracted from available information including the study undertaken by Mackensen and Bauhus (1999). The rates applied are shown in Table 6.40. There are few studies in Australia of litter decomposition rates with most work being focused on wood product longevity trials. The data were 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. This was so that a reasonable balance between turnover (input to litter pools) and decomposition of litter pools was achieved.

Table 6.40 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

Estimate Changes in Soil Carbon

A full description of the soil carbon model (*Roth-C*) and the parameterisation of the model are provided in Appendix 6.B.

Fires

Carbon dioxide emissions from on-site burning associated with land conversion are estimated using *FullCAM* and are reported under 4.B.2 and 4.C.2. The mass of carbon burnt annually (FC_{jk}) is a *FullCAM* output and is used to estimate the non-CO_2 gases associated with burning (4V).

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:

$$E_{ijk} = FC_{jk} * EF_{ijk} * C_i \quad (4.C.2\_1)$$

and for total annual emissions for NO_x and N_2O are:

$$E_{ijk} = FC_{jk} * NC_{jk} * EFi_{jk} * C_i \quad (4.C.2\_2)$$

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

EF_{ijk} = emission factor for gas *i* from vegetation (Table 6.20),

NC_{jk} = nitrogen to carbon ratio in biomass (Table 6.21)

C_i = factor to convert from elemental mass of gas species *i* to molecular mass (Table 6.21).

Carbon dioxide emissions and removals associated with the burning and subsequent regrowth of savanna grasslands which occur on *land converted to grassland* are reported under 4.V.C.2. The method applied is the same as that for *grassland remaining grassland* savanna fires (section 6.9.1.3)

6.7.2 Uncertainties and Time Series Consistency

Uncertainties for *forest land converted to cropland* and *forest land converted to grassland* at the national scale were estimated to be ±27.3% for CO_2. Further details are provided in Annex 2. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to the methodology.

6.7.3 Source Specific QA/QC

The calibration and validation of the *FullCAM* model, along with the associated quality assurance and quality control programme are fully described in Appendices 6.B, 6.C, 6.D and 6.F.

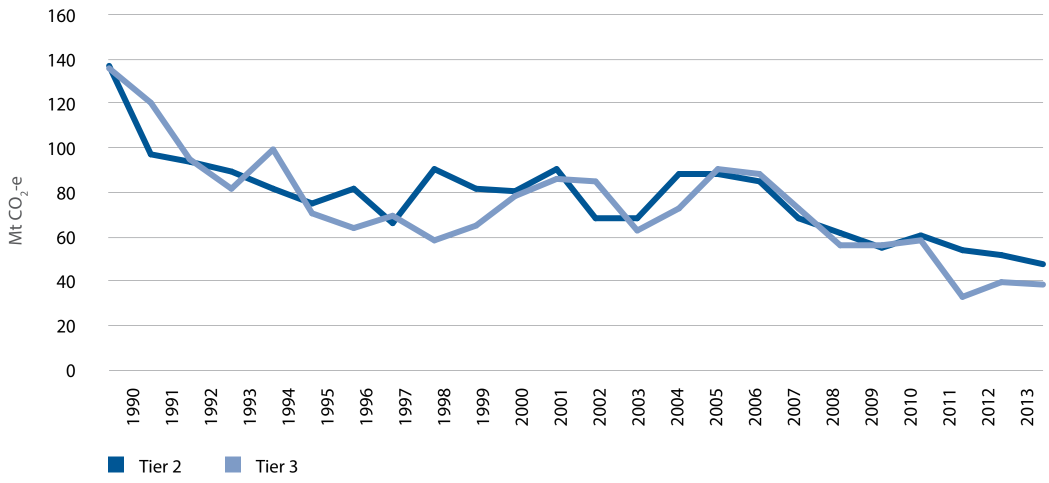
Verification using Tier 2 model

Verification of the Tier 3 based emission estimates from this sub-category was performed through comparison with a Tier 2, Approach 2 method (described in Appendix 6.H). The Tier 2 method is an excel spreadsheet model 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 model includes all carbon pools (living biomass, DOM and soil) and emissions from fire.

The results from the two models are largely consistent and follow the same trend since 1990. By and large, the emissions output does not vary substantially between the Tier 2 and Tier 3 models; however, the discrepancies between the two model approaches can be explained further.

The Tier 2 method uses country-specific coefficients for three regions differentiated by vegetation class to estimate emissions and removals from deforestation (land use change). It standardises the biophysical (soil, climate, etc.) environment, and hence forest productivity, across Australia. That is, the Tier 2 model does not encompass the finely disaggregated spatial variability relating to soil types (and their characteristics) and climate variability (particularly rainfall) which would have an effect on emission levels. As such, CO_2 emissions and removals could therefore be overestimated or underestimated. The Tier 3, Approach 3 method is spatially explicit, operates at a fine scale (25 m) and incorporates the variability of the biophysical environment (climate and soil) across Australia. This therefore includes the effects of climate, better represents regrowth and reclearing cycles and varies emissions based on the site characteristics of the land subject to clearing.

Figure 6.20 Emissions from *forest land converted to cropland* and *grassland* output from Tier 2 and Tier 3 methodology from 1990-2013.



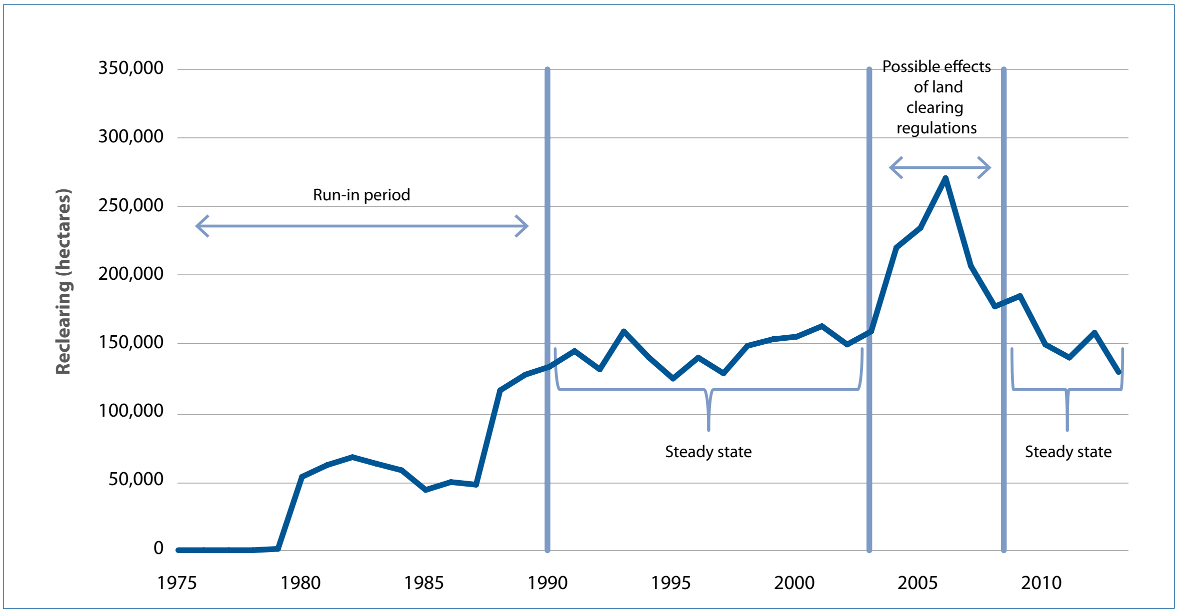
Testing sensitivity of emissions in 1990 to re-clearing prior to 1990

The Tier 2 forest conversion model described in Appendix 6.H has been further used to test the sensitivity of the 1990 estimate of emissions from *forest land converted to other land uses* to the amount of re-clearing prior to 1990.

Re-clearing is the observation of forest clearing on land which has been observed to be cleared previously. Observations of re-clearing are constrained by the availability of Landsat data from 1972 (see Appendix 6.A). Despite this constraint, by 1990, observed re-clearing reaches a level that is consistent with the amount of re-clearing observed subsequently – a steady-state of re-clearing of observed (Figure 6. 21). From 2004 re-clearing rates increase from the steady-state and then decline in the period 2007 to 2013. Aside from the effects of economic drivers, the recent declines may be due to the more restrictive land clearing policy changes implemented in 2007. The current decline may also reflect land managers bringing forward decisions to clear land in the period 2004 and 2006 - the period between the passage of the new laws and before they came into force.

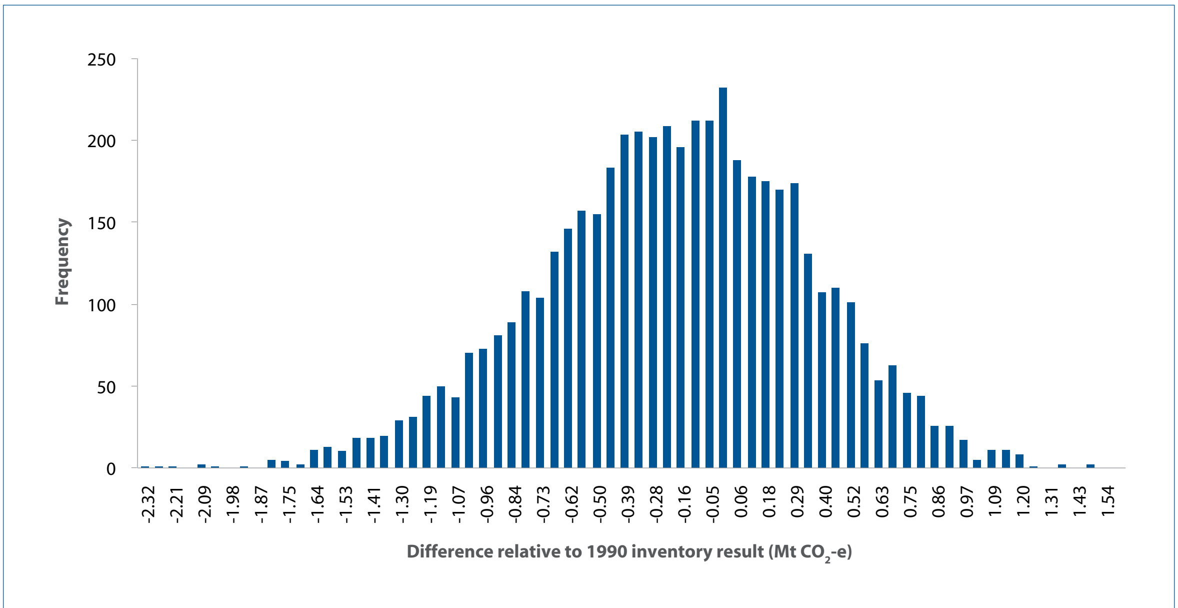
While by 1990 re-clearing had reached a steady state, the observed re-clearing during the run-in period 1972-1989 (Figure 6. 21) are less certain. To test the potential impact of varying levels of re-clearing prior to 1990 on estimated emissions in 1990 a simulation with 5,000 iterations was undertaken using the tier 2 forest conversion model (see Appendix 6.H for a description of this model).

Figure 6.21 Observed re-clearing 1975-2013



The impact of varying re-clearing prior to 1990 on emissions in 1990 was tested using a Monte Carlo simulation through 5,000 iterations. The simulations were set to randomly select an amount of re-clearing within the range of approximately 0-500,000 hectares per year in the period 1972-1989. The results of this analysis are presented in Figure 6. 22.

Figure 6.22 Sensitivity of 1990 emissions estimate (*Forest land converted to other land uses*) to Monte Carlo simulations of re-clearing scenarios prior to 1990



The results of this sensitivity analysis show that the estimate of emissions in 1990 is relatively insensitive to re-clearing prior to 1990 (Figure 6. 22). The results of the 5,000 iterations of the model fell within the range of approximately -2.5 Mt CO_2-e to 1.5 Mt CO_2-e relative to the inventory estimate. To simulate re-clearing rates higher than those observed (Figure 6. 21), it was necessary to simulate a corresponding first time clearing event further in the past[2]. When the re-clearing simulated was higher than the observed rate of re-clearing emissions are estimated to be lower in 1990 under these scenarios because of the additional time available for the decay of soil carbon and forest debris prior to 1990.

The estimates of *Forest Conversion* for 1990 are based on a limited dataset on estimated land use change extending only from 1973-1990. Extending the observed dataset on land use change to include estimates for the missing data on land use change for the period 1940-1972 could be implemented using a range of techniques identified in IPCC 2006.

The implementation of an extended dataset on land use change to 1940 would lead to higher emissions estimates for *Forest Conversion* for the entire time series, with larger impacts at the start of the time series, 1990, than for later periods of the time series. It is assessed that the estimate for net emissions for *Forest Conversion* categories would be 13 Mt CO_2-e higher in 1990, if the land clearing trend is back cast with an assumed clearing peak in 1974 and is applied in the FullCAM tier 2 model (see Appendix 6.A). This step has not yet been implemented. A related question, that of the appropriate length of the transition process, remains open. While the Department of Environment assumes a 50 year period for the reporting of land in a land use change category, the IPCC assumes a default length of transition to a new carbon stock level of 20 years.

6.7.4 Recalculations Since the 2012 Inventory

Improvements and updates made to estimates of emissions and removals of *forest land converted to cropland* and *forest land converted to grassland* sub-category included:

- spatially and temporally explicit agricultural species and management practices database (Appendices 6.B. And 6.E.);
- recalibration of soil decomposition rates (Appendix 6.B);
- a new baseline map of organic carbon in Australian soil (Appendix 6.E.), previously pre-clearing soil carbon map;
- a new clay surface from the Australian three-dimensional soil grid (Appendix 6.E);
- the reclassification of land that was forest in 1990 and has remained forest since 1990 to the *land converted to forest land* classification; and
- updates to the remote sensing time series (see Appendix 6.A).

Table 6.41 Forest conversions: recalculation of total CO_2-e emissions, 1990-2013

Year	Forest land converted to *cropland* and *grassland*			
	2014 submission	2015 submission	Change	
	(Gg CO_2-e)	(Gg CO_2-e)	(Gg CO_2-e)	(%)
1990	140,727	135,857	-4,871	-3.5%
2000	78,294	80,181	1,887	2.4%
2005	94,143	91,182	-2,961	-3.1%
2006	90,567	89,289	-1,278	-1.4%
2007	79,592	74,789	-4,802	-6.0%
2008	65,509	58,145	-7,365	-11.2%
2009	56,826	58,615	1,789	3.1%
2010	59,149	60,780	1,631	2.8%
2011	46,068	35,916	-10,152	-22.0%
2012	44,070	43,047	-1,023	-2.3%

2 Where regrowth (prior re-clearing) was simulated to occur between 5-10 years after first time clearing, which in-turn was simulated to occur between 10-15 year prior to regrowth. As a result the simulation included scenarios where first-time clearing was modelled to occurs as far in the past as 1947 (1972 minus (10+15).

6.7.5 Source Specific Planned Improvements

The Department of Environment has initiated a process to review the relationships and data underpinning the assumed initial above ground biomass regression model. The assumed initial above ground biomass regression model underpins the estimation of emissions and removals for UNFCCC *forest land converted to cropland and grassland* and Kyoto Protocol Article 3.3 *deforestation* (NIR, 2009).

The planned improvements associated with the modelling of crops and grasslands are detailed in *cropland remaining cropland* and *grassland remaining grassland* sections below.

6.8 Source Category 4.B.1 Cropland Remaining Cropland

The *cropland remaining cropland* sub-category includes continuous cropping lands and lands that are cropped in rotation with pastures, systems that change between *grassland* and *cropland* on a regular basis. Croplands are considered to be of high land value with a high return on production and of moderate to high soil nutrient status and are therefore not generally converted to *forest land* or *grassland* but remain as *cropland*.

Anthropogenic emissions and removals on croplands occur as a result of changes in management practices on cropping lands, from changes in crop type and from changes in land use. Permanent changes in management practices generate changes in the levels of soil carbon or woody biomass stocks over the longer term. Changes in carbon stock levels during the transition period to a new stock equilibrium are recorded under croplands.

Anthropogenic emissions and removals from croplands are estimated from changes in specified management practices on croplands including:

- total cropping area;
- crop type and rotation (including pasture leys);
- stubble management, including burning practices;
- tillage techniques;
- fertiliser application and irrigation;
- application of green manures (particularly legume crops); and
- soil ameliorants (application of manure, compost or biochar).

Conversion of pasture to cropping activities is included within the *cropland remaining cropland* estimates.

Carbon dioxide emissions from the application of lime are reported under Agriculture. Nitrous oxide emissions from the application of fertiliser are also reported under Agriculture.

6.8.1 Methodology

Emissions and removals from crop land activities are estimated using methods consistent with the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006), in conjunction with techniques described in the *2013 Revised Supplementary Methods and Good Practice Guidance for LULUCF Arising from the Kyoto Protocol* (IPCC, 2014)[3].

3 According to the IPCC (2014), in all cases, the aim of the estimation processes is to identify and report trends and systematic changes in the carbon stocks resulting from changes in management practices over time. More explicitly, (IPCC 2013, p2.135) countries are encouraged to use higher tier methods (Tier 2 or Tier 3) to develop emissions coefficients or models to represent the effects of management practices rather than those of inter-annual variability and natural disturbances on carbon stocks.

Carbon dioxide emissions and removals from the *cropland remaining cropland* soils component are estimated using *FullCAM* (Appendix 6.B). The CO_2 emissions and removals associated with changes in the area of perennial woody crops are estimated using the tier 2 approach outlined below.

The areas in the *cropland remaining cropland* sub-category are estimated using the ABARES Catchment Scale Land Use of Australia 2014 (version 5) provided by the Department of Agriculture at the mapping scale of 1:25 000 to 1:250 000 (http://data.daff.gov.au).

Soil

In most croplands, the main carbon flux associated with changes in land use and management is from changes in organic carbon in soil (IPCC 2014, p2.140). The CO_2 emissions and removals from *cropland remaining cropland* soils are estimated using Tier 3, Approach 3 *FullCAM*. When configured for *cropland remaining cropland, FullCAM* uses the same climate, site and management datasets as those used in the *forest land converted to cropland* estimates as described in Appendix 6.B and 6.E.

Initial soil carbon values are taken from the baseline map of soil organic carbon (Viscarra-Rossel, 2014) – see Appendix 6.E.

Management practice change has been monitored using the Australian Bureau of Statistics' (ABS) Agricultural Resource Management Survey (ARMS), which surveyed 33 000 of Australia's 135 000 agricultural businesses (funded by the Department of Agriculture). Data from the ABS agricultural censuses (which surveyed all agricultural businesses) have been used with data from the 2007–08 and 2009–10 ARMS to track trends in management practices. Details on data sources for changes in management practices are provided in Appendix 6.E.

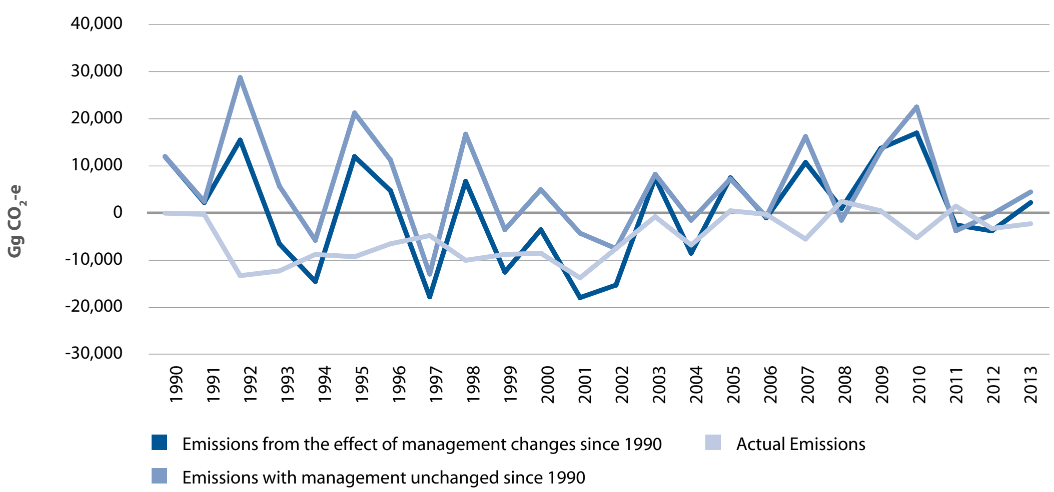
FullCAM simulations commence in 1970 in accordance with IPCC Guidelines.

The *2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol (IPCC* 2014) (KP Supplement) have provision to reduce interannual variability and isolate the impacts of changes in human activities by calculating two time series of emissions and removals in which only the rate of human activities differ. This provision, in conjunction with the new crop management dataset, allows for emissions and removals due to the 'signal' of the impact of human activities, including mitigation measures, to be estimated for this sub-category.

To implement this technique, FullCAM is simulated once with management practices changing over time and once with management practices held constant at 1990 levels. Consequently, estimates of net emissions from changes to management practices since 1990 have been reported (see Figure 6.4).

In this way, estimates of net emissions mimic the outcomes of a tier1/2 approach in which the effects of management practice changes are isolated from all other impacts on soil carbon (IPCC 2014, p2.135) (for example, as is done for estimates of the emissions from liming in this report). Similarly, under *Agriculture*, in this report nitrous oxide emissions from the effects of management practice changes are isolated in tier 1 or tier 2 methods (for example, from the effects of the current year's application of fertiliser).

Figure 6.23 Net CO_2-e emissions from soils in *cropland remaining cropland*, 1990 - 2013



FullCAM estimates emissions from soil as a result of an estimation process involving all on-site carbon pools (living biomass, dead organic matter (DOM) and soil). For non-woody crops in *cropland remaining cropland* the changes in the soil carbon pool are reported. Carbon stock changes from living biomass and DOM of non-woody annual crops are reported to be zero, consistent with the guidance in *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. The rationale for this decision is that for annual crops, increase in biomass stocks in a single year may be assumed equal to biomass losses from harvest and mortality in that same year - thus there is no net accumulation of biomass carbon stocks (IPCC 2006, p5.7). In general, croplands will have little or no dead wood, crop residues or litter (IPCC 2006, p5.12).

Perennial Woody Crops

The CO_2 emissions and removals from changes in the area of perennial woody crops are estimated using a CS Tier 2 approach. The Tier 2 method retains the basic Tier 1 approach from the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, but with the following differences: the period over which biomass accumulates (harvest/maturity cycle), using more accurate crop-specific coefficients and accounting for total crop biomass rather than only above-ground biomass.

Carbon is assumed to accumulate at a steady rate until maturity. Once mature, additional tree growth is assumed to be offset by management practices such as pruning, consequently, CO_2 is no longer removed. Maturity is considered to occur at half the crop's harvest cycle.

Crop-specific coefficients were sourced from the literature to calculate CO_2 emissions and removals. The coefficients required are: total biomass carbon stock at harvest (tonnes C $ha^{-1)}$, harvest cycle (yr), biomass accumulation rate (tonnes C ha^{-1} yr^{-1}) and plot density (trees ha^{-1}). The mathematical relationships between these coefficients are displayed in Table 6.42. Additionally, root to shoot ratios were sourced from the literature and biomass accumulations associated with fruit production were excluded from all calculations.

Table 6.42 Calculations used to develop tier 2 coefficients for perennial woody crops

	total biomass carbon stock at harvest (t C ha^{-1})	harvest cycle (yr)	biomass accumulation rate (t C ha^{-1} yr^{-1})
calculations	(x/2)*y	X	y
e.g. (oranges)	7.5	30	0.5

Note that x and y are sourced from literature and crop maturity is half of harvest cycle.

In total, 27 perennial woody crop types are modelled. However, due to paucity of data, these crops are grouped by major crop-type. The coefficients applied to each group were based on the dominant crop type (Table 6.43). The four main crop-types and dominant crops are: 1) citrus, with crop coefficients represented by orange data, 2) Nuts, with crop coefficients represented by macadamia data, 3) pomes, with crop coefficients represented by apple data and 4) stone fruit, with crop coefficients represented by peach data. Other smaller crops modelled included: olives, grapes, kiwifruit, avocados and mangoes. Grape crop coefficients were used to model kiwifruit, and avocado coefficients were used to model mangoes. Regarding nuts, while macadamias were used as the representative crop, almonds were estimated separately as almond-specific coefficients were available.

Estimates of changes in area of perennial woody crops are taken from the *ABS agricultural commodities statistics (ABS, 2013)*. Most crop data are provided as tree number values and subsequently were converted to area statistics using crop-specific plot density coefficients (Table 6.43).

Table 6.43 Perennial woody crop tier 2 coefficients

Crop type	total biomass carbon stock at harvest (t C ha^{-1})	harvest cycle (yr)	biomass accumulation rate (t C ha^{-1} yr^{-1})	plot density (trees ha^{-1})	root : shoot
Citrus					
Oranges	7.5	30 ***a***	0.5 ***a***	556 ***b***	0.17 ***c***
Nuts					
Macadamias	45	30 ***d***	3 ***e***	355 ***e***	0.25 ***e***
Almonds	15	25 ***a***	1.2 ***a***	222 ***f***	
Pomes					
Apples	10.2 ***g***	28 ***g***	0.7	500 ***g***	0.17 ***c***
Stone fruit					
Peaches	9.8	15 ***a***	1.3 ***a***	740 ***h***	0.17 ***c***
Grapes	3.8	25 ***a***	0.3 ***a***	N/A	0.5 ***c***
Kiwifruits	3.8	25 ***a***	0.3 ***a***	N/A	0.5 ***c***
Olives	6.67	20 ***i***	0.67 ***j***	250 ***k***	0.145 ***c***
Avocados	7.2 ***l***	25 ***a***	0.6	100 ***l***	0.125 ***l***
Mangoes	16 ***l***	25 ***a***	1.3	222 ***m***	0.125 ***l***
IPCC default	63	30	2.1		

Source and location of study is: ***a*** = Kroodsma & Field (2006) USA California, ***b*** = Morgan *et al.* (2006) USA Florida, ***c*** = German and/or Spanish National Inventory Reports (2013), ***d*** = Australian Macadamia Society website, ***e*** = Murphy *et al.* (2013) Australia, ***f*** = Fernandez-Puriatch *et al.* (2013) Spain, ***g*** = Haynes and Goh (1980) New Zealand, ***h*** = Marini & Sowers (2000) USA, ***i*** = Sanfelipe Olives website (2013) USA California, ***j*** = Villalobos *et al.* (2006) Spain, ***k*** = Olives Australia website (2013), ***l*** = Lovatt (1996) USA California and ***m*** = Western Australian Government Agricultural website (2013). Note hat plot density is represented by N/A for Grapes and Kiwifruit as reported in hectares by ABS. All figures not referenced were determined using the calculations presented in Table 6.43.

6.8.2 Uncertainties and Time Series Consistency

Based on a qualitative assessment the uncertainties for *cropland remaining cropland* were estimated to be medium. Further details are provided in Annex 2. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to the methodology.

There are a number of gaps in the time series of *ABS commodities statistics* (ABS, 2013) for perennial woody crops. All data-gaps were filled using extrapolation and interpolation techniques consistent with the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

6.8.3 Source Specific QA/QC

The calibration, validation and verification of the *FullCAM* model, along with the associated quality assurance and quality control programme are fully described in Appendix 6.B.

Additional category specific QA/QC activities are undertaken on the crop yield database and c*ropland remaining cropland* emissions and removal estimates. In relation to crop yields, CSIRO Land and Water has tested the performance of the crop growth model against a database of crop yields (see Appendix 6.E).

Department of Environment also undertakes quality control processes in accordance with the Quality Assurance-Quality Control plan.

6.8.4 Recalculations Since the 2012 Inventory

Since the previous submission, the entire time series for *cropland remaining cropland* has been revised (see Table 6.38) due to the implementation of a:

1. change to the conceptual framework to ensure that net emissions are estimated for changes in management practices only;
2. spatially and temporally explicit agricultural species and management practices database (Appendices 6.B. And 6.E.);
3. recalibration of soil decomposition rates (Appendix 6.B);
4. baseline map of organic carbon in Australian soil (Appendix 6.E.);
5. updated clay surface from the Australian three-dimensional soil grid (Appendix 6.E); and
6. updating of lands classified as croplands (Section 6.3.2).

The change to the conceptual framework to align with the method applied for *cropland management* makes comparisons with previous estimates less meaningful. This change to the *cropland* method has reduced the variability of the estimates, effectively rebased the estimates for soil carbon to 1990 levels and eliminated residual legacy impacts on the trend deriving from the initial activity to clear forest from the land.

The trend in the time series is now determined by the effects of the implementation of the crop management database, and changes in management over time, as recommended in ARR 2012, ARR 2013 and ARR 2014. The changes to soil input data, and the recalibration of the model, has impacts on the responsiveness of the soil carbon outcomes to changes in management.

Table 6.44 *Cropland remaining cropland*: Recalculation of CO_2-e emissions 1990-2012

Year	2014 submission	2015 submission	Change	
	(Gg CO_2-e)	(Gg CO_2-e)	(Gg CO_2-e)	(%)
1990	2,864	-69	-2,932	-102%
2000	3,840	-8,463	-12,302	-320%
2005	4,886	616	-4,270	-87%
2006	5,249	-23	-5,272	-100%
2007	9,559	-5,539	-15,098	-158%
2008	946	2,541	1,594	168%
2009	3,293	711	-2,583	-78%
2010	5,754	-5,027	-10,781	-187%
2011	-2,753	1,797	4,550	-165%
2012	2,539	-3,279	-5,818	-229%

6.8.5 Source Specific Planned Improvements

FullCAM's soil carbon modelling component is planned for improvement through the application of new input data. Fine spatial resolution continental maps of the soil carbon fractions (particulate organic carbon (POC), humic organic carbon (HOC) and resistant organic carbon (ROC)) are currently being generated by CSIRO using a methodology that is similar to that used to derive the baseline map of organic carbon in Australian soil (Viscarra-Rossel et al. (2014)). Largely, these data originated from the Soil Carbon Research Program (SCaRP), and a small number are from two smaller projects that were funded under the Department of Agriculture's *Filling the Research Gap* Programs.

FullCAM's modelling capability will be enhanced through an investigation of the option for utilising the GENDEC module in FullCAM. This module would enable better modelling of the impacts of management strategies on the entry of crop residues into the soil as well as additions of various organic amendments derived from offsite. Further detail is provided in Appendix 6.B.

6.9 Source Category 4.C.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*.

There are three components of the *grassland remaining grassland* emission estimates – the *grassland* component, the *shrubland transitions* component and the CO_2 emissions and post fire removals associated with savanna burning. Shrublands are areas of woody vegetation that are not, by definition, 'forest'. Shrublands are typically sparse tree and shrub formations and are not separable into areas made up of uniquely tree or shrub plant types.

The concepts underlying carbon stock changes in biomass of *grassland remaining grassland* are tied to management practices (IPCC 2006, p6.6). Anthropogenic emissions and removals on grasslands result from changes in management practices on grass lands, particularly from changes in pasture, grazing and fire management; changes in woody biomass elements and from changes in land use.

Permanent changes in management practices generate changes in the levels of soil carbon or woody biomass stocks over the longer term. The national inventory does not record the new carbon stock levels directly, but it is affected during the transition from one carbon stock level to another from changes in the flow of carbon to and from the land. These effects on the national inventory are transitory and are not permanent and, after a time (25 years), the rate of net emissions or removals associated with the changed management practice will approach zero.

The distribution of land areas in the *grassland remaining grassland* sub-category are estimated using the ABARES Catchment Scale Land Use of Australia (DAFF, 2014) at the mapping scale of 1:25 000 to 1:250 000 (http://data.daff.gov.au). 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 grassland* area.

6.9.1 Methodology

Carbon dioxide emissions from the *grassland remaining grassland* category are estimated using a mix of methods. The grass only component is estimated using *FullCAM* (Appendix 6.B), while the shrubland transition component and CO_2 emissions and removals associated with savanna fires are estimated using the Tier 2 methods outlined below.

Non-CO_2 emissions from *grassland remaining grassland* are reported in the *agriculture* sector.

6.9.1.1 Grass and soils component

Emissions and removals for the grass component are estimated using Tier 3, Approach 3 *FullCAM*. *FullCAM* estimates carbon changes from all on-site pools (living biomass, dead organic matter (DOM) and soil).

Anthropogenic emissions and removals from Grass lands and Grazing land management are estimated from changes in specified management practices including:

- the area under grasslands;
- pasture management from fertilisers, irrigation and other inputs and seed selection;
- the area under grazing and changes in grazing intensity;
- woody biomass management; and
- fire management.

Stratification of grasslands

There are two main agro-ecological categories in grasslands:

- native arid and semi-arid grasslands which comprise sparse woody vegetation and woodlands, and remain as primarily native pastures with some introduced species; and
- high rainfall improved pastures.

The key management practices relevant to estimating changes in carbon stocks in the high rainfall pastures include: grazing intensity; pasture composition; fertiliser and organic amendments; and irrigation. For the native arid and semi arid grasslands, the key drivers include grazing intensity, fire management and the presence of woody vegetation.

Data

Initial soil carbon values are taken from the baseline map of soil organic carbon (Viscarra-Rossel, 2014) – see Appendix 6.E.

Management practice change has been monitored using the Australian Bureau of Statistics' (ABS) Agricultural Resource Management Survey (ARMS), which surveyed 33 000 of Australia's 135 000 agricultural businesses (funded by the Department of Agriculture). Data from the ABS agricultural censuses (which surveyed all agricultural businesses) have been used with data from the 2007–08 and 2009–10 ARMS to track trends in management practices. Details on data sources for changes in management practices are provided in Appendix 6E.

Stratification of grasslands is undertaken based on climate and vegetation type. For the high rainfall pastoral regions and semi-arid regions, where cropping also occurs, the impacts of pasture composition and fertiliser and irrigation have been modelled (Appendix 6.E). In rangelands areas, which are semi-arid to arid with native, unimproved pastures, it is assumed that these lands have remained native pastures and as such no stock changes are identified on these lands.

Grazing management practices are not varied for the current *grassland remaining grassland* estimates as comprehensive management data, which is spatially and temporally explicit, is not yet available on a national scale.

Model Equilibration

As for the *cropland remaining cropland* sub-category, *FullCAM* simulations commence in 1970 in accordance with the 2006 IPCC Guidelines. This approach further meets the aim of the reporting exercise to identify and report trends and systematic changes in the carbon stocks resulting from changes in grassland management practices over time (IPCC 2013, p 2.149).

Methods

Emissions and removals from grass land activities are estimated using methods consistent with the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006), in conjunction with techniques described in the *2013 Revised Supplementary Methods and Good Practice Guidance for LULUCF Arising from the Kyoto Protocol* (IPCC, 2014)[4].

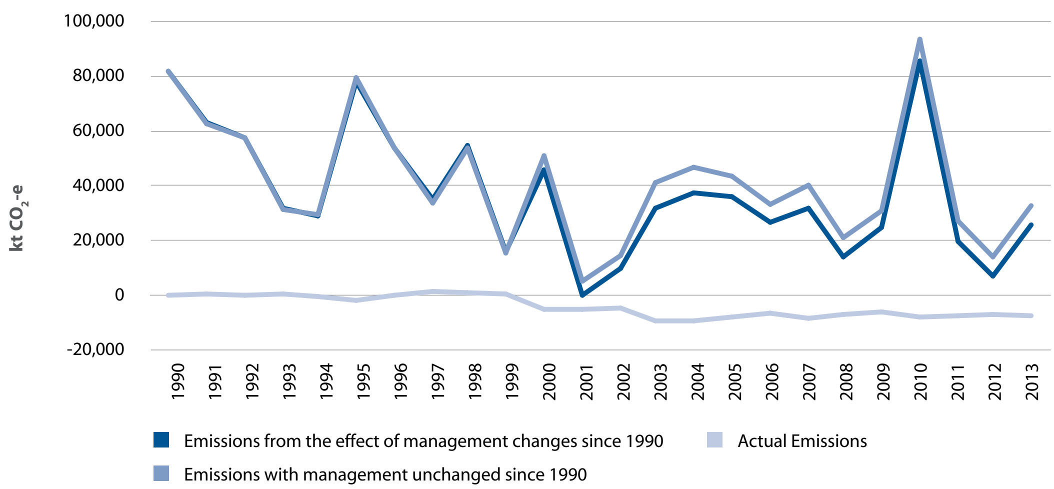
The *2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol (IPCC* 2014) (KP Supplement) have provision to reduce interannual variability and isolate the impacts of changes in human activities by calculating two time series of emissions and removals in which only the rate of human activities differ. This provision, in conjunction with the new crop management dataset, allows for emissions and removals due to the 'signal' of the impact of human activities, including mitigation measures, to be estimated for this sub-category.

To implement this technique, FullCAM is simulated once with management practices changing over time and once with management practices held constant at 1990 levels. Consequently, estimates of net emissions from changes to management practices since 1990 have been reported (see Figure 6.5).

4 According to the IPCC (2014), in all cases, the aim of the estimation processes is to identify and report trends and systematic changes in the carbon stocks resulting from changes in management practices over time. More explicitly, (IPCC 2013, p2.135) countries are encouraged to use higher tier methods (Tier 2 or Tier 3) to develop emissions coefficients or models to represent the effects of management practices rather than those of inter-annual variability and natural disturbances on carbon stocks.

In this way, estimates of net emissions mimic the outcomes of a tier1/2 approach in which the effects of management practice changes are isolated from all other impacts on soil carbon (IPCC 2013, 2.149) (for example, as is done for estimates of the emissions from liming in this report). Similarly, under *Agriculture*, in this report nitrous oxide emissions from the effects of management practice changes are isolated in tier 1 or tier 2 methods (for example, from the effects of the current year's application of fertiliser).

Figure 6.24 Net CO_2-e emissions from soils in *grassland remaining grassland*, 1990-2013



FullCAM estimates emissions from all on-site carbon pools (living biomass, dead organic matter (DOM) and soil). For the herbaceous grass component only the changes in the soil pool are reported. Carbon stock changes from living biomass and DOM are not reported, consistent with the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

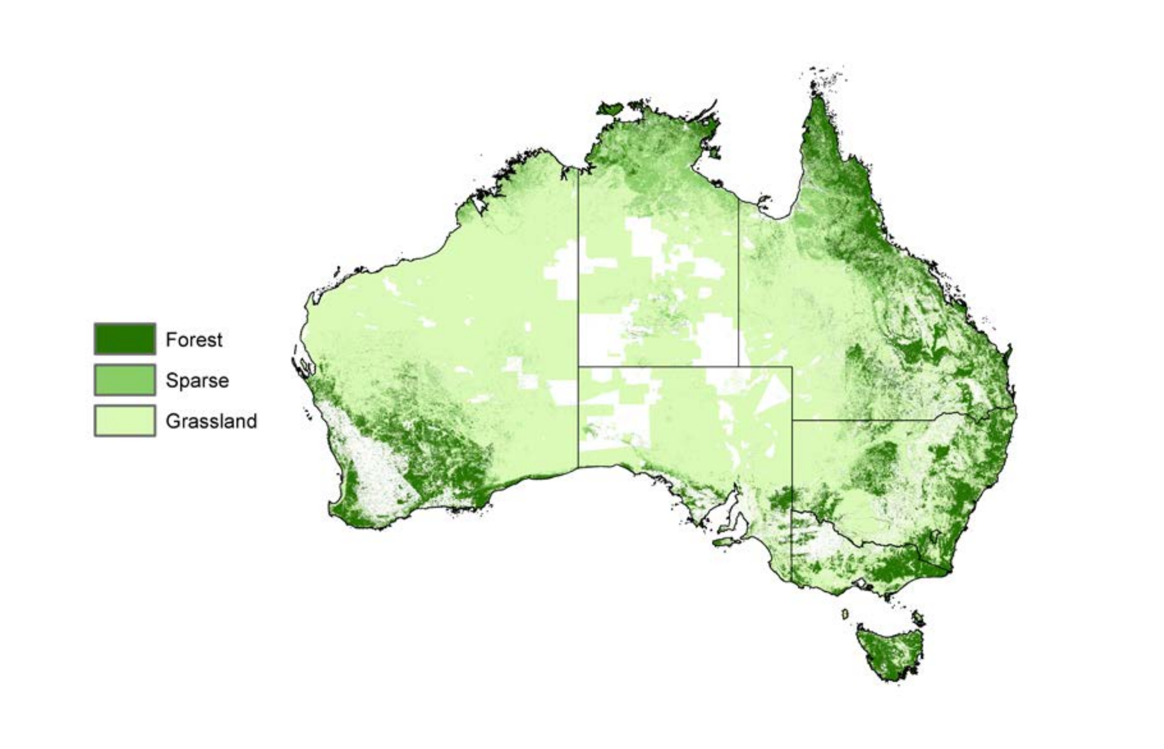
6.9.1.2 Grass and Shrub Transitions

To supplement the forest extent mapping, a national mapping programme has been undertaken to assess both the extent, and changes in extent, of sub-forest forms of woody vegetation using the Landsat TM, ETM+ and OLI data for the years from 1988 to 2014 (Caccetta and Furby, 2004). This method builds on the 2-class (forest and non-forest) time series CPN classification technique, by incorporating an additional spatial texture measure to distinguish between the sparse woody vegetation cover (5-7% to <20% canopy cover) and the forest cover (> 20% canopy cover). This analysis is now fully operational and can only be applied to the higher resolution Landsat TM, ETM+ and OLI data. Data from the earlier Landsat MSS sensors is not able to deal with the low signal to noise ratio in these systems.

The extent of sparse woody vegetation extends for the period from 1988 to 2014, except for a few interior rangeland areas, for which current sparse woody coverage is limited to 2006.

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^{-1} (Raison *et al.* 2003) and presumes a linear loss of that amount over a period of twenty years. Where the area of sparse vegetation increases it is assumed that these will regrow to 10 t DM ha^{-1} over twenty years (i.e., a growth rate of 0.5 t DM ha^{-1} yr^{-1}).

Figure 6.25 Extent of sparse vegetation



6.9.1.3 Fires

The CO_2 emissions and removals associated with the burning and subsequent regrowth of savannas and temperate grasslands that are classified as *grassland* are reported under 4 (V.C.1) *grassland remaining grassland*. Non-CO_2 emissions are reported under 3.E *prescribed burning of savannas* in the *agriculture* sector. Savanna fires occur on lands classified as *forest remaining forest*, *forest converted to grassland* and *grassland remaining grassland*.

For some vegetation and fuel classes (savanna grasslands, temperate grasslands and the fine and shrub fuels for savanna woodlands) the carbon lost during the fire recovers within a year so there is not net change in carbon stocks. Emissions and removals CO_2 are estimated for the coarse and heavy fuel size classes for savanna woodlands.

The CO_2 emissions from savanna burning are estimated from the mass of fuel burnt (M_{ijklmt} Gg) as calculated in Equation 4E_3 (section 5.7) and the carbon content of the fuel:

$$E = \Sigma_i\Sigma_j\Sigma_l\Sigma_m\Sigma_t\,(M_{ijklm,t} \times CC_{jm} \times C_g) \qquad (4.C.1\_1)$$

Where:

$M_{ijklm,t}$ = mass of course and heavy fuels burnt (Gg) (see section 5.7)

CC_{jm} = carbon content (Appendix Table 5.K.7);

C_g = elemental to molecular mass conversion factor (44/12)

The CO2 removals are estimated as the growth increment on land that is burnt in the inventory year and the regrowth increment on lands that were burnt in previous years. The growth increment on burnt lands ($MAB_{ijklm,t}$ Gg DM) is calculated as the difference in the fuel load at the time of burning (t) and the fuel load in the previous year (t-1):

$$MAB_{ijklm,t} = AB_{ijkl,t} \times (FL_{ijkm,t} - FL_{ijkm,t-1}) \times 10\text{-}3 \qquad (4.C.1\_2)$$

The growth increment on previously burnt lands ($MNB_{ijkm,t}$ Gg DM) is calculated as:

$$MNB_{ijkm,t} = ANB_{ijk,t} \times (FL_{ijkm,t} - FL_{ijkm,t-1}) \times 10^{-3} \quad (4.C.1\_3)$$

The CO_2 removals are:

$$R = \Sigma_i\Sigma_j\Sigma_l\Sigma_m\Sigma_t ((MAB_{ijklmt} \times CC_{jm}) + (MNB_{ijkmt} \times CC_{jm})) \times C_g \times -1 \quad (4.C.1\_4)$$

Where:

$AB_{ijkl,t}$ = area of savanna woodland burnt (ha)

$ANB_{ijkl,t}$ = area of savanna woodland burnt in previous years (1-11 years since last burnt) (ha)

$FL_{ijkm,t}$ = fuel load (t DM) as calculated in equation 3E_2 (section 5.7)

CC_{jm} = carbon content (Appendix Table 5.K.7);

C_g = elemental to molecular mass conversion factor (44/12)

Net CO_2 emissions/removals are calculated as:

$$\text{Net } CO_2 = E + R \quad (4.C.1\_5)$$

The emissions and removals from this source are highly variable (i.e moving from a net source to a net sink from year to year) largely reflecting variations in climatic conditions (Meyer 2004). This means that the 'signal' of the impact of human activities, including mitigation measures, on emissions and removals in this category are not discernible against the 'noise' of the climate driven variability. Through the Carbon Farming Initiative and future Emission Reduction Fund projects the Australian Governments is supporting mitigation activities to reduce emissions from savanna burning. To reduce the extent to which the climate variability is captured, estimates are reported as five year averages. The five year period was selected as it allows the underlying trends in the annual data to become apparent (i.e. emissions rising to a peak in 2001 but no discernible trend between 1996-2012) and it is consistent with suggested periodic measurement time-frames for the estimation of stock changes.

6.9.2 Emission estimates

Emission estimates for the components of *grasslands* are reported in Table 6.3.

6.9.3 Uncertainties and Time Series Consistency

Based on a qualitative assessment the uncertainties for *grassland remaining grassland* were estimated to be medium. Further details are provided in Annex 2. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to methodology.

6.9.4 Source Specific QA/QC

The calibration and validation of *FullCAM* along with the associated quality assurance and quality control programmes are described in Appendices 6.B and 6.E. Additional category specific QA/QC activities are undertaken on the yield database and *grassland remaining grassland* emissions and removal estimates.

The quality assurance and control process associated with the yield data is the same as that performed for *cropland remaining cropland* (see section 6.8.3). Department of Environment also undertakes quality control processes on the outputs of the spatial *FullCAM* simulations by reviewing and evaluating them against the outputs from the previous inventory.

The fire data for the shrubland component is collated and quality assured by CSIRO Sustainable Ecosystems (Darwin) before being received by Department of Environment. Once the fire data is received by Department of Environment, it undergoes a quality control process by comparing the most recent data to the previous year's data.

6.9.5 Recalculations Since the 2012 Inventory

Since the previous submission, the entire time series for *grassland remaining grassland* has been revised (see Table 6.45).

The time-series for soils has been recalculated following the implementation of a dynamic crop/pasture growth module in *FullCAM*. Previously plants yields were selected from a yield database.

Refinements to methods and data introduced into this national inventory report include:

1. change to the conceptual framework to ensure that only net emissions from changes in management practices are estimated;
2. spatially and temporally explicit agricultural species and management practices database (Appendices 6.B. And 6.E.);
3. recalibration of soil decomposition rates (Appendix 6.B); and
4. baseline map of organic carbon in Australian soil (Appendix 6.E.), previously pre-clearing soil carbon map; and
5. updated clay surface from the Australian three-dimensional soil grid (Appendix 6.E); and
6. updating of lands classified as grasslands (Section 6.3.2).

As with the changes to Croplands, the change to the conceptual framework to align the method for soil carbon under Grasslands with the method applied for *grazing land management* makes comparisons with previous estimates less meaningful. This change to the *grassland* method has reduced the variability of the estimates, effectively rebased the estimates for soil carbon to 1990 levels and eliminated residual legacy impacts on the trend deriving from the initial activity to clear forest from the land.

The trend in the time series is now determined by the effects of the implementation of the pasture management database, and changes in management over time, as recommended in ARR 2012, ARR 2013 and ARR 2014. The changes to soil input data, and the recalibration of the model, has impacts on the responsiveness of the soil carbon outcomes to changes in management.

Table 6.45 *Grassland remaining grassland*: Recalculation of CO_2-e emissions 1990-2012

Year	2014 submission	2015 submission	Change	
	(Gg CO_2-e)	(Gg CO_2-e)	(Gg CO_2-e)	(%)
1990	35,779	-883	-36,663	-102.5%
2000	5,314	4,164	-1,151	-21.6%
2005	25,646	2,004	-23,642	-92.2%
2006	11,507	3,477	-8,029	-69.8%
2007	26,174	-576	-26,750	-102.2%
2008	28,287	160	-28,127	-99.4%
2009	13,991	-759	-14,750	-105.4%
2010	11,337	-1,332	-12,669	-111.7%
2011	619	-3,995	-4,614	-745.5%
2012	1,405	-5,462	-6,867	-488.8%

6.9.6 Source Specific Planned Improvements

As for Croplands, FullCAM's soil carbon modelling component is planned for improvement through the application of new input data including fine spatial resolution continental maps of the soil carbon fractions (particulate organic carbon (POC), humic organic carbon (HOC) and resistant organic carbon (ROC)). The Department of Environment will also be commissioning CSIRO to conduct a more in depth analysis of the literature and national statistics to develop and enhance the grazing practices database.

FullCAM's modelling capability will be enhanced through an investigation of the option for utilising the GENDEC module in FullCAM and , in conjunction with CSIRO, the Department of Environment will investigate a potential perennial growth model that would take into account such considerations as water and nutrient availability and senescence amongst species. Further details are provided in Appendix 6.B.

Processing of a few remaining sparse woody vegetation data for the period from 2007 to 2014 will continue to make new inputs available for application in future inventory submissions.

Further analysis of the savanna woodland fuel accumulation curves is currently underway. Once the analysis is complete the accumulation curves used in the inventory method will be reviewed and revised where necessary.

6.10 Source Category 4D Wetland

6.10.1 Methodology

6.10.1.1 Wetlands Remaining Wetlands

Emissions and removals from this voluntary reporting category were not estimated.

6.10.1.2 Land Converted to Wetlands

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*. Therefore, emissions and removals from this category are reported as 'Included Elsewhere'.

6.11 Source Category 4E Settlements

6.11.1 Methodology

6.11.1.1 Settlements Remaining Settlements

Emissions and removals from this voluntary reporting category were not estimated.

6.11.1.2 Land Converted to Settlements

Estimates of emissions and removals for the classification *forest land converted to settlements* is included with the 2015 inventory submission. At this stage of system development the emissions associated with *forest land converted to settlements* cannot be disaggregated from emissions due to *forest land converted to grassland*, and as a consequence these emissions the IE notation is used in the CRF table. Systems are underdevelopment to enable the disaggregation of emissions due *land converted to settlements*, however in the current submission these emissions continue to be included with the *land converted to grassland* classification.

6.12 Source Category 4F Other Lands

6.12.1 Methodology

6.12.1.1 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. *Other lands* typically occur in unmanaged regions of central Australia, e.g., deserts.

6.12.1.2 Land Converted to Other Land

Other land, by definition, cannot include any land on which a forest has been observed in the Landsat time series since 1972. As a consequence this definition land converted to *other land* is not observed.

6.13 Source Category 4G Harvested wood products

6.13.1 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. Emissions from landfill are reported under the *waste* sector of the inventory.

6.13.1.1 Methodology

A national database of domestic wood production, including import and export quantities, has been maintained in Australia since the 1930s. This consistent and detailed collection of time-series data provides a sound basis for the development of a national wood products model.

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 1940, have been proposed. Annual log removals data are available through the Australian Forests Products Statistics published quarterly (ABARES, 2014a). Log removals data are also published by the relevant State Forest Services and these provide a valuable crosscheck on ABARES data.

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" percentage sawdust, shavings or sander dust for on-site energy generation or compost, "y" percentage woodchips for other manufacturing processes, "z" of sawn timber products, panel products and paper;
- 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, panel boards for use in furniture and cabinets, newsprint paper, and writing and printing paper;
- 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 obtained from the ABARES (2014a) by end use categories.

Details of the flows are shown in Appendix 6.I.

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.

Basic Density and Carbon Content

Basic wood 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, and treated softwood and hardwood poles, weighted basic densities for the species involved have been applied across each category and the values adopted have been based on Ilic *et al.* (2000). For board products and paper, which have been subjected to varying amounts of compression during manufacture, their basic densities have been adjusted to that 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 for 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.

Table 6.46 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 [(a)]	
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
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

(a) Basic density = (mass of oven dry wood in kg) / (volume of green wood in m^3)

Wood Flows from Processing

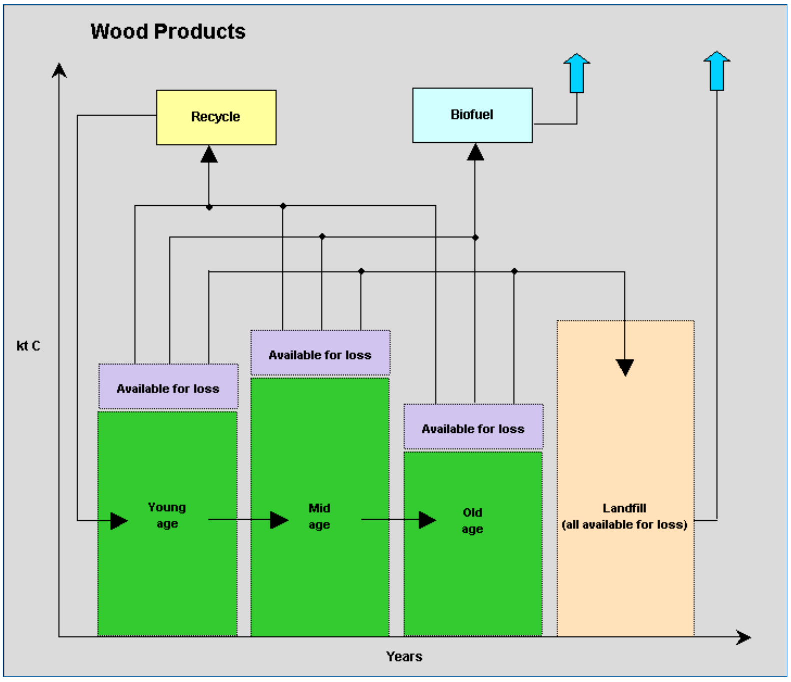
Wood flows in the various wood products produced in Australia have been developed under the following species/industry headings:

- 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.

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 6.26).

Figure 6.26 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

- Paper and paper products.
- Age: young = 1; medium = 2; old = 3

Short-term products – Pool 2

- Hardwood – pallets and palings.
- Softwood – pallets and cases.
- Particleboard and MDF – shop fitting, DIY, miscellaneous.

- Plywood – form board.
- Hardboard – packaging.
- Age: young = 2; 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

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 is 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 1940. 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 1940) 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, bioenergy and the atmosphere.

The model estimates used are presented in Tables 6.47 and 7.5 (in Chapter 7).

Table 6.47 Decomposition rates and maximum possible loss

Pool	YOUNG		MEDIUM		OLD	
	Loss Yr^{-1}	Proportion of in use Pool exposed to decay	Loss Yr^{-1}	Proportion of in use Pool exposed to decay	Loss Yr^{-1}	Proportion of in use Pool exposed to decay
1	1.0	0.60	1.0	0.65	1.0	0.90
2	0.50	0.30	0.25	0.50	0.25	0.90
3	0.10	0.15	0.1	0.65	0.1	0.45
4	0.05	0.25	0.1	0.65	0.05	0.80
5	0.033	0.20	0.05	0.55	0.025	0.95

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.

Table 6.48 Carbon stock and emissions outcomes (kt C)

Year	Domestic Production of Wood Products (a)	Imports of Wood Products	Exports of Wood Products(a)	Increase Due to Wood Products	Carbon Pool (excl. landfill)
	kt C	kt C	kt C	kt C	kt C
1990	2,190	730	80	2,839	75,627
2000	2,726	920	313	3,333	88,026
2005	3,009	1,005	479	3,610	94,651
2008	3,069	1,056	468	3,657	98,716
2009	2,881	922	483	3,320	99,783
2010	2,899	989	515	3,373	100,973
2011	2,796	1,088	556	3,328	102,148
2012	2,697	1,040	568	3,170	103,238
2013	2,592	1,041	558	3,076	104,285

(a) Exports of wood products excluded exports of woodchips

6.13.1.2 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.

6.13.1.3 Source Specific QA/QC

Wood product data are available through the Australian Forests Products Statistics published quarterly by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES, 2008a). 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), and are also published by the relevant State Forest Services and these provide a valuable crosscheck on ABARES data.

An independent review of the models used to estimate emissions in the wood products category was undertaken by Jaakko Pöyry Consulting.

6.13.1.4 Recalculations since the 2012 inventory

Table 6.49 Recalculations of the HWP inventory

Year	2014 submission	2015 submission	Change	
	(Gg CO_2-e)	(Gg CO_2-e)	Change (Gg CO_2-e)	Change (%)
1990	-5,047.60	-4,209.16	838	16.6%
2000	-5,346.49	-4,912.82	434	8.1%
2005	-5,560.71	-5,125.10	436	7.8%
2006	-5,332.94	-4,989.68	343	6.4%
2007	-5,252.97	-4,894.49	358	6.8%
2008	-5,744.28	-5,197.22	547	9.5%
2009	-4,561.30	-3,927.47	634	13.9%
2010	-4,768.36	-4,333.98	434	9.1%
2011	-4,699.31	-4,380.78	319	6.8%
2012	-4,169.01	-3,963.53	205	4.9%

6.13.1.5 Source Specific Planned improvements

A review will be undertaken into the interactions of the harvested wood product model with the *forest land* classification (the source of biomass gains), the *energy* sector (source of loss), and the *waste* sector (source of loss). The purpose of the review is to ensure that any improved understanding in scientific and technical literature of these interactions is reflected in the operation of the model.

6.14 N_2O Emissions from N Fertilisation 4(I)

Nitrous oxide emissions, associated with nitrogen fertilisers, are reported under the *agriculture* sector (3D). N_2O released from the application of N fertiliser on forests is reported as IE (agriculture). The amount of N applied to lands in Australia is obtained from national statistics of the amount of N purchased. It is not possible to split the use of N fertiliser between agriculture and forests.

N fertilisation of native forests is very rare, if occurring at all. There is a limited amount of N fertiliser applied to forest plantations in Australia. Fertiliser application in plantations is typically done to correct for nutrient deficiencies and trace element correction at establishment. N may be applied on sites where it is shown that it is a significant limiting nutrient, but as most establishments are on pasture systems, background nutrient levels are typically sufficient.

6.15 Emissions and removals from drainage and rewetting and other management of organic and mineral soils 4(II)

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

6.16 Direct and Indirect N_2O emissions from managed soils - 4(III) and 4(IV)

6.16.1 Methodology - N_2O emissions from N mineralisation associated with loss of soil organic matters

An increase in N_2O emissions can be expected following a decline in soil organic carbon stocks. This is a consequence of enhanced mineralisation of soil organic matter that takes place as a result of soil disturbance. The conversion not only results in the net loss of soil organic carbon, but the corresponding effects on mineralised nitrogen can result in N_2O emissions from the process of nitrification and denitrification.

The IPCC (2006) methods are used to calculate N_2O emissions from this source. The amount of nitrogen mineralised is calculated from the C:N ratio of soil. The C:N values used are 18 for *forest land* and forest conversion categories and 10 for *grassland remaining grassland*, reflecting the approximate median value extracted from a survey of national estimates (Snowdon *et al.* 2005). The country specific emission factor for fertiliser additions to non-irrigated crops and pastures (0.002 (Gg N_2O-N/Gg N)) is then applied.

Emissions associated with N mineralisation in *cropland remaining cropland* soils are reported in the Agriculture sector (3.D).

6.16.2 Leaching and Run-off

In accordance with the IPCC Guidelines, estimates are made of emissions associated with leaching and run-off of the N mineralised through loss of soil carbon. The CS method used for estimating leaching and run-off from agricultural N sources is used (see section 5.6.10).

Annual nitrous oxide production from leaching and runoff is calculated as:

$$E_{ij} = M_{ij} \times FracWET_{ij} \times FracLEACH \times EF \times C_g \qquad (4IV\_1)$$

Where:

M_{ij} = mass of N mineralised due to a loss of soil carbon (Gg N)

$FracWET_{ik}$ = fraction of N available for leaching and runoff (Appendix 5.J.I)

FracLEACH = 0.3 (Gg N/Gg applied) IPCC default fraction of N lost through leaching and runoff

EF = 0.0075 (Gg N_2O-N/Gg N) IPCC (2006) default EF

C_g = 44/28 factor to convert elemental mass of N_2O to molecular mass

6.16.3 Uncertainties and time series consistency

Further details are provided in Annex 2

6.16.4 Source specific planned improvements

all data and methodologies are kept under review and development.

6.17 Source Category 4(v) Biomass Burning

the methods applied to estimate emissions and removals associated with biomass burnt are described under 4.A *forest land* and 4.C *grassland*.

Appendix 6.A: Land Cover Change

6.A.1 Introduction

The estimation of net emissions for the land sector is supported by the use of remote sensing imagery to determine a time series consistent assessment of land use change in Australia.

The Department of the Environment has assembled a series of national coverages of Landsat satellite data (MSS, TM, ETM+ and OLI) across 23 time epochs from 1972 to 2014 which are analysed to identify both where and when land use change occurs.

Appendix

The archive of time series of historic cover and cover change information managed by the Department of the Environment extends as far as possible given the importance of time series consistent data from 1990 to the present. Additionally, the effects on emissions from land cover change are typically long lasting, and historic activities may still contribute to current estimates. Moreover, estimates of emissions from current activities will be affected by the site history. For example, a current conversion event will likely generate fewer emissions if the forest cleared is secondary forest (regrowth after a previous deforestation) rather than a primary (mature) forest. Consequently, an extensive record of past land management history is a critical input into the preparation of accurate emission estimates.

6. A.2 Monitoring Change with Remote Sensing Imagery

6. A.2.1 Data processing

A detailed protocol of remote sensing specifications for land cover change was developed by Furby (2002) through extensive pilot testing (Furby and Woodgate, 2002) to ensure time series consistency of methods, and the provision of spatially accurate land cover change data through time. These specifications determine the exact way that images are acquired, processed and classified.

The sequence of processing stages carried out in producing the assessment of Australia-wide land cover change is:

- image acquisition and selection;
- image registration[5] and calibration[6];
- sun-angle (terrain illumination) correction (Wu *et al.* 2004);
- mosaicing[7] of registered and calibrated images to the single map tiles for each time sequence;
- thresholding[8] through all time sequences; and,
- conditional probability network (CPN) analysis (Kiiveri et al., 2001), each year over the entire time series
- attribution[9] of change to direct human-induced change.

5 Registration uses stationary and identifiable ground features (ground control points) as constant reference points for the image sequence. This step is not applicable to Landsat 8 imagery.

6 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. This step is not applicable to Landsat 8 imagery.

7 Mosaicing aggregates images into the map tiles shown in Figure 6.A 2, removing overlaps in the original 185 km*185 km images.

8 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.

9 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.

Figure 6.A.1 The 37 1:1 million scale map tiles used in the remote sensing programme

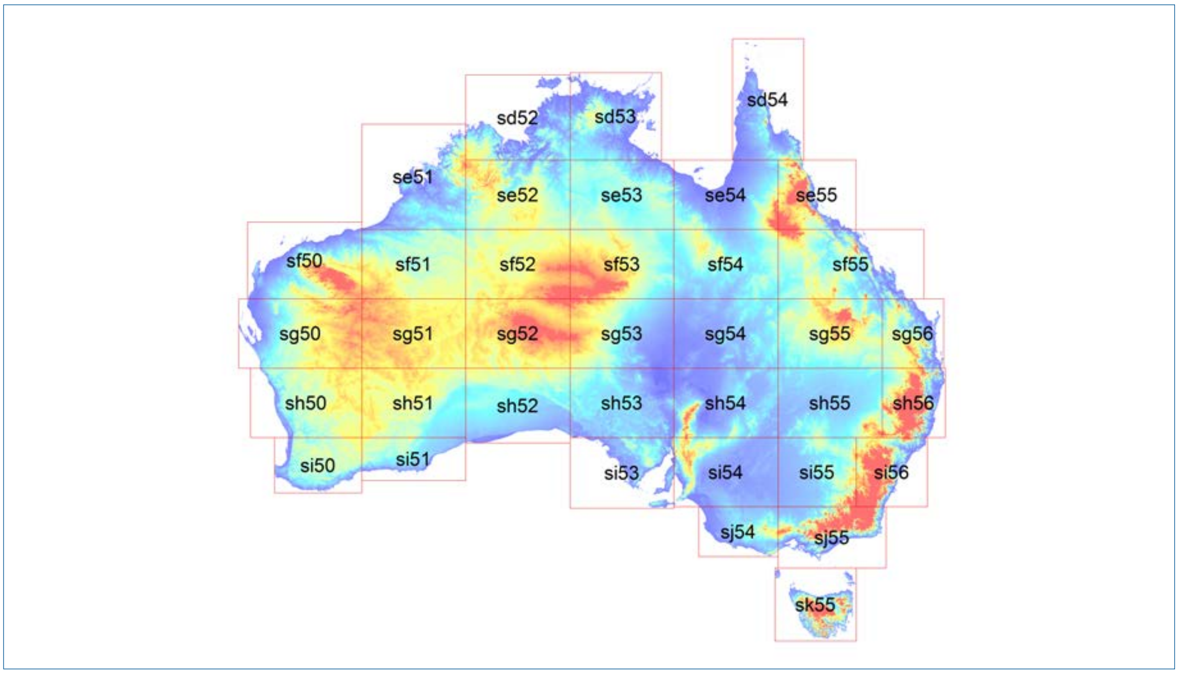


Image Acquisition and Selection

The time series of available Landsat images extends from 1972 to 2014. The selection of periods for analysis, shown in Table 6.A1, was designed to give maximum temporal resolution immediately before and after 1990 and for the period from 2004 onwards to maximise accurate detection of trends in land cover change over time.

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 is randomly generated by *FullCAM* (see section 6.7.1.1), within the sequence of coverage dates for the relevant map tile. This method provides 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.

Appendix

Appendix

Table 6.A.1 Landsat Image sequence

Year	Resolution (m)	Time Since Previous Image (yrs)
1972	50	-
1977	50	5
1980	50	3
1985	50	5
1988 (early)	25/50	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
2008	25	1
2009	25	1
2010	25	1
2011	25	1
2012	25	1
2013	25	1
2014	25	1

Unit of analysis – spatial resolution of the imagery

The 'natural' pixel size of the 1972 to 1985 Landsat MSS (57 m × 79 m) is re-sampled to a 50 × 50 m pixel. The 30 × 30 m native resolution of the Landsat TM, ETM+ and OLI data available after 1985 is produced as 25 × 25 m pixels. This approach deals with the change in pixel size of the various Landsat sensors over time and supports the need for spatially and temporally consistent integration with other spatial data used in *FullCAM*,

To apply the pixel-by-pixel analysis over the period where the pixel size changed from 50 m to 25 m, a 50 m MSS equivalent (in both spatial and spectral resolution) is derived from the 1989 TM (25 m) data, and then forest extent is calculated separately from both the 50 and 25 m data sets. Differences in the extents of forest between these two outputs are due to "sensor change". An overlap technique is used to ensure time-series consistency such that the assessment of land cover change for 1988-89 is then based on a 50 m to 50 m comparison, while the 1989-1991 data is a 25 m to 25 m comparison. As part of the continuous improvement, processing of 1988 Landsat TM data at 25m spatial resolution has been completed replacing the 50 m resolution MSS data for 1988. Consequently the entire land cover time series data has been recalculated making use of best available data while maintaining time series consistency. This approach is consistent with good practice for ensuring time-series consistency where the instruments used to collect activity data change or degrade through time (IPCC, 2003 page 5.58).

All Landsat derived data are used at a consistent 25 m resolution for the full time series analysis by re-sampling the 50 m pixels (1972-1985 information products) into four 25 m pixels. The spatial-temporal model (see the Conditional Probability Network described below in the *Time Series Consistency* section) is used to reduce the effect of "mixed" isolated and edge pixels in the overlap period. The ability to determine, from 1988 onwards, the effects of land use change to 0.2 ha 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.

Re-sampling Landsat TM, ETM+ and OLI sensor data to 25 m pixels is a common practice. Using a 50 m re-sample to provide consistency over the multiple resolutions of Landsat sensors also provides for uniformity in the time series. Quality assurance and validation processes confirm that accurate results are achieved with this re-sampled data.

Use of Landsat 8 Data

Observations of recent land cover change has been derived from the latest sensor on-board the Landsat 8 satellite, Operational Land Imager (OLI). OLI is an advanced sensor designed to collect improved quality data, ensuring continuity of previous instruments - Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) sensors. Landsat 8 products supplied by Geoscience Australia are in a new format known as the Australian Reflectance Grid (ARG25). ARG25 is a pre-processed product corrected for geometric distortions and calibrated as absolute surface reflectance, hence the specifications of this new product are quite different to the previous Landsat 5 and 7 data products used for the national inventory Land Cover Change Programme (LCCP). To ensure time series consistency and compatibility with the existing LCCP, a detailed technical assessment of the geometric and radiometric consistency and interoperability between these two products has been undertaken.

First, geometric consistency was assessed by matching about 13,300 ground control points (GCP) drawn from the LCCP scenes held in the national inventory data library and the corresponding ARG25 scenes. Assuming that the correlation matching succeeds in correctly registering each point, the position residuals provide a measure of the accuracy of co-registration of the two datasets. This analysis showed that whilst the temporal geometric accuracy of ARG25 products is highly consistent, several GCPs had residual matching errors ranging from 1, 2 and greater than 2 pixels compared to the LCCP products. The mis-registration, if not accounted for, would result in false change being reported. To resolve this, the mean residual vector for each ground control point (GCP) was calculated and applied to the LCCP scenes to align with the ARG25 product base. The scene specific transformation coefficients ensured that the two products are aligned and consistent to within a pixel for the entire country.

The second step in the process was to assess the radiometric consistency between the ARG25 and LCCP products using a total of 339 image pairs from the 2005 continental coverage. The two products were paired up based on the Landsat path and row, and image acquisition date. Null pixels in either image were discarded. Pixels located in very dark or very bright regions in the LCCP images were also excluded from the analysis, since such values may have potentially saturated during the pre-processing. The remaining pixels were linearly regressed against each other, assuming that the relationship will be strongly linear if both products are internally consistent in relation to radiometric characteristics. For each band, gain, and offset combination correlation values were calculated. The gain and offset values for converting LCCP pixel values into ARG25 pixel values can be expressed as -

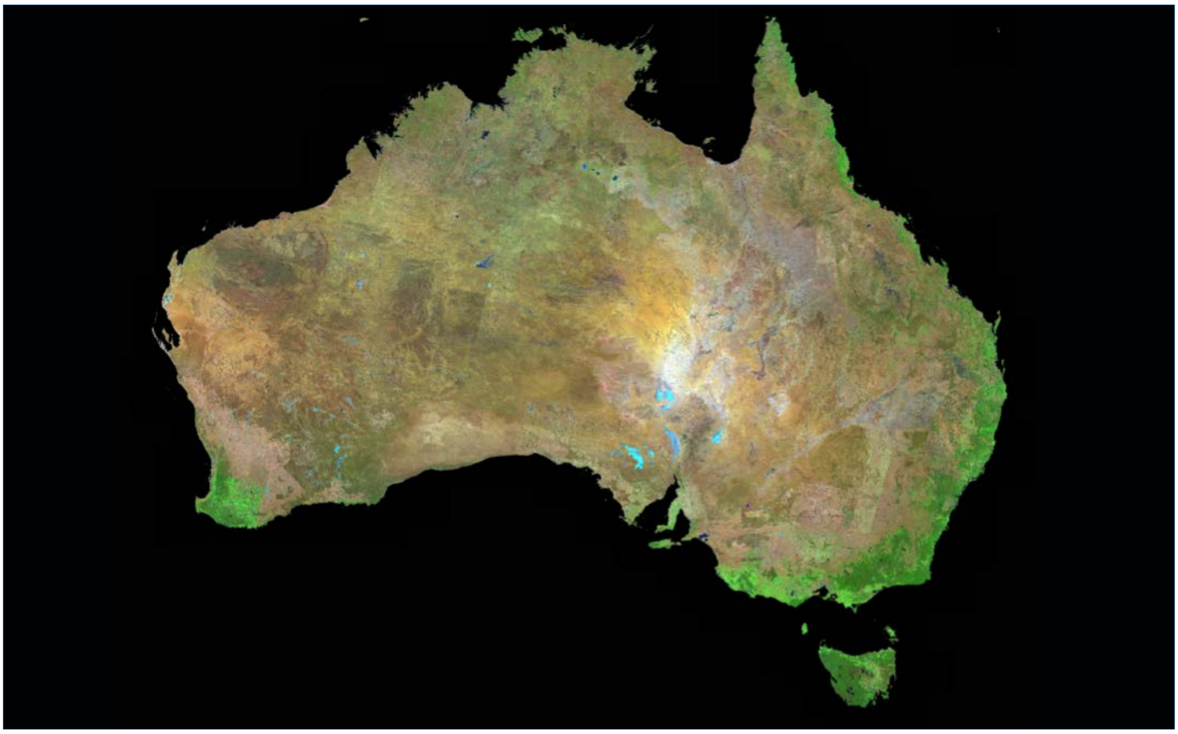
$$\text{ARG25} = \text{gain} \times \text{LCCP pixel value} + \text{offset}$$

The relatively high correlations found in the 2005 coverage confirm that there is a strong linear relationship, across all bands, between the LCCP values and the equivalent ARG25 image values. Based on this study a scene specific, linear transformation coefficient for each band was calculated to convert the LCCP calibrated pixel values into consistency with the ARG25 surface reflectance values (Devereux, et al. 2013). The time series consistency of this method was also assessed for selected sites using eight years of surface reflectance data.

Based on this study, the 2014 ARG25 Landsat 8 datasets have been processed to a consistent quality, LCCP compatible data for further processing, namely, mosaicing and thresholding. Mosaicing of the individually calibrated surface reflectance images into 1:1,000,000 map sheet tiles to form a seamless base (Figure 6.A 2) for image classification using thresholding techniques discussed below.

Appendix

Figure 6.A.2 2014 Landsat 8 surface reflectance image of Australia



Thresholding

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, ground 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 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 % canopy cover and a minimum potential height of 2 m.

Conditional Probability Network

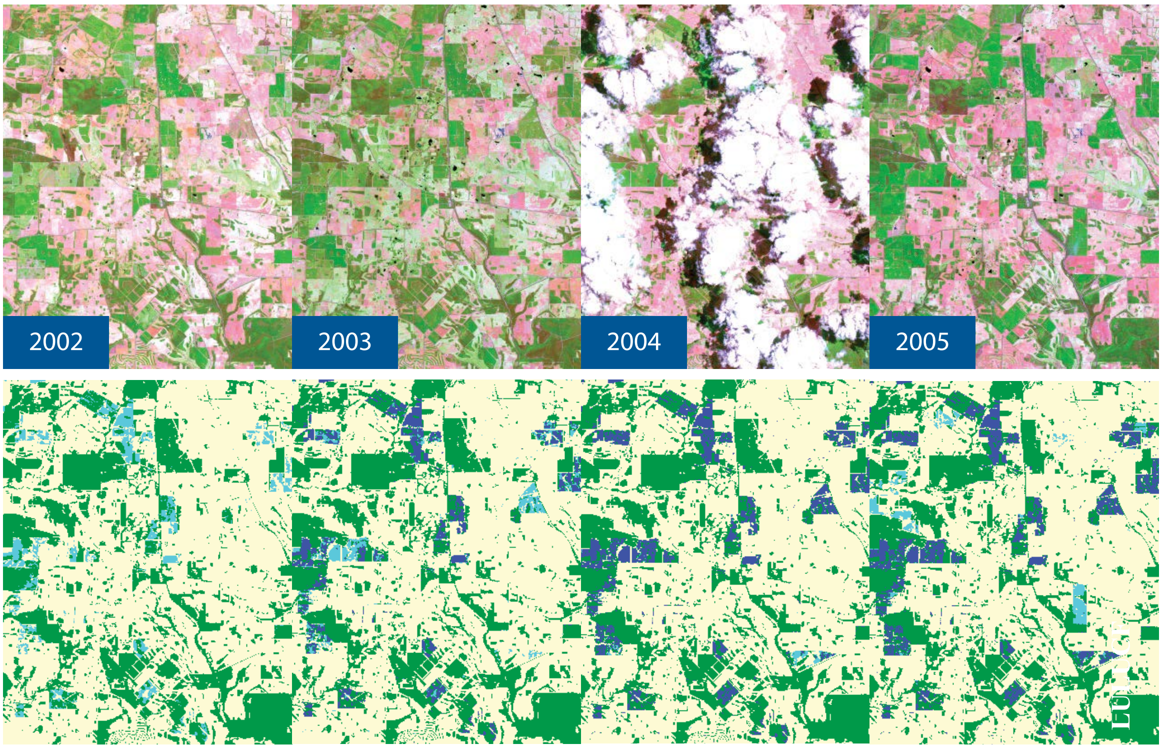
The land cover change programme uses a Conditional Probability Network (CPN) to strengthen confidence in the 'forest' or 'non-forest' classification of a pixel by considering the previous and subsequent images in a sequence to resolve any uncertainty in the classification (forest/non-forest) of a particular 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. That is, it ensures that the forest cover status of a pixel at a point in time is sensible based upon the forest cover status of that pixel in the previous and subsequent images. This helps to eliminate false change from a single image that may be due to anomalies in the data such as unseasonal greenness, wetness or flooding. The CPN also allows areas of missing data, such as cloud cover, to be filled in based on the cover status of the surrounding images (Figure 6.A 3).

Appendix

Figure 6.A.3 Images of forest extent and change based on CPN analysis 2002-2005: area - 16 x 20 km



Green: forest 2000 Blue: new forest 2000-02	Green: forest 2000 Dark Blue: new 2000-02 Light Blue: new 2002-04	Green: forest 2000 Dark Blue: 2000-04 Light Blue: 2004-05	Green: forest 2000 Dark Blue: 2000-05 Light Blue: 2005-06

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 (e.g., 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 'flickering' false change in scattered and edge forest pixels. This method ensures that individual and small clusters of forest pixels have a high classification certainty in relation to their neighbouring pixels and through time, minimising false detection of individual forest pixels and minimising false change in forest classification that would otherwise occur as a result of small changes in the crown cover of isolated pixels.

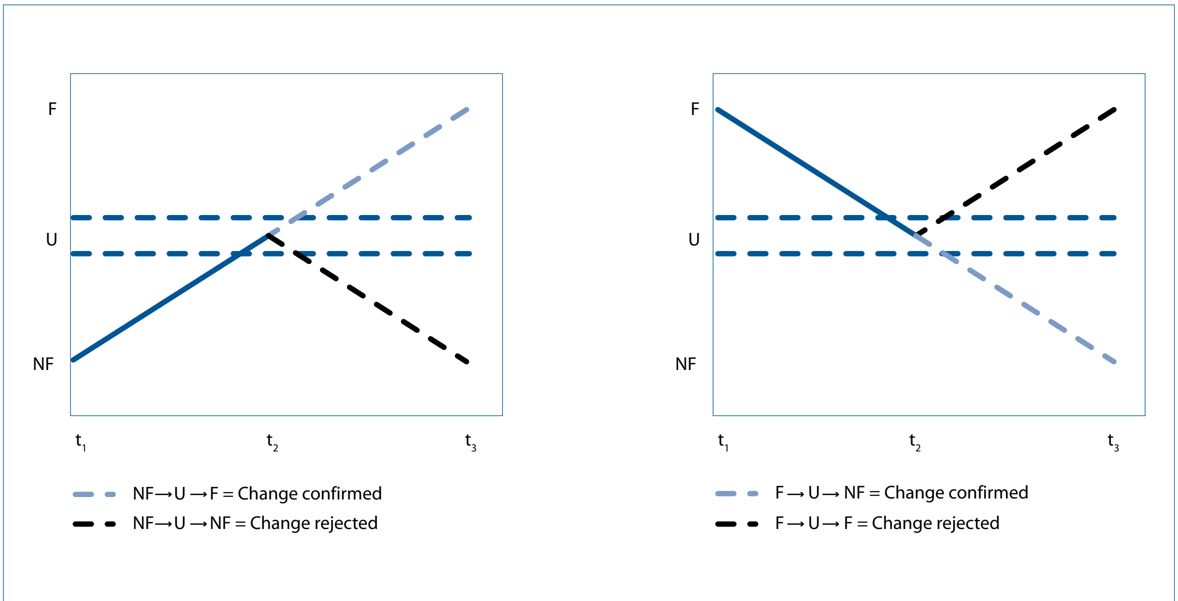
Forest extent and change analysis

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 (See for example Figure 6.A 4). 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 only includes the area of forest canopy loss and not 'gaps' in the forest canopy. This approach provides a much lower estimate of area cleared 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 in the certainty of identifying forest cover change is provided 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. Therefore, the last step allows uncertainties to be confirmed in a time-series update and CPN re-run (Figure 6.A 4). The three-class approach is most relevant to a multiple time series (as opposed to pair-wise) change analysis. It is this approach that leads to small adjustments to the areas cleared over the last two to three years of the time series as the CPN becomes more definitive as new images become available to confidently assign change from a prior condition.

Figure 6.A.4 Three class determination of forest cover and confirmation/rejection of change over time using the CPN. F- Forest, U – uncertain, NF – Not Forest.



Appendix

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 as either direct human-induced and permanent or due to natural temporary effects or methodological artefacts. Land cover change due to temporary tree dieback, natural dynamics of tree mortality and recruitment, drought and both seasonal and inter-annual variability (causing green 'flushes' of growth with similar spectral signals to regrowth) are also identified and excluded by means of an automated, rule based monitoring system, that monitors the temporary loss of forest cover for x number of years to determine if a permanent change in land use or deforestation has occurred. Qualified technical staff use visual image backdrops such as Landsat , Google Earth or SPOTMaps data to differentiate permanent land use change events from those of temporary forest cover loss events such as harvesting or forest fire.

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 are designed to exclude change due to:

- intermittent water features and irrigation areas that may give a false change signal;
- drought and growth flushes; and,
- terrain illumination.

Two major innovations have been introduced this year to improve the attribution efficiency and reduce the subjectivity of visual attribution of change.

a. Procedural changes to improve the attribution efficiency:

- A software tool was introduced to automatically extract patches of land use change based on a point selected by the interpreter which improved the accuracy of delineations of the land use change pixels.
- Apart from high resolution Google Earth imagery, the interpreter was also provided with additional information such as permanence of clearing for a given area, drawn from time series historical data, which gives an indication of whether the observed clearing is permanent or temporary.
- A software tool has been developed to define the attribution masks as close to the change pixels as possible, eliminating false clearing pixels entering the account.

b. Automated tools to monitor permanent land use changes

- A suite of software tools have been developed to generate forest cover loss and regrowth statistics based on the 42 years of historical land cover change data. A number of additional variables have been calculated from the time series data such as (a) number of years a pixel has been cleared, (b) year cleared, (c) whether the last event was clear or regrowth, (d) number of clear and regrowth events from 1972 to present, (d) clear pixel exceeds a given threshold of X years, etc. These additional variables were subsequently used in a rule based system to identify additional areas that have been subjected to permanent land use change within the managed forests and settlements.

6.A.3 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 and 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 ground training data. The method uses an automated spectral discrimination and is described in Caccetta and Chia (2004). Currently, only Landsat TM, ETM+ and OLI data is used for plantation classification.

6.A.4 Quality Assurance and Quality Control

6.A.4.1 Programme implementation

During the initial implementation of the remote sensing programme, 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 quality assurance and quality control (QA/QC). The results of the pilot studies are published in Furby and Woodgate (2002).

The approach to programme administration provides for centralised progress monitoring and QA/QC at each stage in the processing of the Landsat data. 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 6.A 1).

The QA/QC and data validation procedures for each of these items in the Australia's land cover change methods are summarised below – see also Furby (2002).

6.A.4.2 Acquisition & selection of satellite imagery

Data (scene) selections and raw data quality are thoroughly checked and reviewed by the CSIRO and the Department of the Environment (DE) to ensure that:

- the images procured overlap to prevent gaps in the coverage;
- optimal, spatially and temporally consistent image dates are procured;
- cloud in overlap areas is covered by cloud-free data in adjacent images whenever possible;
- when the first selection is identified as having a high proportion of cloud cover, image searches are repeated to ensure that better images have not been overlooked; and,
- image problems are correctly entered into a scene selection database.

6.A.4.3 Registration & Calibration

The Landsat 8 data has been pre-processed by Geoscience Australia including image registration and calibration. Each pre-processed scene contains an extra band informing the quality of the data at pixel level. Each registered and calibrated image has been verified prior to supplying the data to contractors for further processing. The verification includes:

- the information and data provided is checked for completeness and the registration assessed, based on the summary information and the pixel quality data; and
- if the registration accuracy appears doubtful, unacceptable or cannot be determined from the information provided, it is further investigated so that the exact nature of any problem can be identified and corrected.

6.A.4.4 Mosaicing

All mosaiced images (quadrants and time slices) for a particular map sheet tile are assessed at the same time. The assessment of each image is performed in two stages:

- the information and data are checked for completeness and consistency of the mosaiced image assessed; and,
- the processing status of the mosaic image is updated in the Image Catalogue, and the images are reprocessed if required.

The individual steps involved in the assessment of the image are listed in Furby (2002).

6.A.4.5 Thresholding

Two review processes are applied to the thresholding products. A quality assurance process is applied during and at the end of the thresholding stage of processing. The aim of this quality assurance process is to ensure that the methodology has been correctly applied and that the intermediate and final products are consistent with the supplied ground data and with each other across stratification zone and map sheet boundaries. The assessment of the thresholding products is performed in several stages:

- Information and data provided by the contractor after the single-date probability images are created (Step 8; see Furby, 2002) is checked for completeness. The adequacy and consistency of the analyses and the accuracy of the probability images is also assessed by CSIRO.
- If the analyses or probability images appear doubtful or inconsistent, further investigations are carried out so that the exact nature of any problem can be reported to the contractor.
- An Initial Assessment report is completed and the contractor advised of the results of the assessment and the actions required (either review of the analyses or continuation of the processing sequence).
- The plausibility of the change images produced by the contractor is checked by CSIRO.
- If the accuracy appears doubtful, images are further investigated so that the exact nature of any problem can be reported to the contractor.
- A Change Image Assessment report is completed by CSIRO and the contractor advised of the results of the assessment and the actions required (either review of the analyses or continuation of the processing sequence).
- The final products supplied by the contractor are checked for completeness and the remainder of the processing by the contractor is assessed.
- A Final Assessment report is completed and the contractor advised of the results of the assessment and the actions required (either review of the analyses or continuation of the processing sequence).

The first three steps are performed during the thresholding processing (step 8 of Furby, 2002), based on preliminary information provided by the contractor. The next three steps are performed during the thresholding processing (step 11 of Furby, 2002). The final two steps are performed after the final products had been delivered.

6.A.4.6 Time-series consistency

Remote sensing pilot testing demonstrated the need for time-series consistency in image data pre-processing, analysis, and subsequent formation of time-series forest/non-forest labels. The operational standards (Furby, 2002) give explicit emphasis through documented rule sets to each of these areas 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/non-forest labels. This process produces superior forest extent and change results compared to 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 from 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/non-forest and forest change (forest and non-forest conversions). The temporal rules bias against unlikely events such as multiple one year conversions between forest and non-forest. 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 from year to year) and subsequent error in pixel and change labelling.

6.A.4.7 Improvement & Verification

The verification of the remotely sensed land cover mapping is conducted within a continuous improvement and verification programme. An independent programme of checking the Landsat results is conducted by external agencies, both to verify the method (and hence the accuracy of the product) and to identify areas for improvement. This programme involves checking the results of the land cover mapping against high resolution satellite and air photograph interpretation using a stratified sampling technique.

The first verification considered the initial time-series of change data from 1972-2000 and was done using air photograph comparisons(Lowell *et al.* 2003; Jones *et al.* 2004; Lowell *et al.* 2005).

The initial independent assessment of the "raw" accuracy of the classification of forest and non-forest areas across the continent and over the period of 1972 – 2000 indicated that 94-98% of forest and 85-96% of non-forest vegetation was correctly classified (Jones *et al.* 2004). Accuracy in the data used for estimated rates of change (afforestation/regrowth or deforestation) was higher than the above, because the process of manual attribution, described previously, was used to confirm or reject changes in cover in the final dataset.

A second verification programme assessed the accuracy of forest/non-forest classification for the period from 2002-2010 using the same methodology that was used previously (Lowell *et al.* 2012). This involved establishing four hundred points selected in accordance with a temporally stratified random sample across each mapsheet, followed by human interpretation of the likelihood of forest for each point using very high resolution imagery and cross tabulating the interpretation against the CPN classification.

The study concluded that 92% of points were definitely or probably correct. A relatively small 3% of points were incorrectly classified and 7% were probably incorrect. About 81% of interpretations are consistent with the change for points that underwent land cover change at some point between 2002 and 2010.

In response to an ERT recommendation[10], the above study has been extended to assess the commission and omission errors resulting from application of the CPN algorithm. The CPN algorithm is designed to contribute to the process of minimising false changes as the entire time series data is reprocessed each year taking into account of both spatial and temporal history of each Landsat pixel. The resulting change product is subjected to a two step attribution process, described above, to detect human induced land cover changes.

The following assessment relates to the verification of the raw CPN land cover change product (not the attributed product) using high resolution satellite imagery acquired between 2001 and 2012. The methodology developed for this project (Lowell, *et al.* 2014) enables the mapping of the 7680 sample points from the second verification program in 2012 to the multi-temporal confusion matrix in Table 6.A 2. This matrix shows all possibilities for a point correctly or erroneously classified as forest or non-forest at the start or end of the time interval - Time 1 (t_1; columns) or Time 2 (t_2; rows) respectively.

10 FCCC/ARR/2013/AUS, paragraph 84; FCCC/ARR/2014/AUS, paragraph 54

Table 6.A.2 Sample point distribution in a confusion matrix for temporal land cover change

			Time 1		
		Erroneously labelled Forest	Erroneously labelled Non-forest	Correctly labelled Forest	Correctly labelled Non-forest
Time 2	Erroneously labelled Forest	*Correctly detected No Change (although t1 and t2 classifications are both erroneous)*	*Undetected Deforestation*	*Undetected Deforestation*	*Erroneously detected Regeneration*
	Erroneously labelled Non-forest	*Undetected Regeneration*	*Correctly detected No Change (although t1 and t2 classifications are both erroneous)*	*Erroneously detected Deforestation*	*Undetected Regeneration*
	Correctly labelled Forest	*Undetected Regeneration*	*Erroneously detected Regeneration*	*Correctly detected No Change*	*Correctly detected Regeneration*
	Correctly labelled Non-forest	*Erroneously detected Deforestation*	*Undetected Deforestation*	*Correctly detected Deforestation*	*Correctly detected No Change*

- Green cells are those that are correct on the change map. The four cells in the lower right are self-evident: points were correctly labelled at both t_1 and t_2 and therefore correctly identify No Change (NC), Deforestation (DEF)[11], and Regeneration (REG). The two green cells on the upper left diagonal are correctly labelled NC even though the classifications at both t_1 and t_2 are incorrect.
- Red cells are errors of commission for change – DEF or REG. Two possibilities exist for both DEF and REG. DEF will be erroneously detected if a point is 1) erroneously identified as forest at t_1 and correctly identified as non-forest at t_2 and 2) correctly identified as forest at t_1 but erroneously identified as non-forest at t_2. The same is true for REG
- Lavendar cells are errors of omission for DEF while blue cells are errors of omission for REG. For each of DEF and REG there are three possible interpretation combinations that yield errors of omission.

Out of the 7680 total sample points re-analysed, 7213 points had no change and the remaining 467 change points were further analysed to generate the confusion matrix shown in Table 6.A3. To map a verification point to the temporal confusion matrix, multiple sources of information including GoogleEarth™, Google Streetview™, IKONOS and SPOT imagery acquired before and/or a change event, were visually interpreted as “ground truth” to assess the accuracy of a change class.

Over the entire study area and for all land cover change from 1998 to 2012, errors of commission for REG and DEF were 223 or 3% of the total 7680 points; the total of the lavender and blue cells (errors of omission for REG and DEF) is 23 or 0.3% of the total. These low numbers reflect the relative rarity of change in the area examined and the high classification accuracy of time series land cover classification using CPN.

11 Deforestation (DEF), in this section, refers to raw clearing pixels from the image processing and CPN procedures. This should not be confused with deforestation as used in the Kyoto Protocol context.

Appendix

Table 6.A.3 Collapsed confusion matrix showing the distribution of sample points

All Periods summary -- Definite + Probable					
			"Truth"		
		NC	DEF	REG	Total Est.
	NC	7213	11	12	**7236**
NCAS	DEF	136	124	0	**260**
	REG	87	0	97	**184**
	Total	**7436**	**135**	**109**	**7680**

NC – No Change, DEF – Deforestation, REG – Regrowth).

Colours equate to colours in the temporal change matrix shown in Table 6.A2.

The temporal confusion matrix not only indicates correctly classified pixels at any given time but also accuracy of land cover change pixels which is of equal interest that the total national amount of land cover change is accurately estimated. This is indicated by the gross over- or under-estimate for each class. For example, there were 135 "true" deforestation points but the CPN estimates 260 deforestation points as shown in Table 6.A3 – an overestimate of 1.6% of the total sample points. Similarly, about 75 points or 1.0% of the total number of points were overestimated as regrowth. This means that an area equivalent to 2.6% of the total area evaluated were erroneously mapped as land cover change.

Table 6.A.4. Summary statistics for the information in the temporal confusion matrix (Table 6.A3).

Time Intervals	Error Strength	Global Accuracy (%)	Global *Kappa*[1]	Change Classes:	No Change	Deforest	Regrowth
All	Definite and Probable	96.8	0.63**	User's Accuracy(%)	99.7	47.7	52.7
				Producer's Accuracy(%)	97.0	91.9	89.0
				Conditional ***Kappa***[1]	0.90**	0.47**	0.52**
				Gross Over/Under-estimate(%)	2.6	1.6	1.0
				Net Over/Under-estimate(%)		0.7	0.7
	Definite Only	97.6	0.63**	User's Accuracy(%)	99.9	50.3	45.2
				Producer's Accuracy(%)	97.7	91.4	100.0
				Conditional ***Kappa***[1]	0.94**	0.50**	0.45**
				Gross Over/Under-estimate(%)	2.1	1.3	0.9
				Net Over/Under-estimate(%)		0.4	0.4

[1]**Indicates that the CPN classification is significantly better than random (p<0.01).

As shown in Table 6.A4, over all time intervals, global accuracy is high (approximately 97%) and *kappa* is statistically significant. Class-based statistics show a high user's accuracy which is reflected in the statistical significance of the conditional *kappa*. However, user's accuracy for DEF and REG change classes is roughly 50%. Combined with the producer's accuracy for these classes, this indicates that the CPN classification has identified more change than is the case. That is, errors of commission were more than the omission errors. However, the high producer's accuracy for these classes indicates that most of the real change was identified by the classification, but at an "accuracy cost" of having many false positives.

It is important to note that the subsequent step in the data processing, which is visual inspection of all change pixels for each epoch through an attribution process, discussed in Section 6.A.2 and 6.A.4.8, was essentially designed to control for remaining false positive pixels. .

6.A.4.8 Attribution

The final quality control requires attribution of changes identified in cover change maps by the CPN as either direct human-induced, temporary change or methodological artefacts such as false positive change. The latter effects are well understood and include green flushing in images due to climate, terrain illumination variability, irrigation, water bodies and fire scars. The Department of the Environment staff use visual image backdrops such as Landsat imagery, Google Earth™ or SpotMap™ data for this discrimination. Results of this discrimination are then quality controlled. This attribution step provides a final quality control process designed to mitigate the risks of errors identified in the confusion matrix in Table 6.A 3.

6.A.4.9 Plantation typing

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 programme 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. Incorrect forest typing (e.g., labelling hardwood as softwood and vice versa) contributed 5% of the error, with only 4% being incorrect for both location and type. Methods for plantation typing of pre-1990 plantations are being developed. Similar to post-1990 plantation typing (into hardwood and softwood plantations), pre-1990 softwood plantations are being distinguished from native forests using the Landsat MSS/TM data from 1972-88. Validation of softwood plantation type mapping pre-1990 is currently being carried out by validating (and calibrating) against ancillary field data.

6.A.5 Planned Improvements

The remote sensing programme is further advancing the methods to identify:

i. Ongoing improvements and development of rule based methods for change detection;

ii. Annual updating of Landsat time series data prior to 2004 subject to availability of data;

iii. Updating of pre-90 plantation database by combining remote sensing data with existing spatial data held by other agencies

iv. Mapping of areas subject to harvest in the *Harvested Native Forests*, and

v. processing of remaining areas of sparse woody vegetation for parts of central Australia to complete the national coverage.

6.A.6 Land clearing prior to 1972

Forest land converted to crop or grassland remains in the *converted* category for 50 years.

Estimates of *forest land converted to crop or grassland* since 1972 are derived from observations of forest cover loss using Landsat satellite data.

Estimates of the area of forest land converted to crop or grassland for the period 1940-1972 is a gap in the activity data used to prepare the estimates for the *forest conversion* categories. Approaches to the estimation of these missing data have been explored, in line with recommendations in the ARR 2010, ARR 2011 and ARR 2012 reviews of the Australian inventory. Estimates have been produced using extrapolation techniques provided in IPCC 2006 Volume 1, chapter 6. The results are compared below.

Previous studies

Graetz *et al* estimated that 102.964 million hectares of forest were cleared between 1788 and 1990, or an average of 514,820 ha per year. Similar conclusions have been reached in the *State of the Environment Report* for Australia[12], with the area of forest cover cleared since 1788 estimated to be around 100 million hectares. A study by Barson et al. (2000)[13] found that approximately 92.5 million hectares of forest had been cleared since 1788.

If extrapolated to the period 1940-1972, the Graetz *et al* estimate translates into a cumulative area cleared over the period of 16.4 million hectares (Table 6.A2).

Forest conversion required to meet additional crop and livestock activity 1940-1972

The demand for additional pasture or cropland was high in the period 1940-72, reflecting relatively high prices paid for agricultural commodities. Cropping lands increased by 50 per cent, or around 6 million hectares in the period 1940-1972. For grazing activity, demand for land increased by the equivalent of 60-100 million hectares (based on agricultural activity data published by the Australian Bureau of Statistics).

The estimated demand for grazing lands was derived from the increment in cattle and sheep numbers over the period 1940-1972. These data were converted into a demand for cleared land. The conversion was based on assumptions regarding the amount of grazing land needed to support the number of sheep and cattle indicated in the national statistics (1-2 sheep per hectare, 1 cow equal to 10 sheep based on data provided in Hamblin (2001)[14] and Henzell (2007)[15].

Not all of the additional demand for pastures would have required a clearing event. With a discount of 50 per cent, the cumulative increase in area of land needed to support the increment in livestock activity was estimated to be 60-100 million hectares in the period since 1940-1972 (Table 6.A2).

Back cast regression of observed clearing on the farmer's terms of trade 1940-1972

Observed land clearing activity has also been established to respond to the farmers' terms of trade index of prices received to prices paid. A linear regression linking area cleared to the farmers' terms of trade was performed for the period where satellite-based land clearing estimates are available (1973 to 2010). The coefficients from this regression were used to back-cast land clearing activity to 1940 (Figure 6.A).

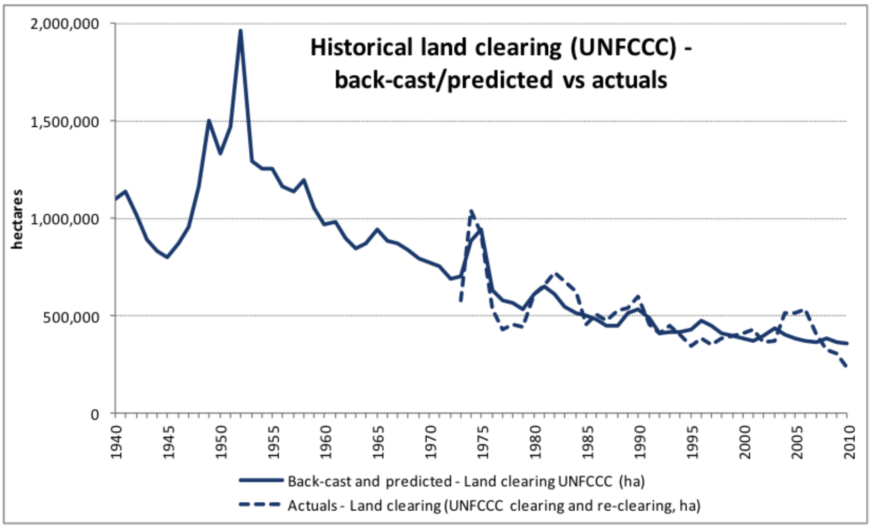
12 State of the Environment 2011 Committee. Australia state of the environment 2011. Independent report to the Australian Government Minister for Sustainability, Environment, Water, Population and Communities. Canberra: DSEWPaC, 2011.

13 Barson, M., Randall, L. And Bordas, V. (2000) Land cover change in Australia, Bureau of Rural Sciences, Australian Government, Canberra.

14 Hamblin, A.P. (2001) *Land, Department of the Environment and Heritage, Canberra.*

15 Henzell, T. (2007) Australian agriculture: Its history and challenges, CSIRO publishing, Collingwood.

Figure 6.A.6 Estimated area of land clearing and actual land clearing



Source: ABARES various.

Inverted back cast of 1973-2010 trend

Trends in area under cropland and cattle and sheep numbers indicate a peak of agricultural activity in the early 1970s. The Landsat timeseries indicates that the peak in land clearing in the period 1972-2013 occurred in 1974. Under this scenario it is assumed that land clearing gradually increased in the period 1940-1970 and peaked in 1974. This estimation of the historical trend was made by inverted in the trend observed in the period 1973-2013.

Table 6.A.5 Estimated land clearing 1940-1972: comparison of extrapolation methods

Extrapolation method	1940-1972		1973-1990
	Extrapolation		Landsat imagery
	Cumulative land clearing (ha)	Annual clearing (ha)	Annual clearing (ha)
Graetz *et al* average annual forest conversion 1788-1972	16,474,240	514, 820	547,222
Forest conversion required to meet additional crop and livestock activity 1940-1972	60,000,000	1,875,000	547,222
Back cast regression of observed clearing on the farmer's terms of trade 1940-1972	34,200,000	1,069,000	547,222
Back cast of 1960-1990 trend in farmers' terms of trade model with clearing peak in 1974	25,200,000	763,636	547,222

The data in Table 6.A indicates that the rates of land use change observed from the Landsat record, at 547,222 hectares a year for the period 1973-1990, are similar to the long run average rate of change calculated by Graetz et al of 514,820 hectares a year. There are good reasons to believe, however, that the rates of land use change experienced during the period 1940-1972 were higher than the period 1973-1990. Independent data on a range of economic forces, including higher prices for agricultural products and reduced costs of forest conversion for this period compared with earlier periods, anecdotal country histories and observed increases in national livestock numbers and cropping areas all indicate that the period 1940-1972 was a period of strong land use change in Australia.

The estimates of *Forest Conversion* presented in Section 6.5 for 1990 are based on a limited dataset on land use change extending only from 1973-1990. Extending the observed dataset to include estimates for the missing data on land use change for the period 1940-1972 could be implemented using a range of techniques identified in IPCC 2006 based on the data presented in Table 6.A.5.

The implementation of an extended dataset on land use change to 1940 would lead to higher emissions estimates for *Forest Conversion* for the entire time series, with larger impacts at the start of the time series, 1990, than for later periods of the time series. It is assessed that the estimate for net emissions for *Forest Conversion* categories would be 13 Mt CO_2-e higher in 1990, if the land clearing trend is back cast with an assumed clearing peak in 1974 and is applied in the FullCAM tier 2 model. This step has not yet been implemented in the estimates presented in section 6.1. A related question, that of the appropriate length of the transition process, remains open. While the Department of the Environment has assumed a 50 year period for the reporting of land in a land use change category, the IPCC assumes a default length of transition to a new carbon stock level of 20 years.

Appendix 6.B: *FullCAM* framework

Land sector reporting within Australia's National Inventory System integrates a wide range of spatially referenced data through a process based empirical model (Tier 3) to 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 (DOM) and soil), all principal greenhouse gases (CO2, CH4 and N2O), and covers both forest and non-forest land usesA Tier 3 method is used to estimate carbon stock changes for agricultural soils, living woody biomass (excluding perennial woody horticulture) and dead organic matter. This approach has several advantages over an IPCC Tier 1 or 2 method:

1. Models have the potential to improve coverage and completeness as they can extend beyond existing data to improve geographic coverage/distribution and coverage of source/sink categories by filling in gaps in data.
2. Measured climate data are interpolated using a mathematical (multivariate spline) function at the 1 km scale (Appendix 6.E.3) rather than broad climatic region classification. This enables quantification of carbon stock changes at finer spatial scales.
3. The method includes detailed characterisation of spatially mapped soil properties (Appendix 6.E.1) that influence soil carbon dynamics as opposed to broad soil taxonomic classification of the IPCC methodology
4. The method provides a more detailed representation of management influences and their interactions. This increases the spatial and temporal resolution of estimates compared to those that are represented by a discrete factor-based approach.
5. Soil carbon stock changes are estimated on a more continuous, non-linear and dynamic, monthly basis as a function of the interaction of climate, soil, and land management compared with the linear averaging as applied in Tiers 1 and 2.

6.B.1 Overview of the *FullCAM* Model Framework

FullCAM is a process based ecosystem model that calculates greenhouse gas emissions and removals in both forest and agricultural lands using a mass balance approach to carbon cycling. The *FullCAM* framework and its development are described in Richards (2001) and Richards and Evans (2004).

FullCAM has been selected for the Tier 3 method based on several criteria:

1. The model has been developed in Australia and extensively tested and verified for Australian conditions (Appendix 6.B.1.3 and 6.B.5.1). In addition, the model has been widely used for simulating soil and biomass carbon dynamics at project level (Australian Government Carbon Farming Initiative and future Emission Reduction Fund) and nationally.
2. *FullCAM* is capable of simulating, cropland, grassland, and forest eco-systems and land-use transitions between these different land uses at the 25m pixel level. As most emissions and removals of greenhouse gases occur on transitions between forest and agricultural land use, integration of agricultural and forestry modelling was essential.
3. The model is designed to simulate management practices that influence soil carbon dynamics including quantification of inter-annual variability. The *2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol* (IPCC 2014) (KP Supplement) have provision to reduce interannual variability and isolate the impacts of changes in human activities by calculating two time series of emissions and removals in which only the rate of human activities differ. This provision, in conjunction with new modelling techniques allowsfor emissions and removals due to the 'signal' of the impact of human activities, including mitigation measures, to be estimated using *FullCAM*.

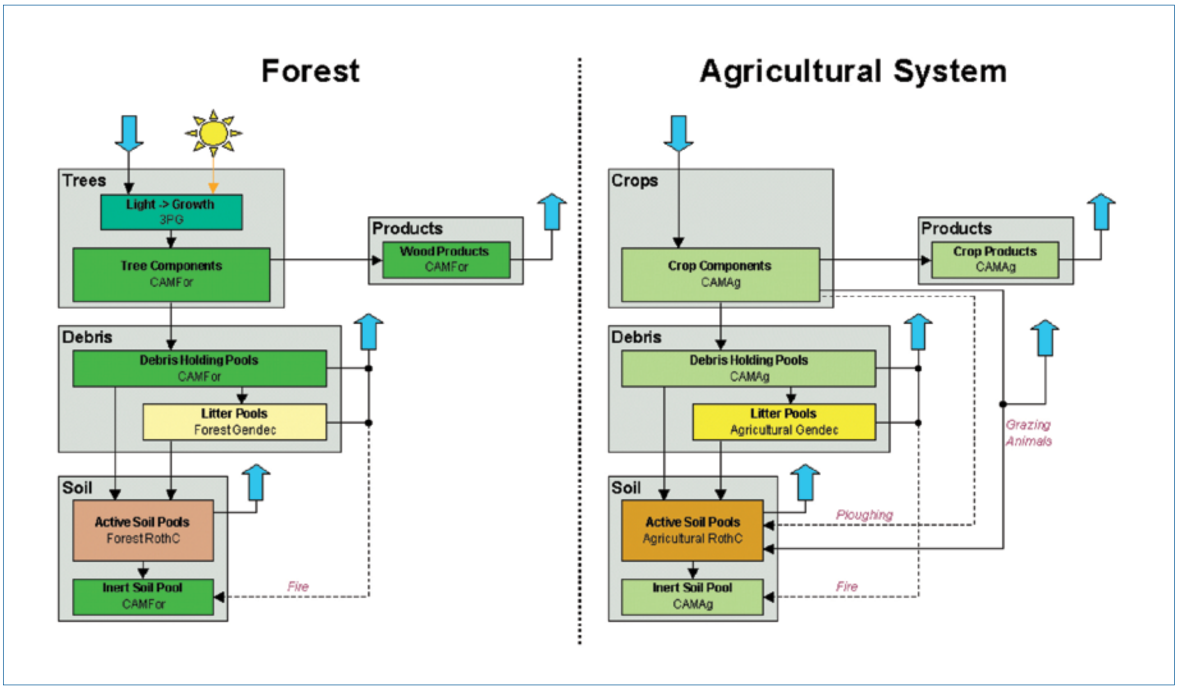
4. *FullCAM* has components that deal with both the biological and management processes which affect carbon pools and the transfers between pools in forest, agricultural and transitional systems. The exchanges of carbon, loss and uptake between the terrestrial biological system and the atmosphere are accounted for in the full/closed cycle (mass balance) model which includes all biomass, litter and soil pools (Table 6.B 2).
5. The data required for *FullCAM* to simulate is available nationally at appropriate scales for the data in a spatially and temporally time series consistent format.

6.B.1.1 *FullCAM* Sub-Models

FullCAM has been developed as an integrated compendium model that provides the linkage between various sub-models. The three sub-models integrated to form FullCAM as used in the National Inventory are:

1. *CAMFor* (Richards and Evans, 2000a), the carbon accounting model for forests (Figure 6.B1).
2. *CAMFor* is used to model carbon mass and transfers between the living tree and debris pools of forest lands. *CAMFor* has its origins in the 1990 CO_2 Fix model of Mohren and Goldewijk (1990);
   CAMAg (Richards and Evans, 2000b), the carbon accounting model for cropping and grazing systems (Figure 6.B1).
   The *CAMAg* model reflects the impacts of management on carbon accumulation and allocates masses to various plant, debris and soil pools. Yields need to be prescribed in the model;
3. Rothamsted Soil Carbon Model, *Roth-C* (Jenkinson, *et al.* 1987, 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. It is used in conjunction with both *CAMFor* and *CAMAg*.

Figure 6.B.1 The *FullCAM* model pool structure



6.B.1.2 Sub-model integration

The sub-models described above are integrated into *FullCAM* which was developed in the programming language C++ with a graphical user interface (Richards, 2001; Richards and Evans, 2004). The individual sub-models can be applied independently or in various combinations within the *FullCAM* framework. By embedding both the forest and agricultural models within *FullCAM*, it is possible to represent 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.

6.B.1.3 Quality Assurance and Quality Control

Sub-model integration

The integration of the sub-models into a single compendium model was initially undertaken in Excel as a test version. The prototype forest model derived (Richards and Evans, 2000c) 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.

Model coherence and validation

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[16]. Tests of model coherence and validation can only be meaningfully undertaken at the pixel level. This is the approach taken 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 validate the national results. Therefore, programmes to test model cohesion 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 *FullCAM* simulations 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 initial biomass, debris and soil carbon validation results are shown in Appendix 6.D, section 6.B.3, and section 6.B.5, 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 growth, transfers between carbon stocks in pools, and emissions from pools for every pixel modelled. Taking a mass balance, full carbon-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

16 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. Analysis of IEFs in the LULUCF sector is further complicated by reporting of accumulating land areas.

aspect of the model. The results from the Tier 3 model have also been compared with the results using Tier 2 methods (see section 6.3.3 and 6.7.3) and were found to be broadly consistent.

Transparency and Peer Review

For the complex Tier 3 methods, which incorporate models and large datasets, different approaches to transparency and peer review are required. Transparency and review of the land sector accounts is founded on:

1. published specifications, protocols and methods;
2. published verification results;
3. public release of models, tools and data ; and,
4. publication in peer reviewed journals or other literature.

Appendix

Australia has published six series of strategic and technical reports which document the development of *FullCAM*, the specifications, protocols and methods used, and the results of verification, validation and calibration of *FullCAM*. All reports are accessible by the public via the DE website (http://pandora.nla.gov.au/pan/102841/20090728-0000/www.climatechange.gov.au/publications/index.html). The methods and data used as part of the land sector accounts have also been extensively published in peer-reviewed papers in scientific journals.

The Australian Centre for Ecological Analysis & Synthesis undertook a modelling workshop in 2011 on Improving long-term predictions of carbon and nutrient dynamics in Australia's agro-ecosystems (http://aceas.org.au/index.php?option=com_content&view=article&id=74&Itemid=76). In the workshop FullCAM soil carbon outputs were compared with those from DayCENT, Century and a Microsoft Excel version of RothC, initially for two sites, Hermitage and Wambiana. Preliminary results suggested little difference between outputs of the four models over the study period. Further, if input data were the same or very similar then all models appeared to simulate soil carbon stocks to within 10 t C/ha (0-30 cm soil profile) of the final result based on a measured value of soil carbon stock (2010 site data).

6.B.2 Estimating Changes in Forest Biomass

6.B.2.1 Forest Growth

Forest growth in *FullCAM* is controlled through two separate biomass increment components of the model:

1. The tree yield formula (Richards and Brack (2004a), Brack *et al.* (2006) and Waterworth *et al.* (2007); and
2. Direct entry of biomass increment data.

Tree yield formula

The tree yield formula is embedded into the *FullCAM* code and when applied within the National Inventory System provides an empirically constrained process model for the calculation of biomass increment in the living components of *forest land*. The tree yield formula allows for responses to climatic variability while empirical data and parameters constrain initial aboveground biomass, forest growth, and relative movements between pools. It is the empirical data that constrains the model to reflect extensive field data (both existing and specifically collected).

The tree yield formula is applied to estimate the forest biomass increment in the following sub-categories:

- Forest land converted to Cropland;
- Forest land converted to Grassland; and
- Grassland converted to Forest land.

The tree yield formula is provided in Equation 6B_1:

$$\text{Aboveground Tree Mass at age a} = M \times e^{(-k/a)} \quad (6B\_1)$$

Where:

a = age of the tree stand

M = biomass predicted by the assumed initial biomass model (Appendix 4D), and

k =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 0.5*k*. In *FullCAM* this value is known as BI_a, the age of maximum aboveground biomass increment.

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*) (see Appendix 6.C):

$$I_a = (6.011 \times \sqrt{P} - 5.291)^2 \times (e^{(-k/a)} - e^{(-k/a+1)}) \quad (6B\_2)$$

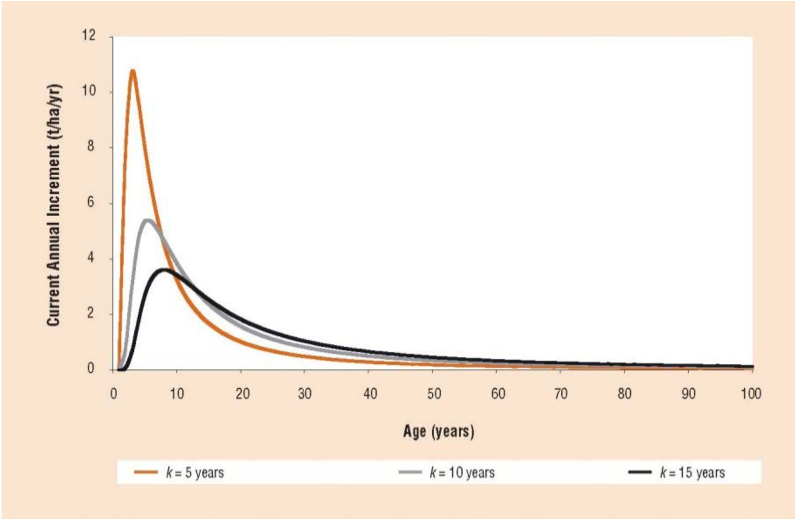
However, as productivity in any given year may vary around the average due to non-average weather or other factors, the average annual increment may be adjusted by the productivity in a given year (P_a) as a ratio with the long-term average productivity (*P*):

$$I_a = I_a \times P_a/P \quad (6B\_3)$$

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.

Maximum aboveground biomass increment One of the key parameters in the tree yield formula is the age of maximum aboveground biomass increment (BI_a). Figure 6.B.2 presents the results of an analysis of the effects of varying age of maximum aboveground biomass increment between the ranges of five 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 (Figure 6.B.2).

Figure 6.B.2 Effects of varying age of maximum current annual increment



Appendix

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 analysis 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. Available data, such as that reported by West and Mattay (1993), suggest that 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 *forest land converted to grassland* sub-categories 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 one to two 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 one to two 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 BI_a of ten is equivalent to an effective age of maximum current annual increment in stemwood volume of around 14 years. A BIa of ten is higher than that found in most eucalypt plantations, which reach this peak between two to seven 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.

Direct entry of biomass increment data

When the direct entry of biomass increment data component of *FullCAM* is in use, the model uses these data in calculations and so there is no calculation of biomass increment within *FullCAM*. The direct entry of biomass increment data component of *FullCAM* is applied in the source category *forest land remaining forest land*.

6.B.3 Estimating Changes in Forest Debris

FullCAM allows for the modelling of debris accumulation and decay based on forest growth and management. Debris accumulates from the turnover of dead plant material (e.g., branches, bark, leaves, and roots). In the absence of forest disturbances such as harvest or fire, debris mass increases with age to a steady state where the addition of forest material to the debris pools and loss from decomposition is in balance. Debris pools are also increased by the addition of slash material following harvest and decreased by any residue management techniques, in particular residue burning.

The turnover rates determine the amount of material being added to the debris pool. Decomposition rates determine the rates of loss of carbon back to the atmosphere as the debris breaks down. The balance of these two factors determines the amount of debris on site excluding the effects of management.

6.B.3.1 Calibration and Validation of Debris Calculations

To estimate debris accumulation and loss, *FullCAM* was calibrated and validated using litter decomposition rates taken from studies conducted around the world, representing a range of environmental settings within forest and agriculture. Half the dataset was used to calibrate algorithms and the other half was used to validate the decomposition predictions (Paul *et al.* 2004).

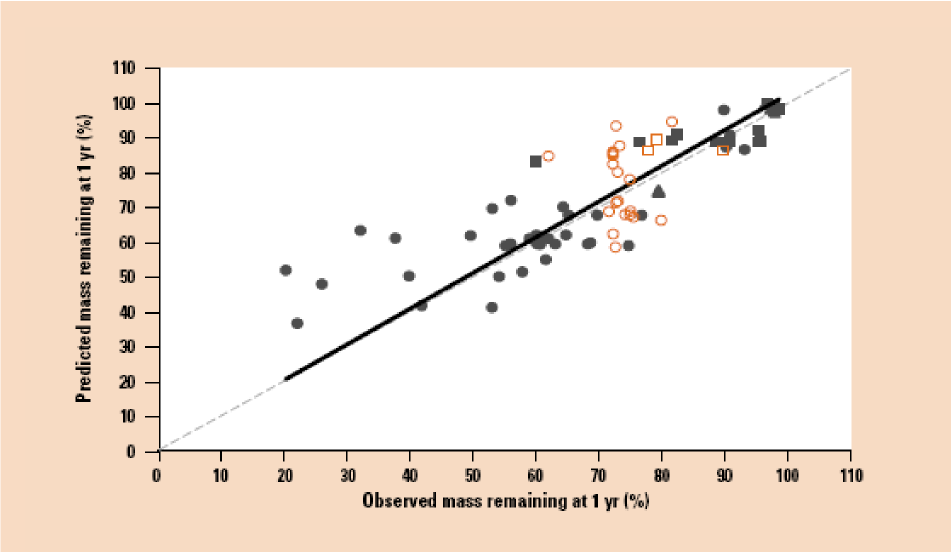
To calculate the decay rate of plant material before it enters the soil pool two groups of parameters used are calibrated: i) decomposable fraction of plant residues, and ii) rate constants for decomposition of decomposable and resistant debris pools of plant residues. The model was set-up to run using field measured rates of plant residues and observed climate conditions. For forest systems the model was run for one year, then for the number of years corresponding to field measured published data. For agriculture, the model was run for a number of pilot agricultural systems over several years, then for the number of years corresponding to field measured and published data (Jeff Baldock, CSIRO Land and Water, *pers. comm.*). The simulated mass of aboveground dry matter available to enter the soil pool as plant debris is compared to that observed in published studies. Rates of decomposition in the model are then adjusted so that the simulated mass remaining best matches the field measured data from similar environmental settings.

A model efficiency index (MEF) is calculated as the difference between the field-measured and model-simulated mass of litter remaining. Values of MEF can be positive or negative with a maximum and minimum value of 1 and -1, respectively. A positive value indicates that the simulated values describe the trend in the measured data better than the mean of the observations, with a value of 1 indicating a perfect fit. A negative value indicates that the simulated values describe the trend in the measured data to a lesser extent than a mean of the observations. Deviations of predicted mass remaining, or predicted litter accumulation, are assessed using the mean square error (MSE). The smaller the MSE the better the model explains the data.

Once calibrated, the model predicted the observed mass remaining after one year of decomposition with an MEF of 0.65 and a MSE of 117 g^2 100 g^{-2} (Paul *et al.* 2004). The line of best fit between field measured and simulated data had a slope near unity (1.03) with an R^2 of 0.57 (Figure 6.B.3).

Figure 6.B.3 Relationship between observed mass remaining after one year of decomposition of eucalypt leaf (●), eucalypt bark (▲), eucalypt dead wood (■), pine needles (○) and pine dead wood (□) from the calibration dataset, and that predicted using *CAMFor.*

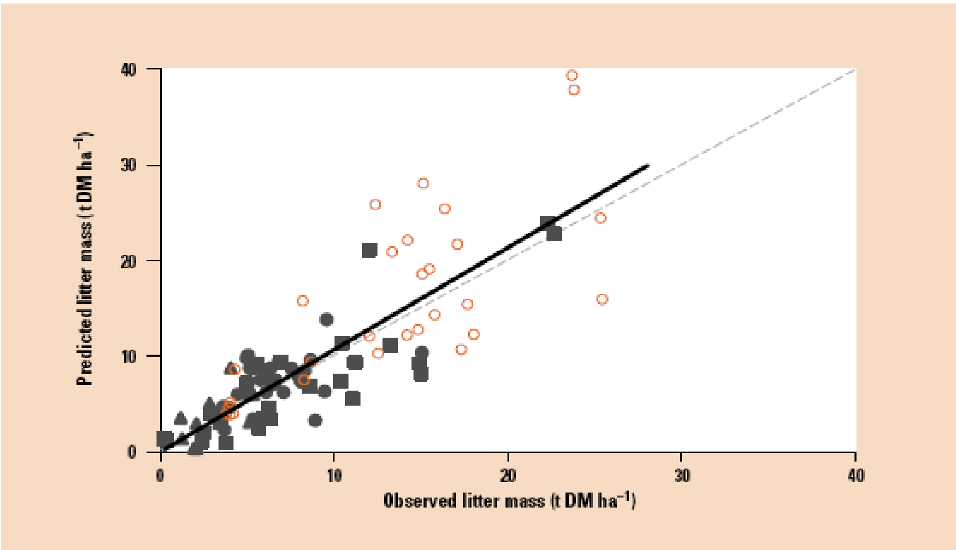
Dashed line represents the 1:1 line. Solid line represents the linear function of best fit when forced through the origin (Slope=1.03, R^2=0.57, n=80). MEF and MSE were 0.65 and 177 g^2 100 g^{-2}, respectively.



Using the validation data, the model predicted mass remaining with an MEF of 0.70 and an MSE of 80 g^2 100 g^{-2}. The line of best fit between field measured and simulated mass remaining after one year had an R^2 of 0.60 (Figure 6.B.4).

Figure 6.B.4 Relationship between observed mass remaining after one year of decomposition of eucalypt leaf (●), eucalypt bark (▲), eucalypt dead wood (■), pine needles (○) and pine dead wood (□) from the validation dataset, and that predicted using *CAMFor.*

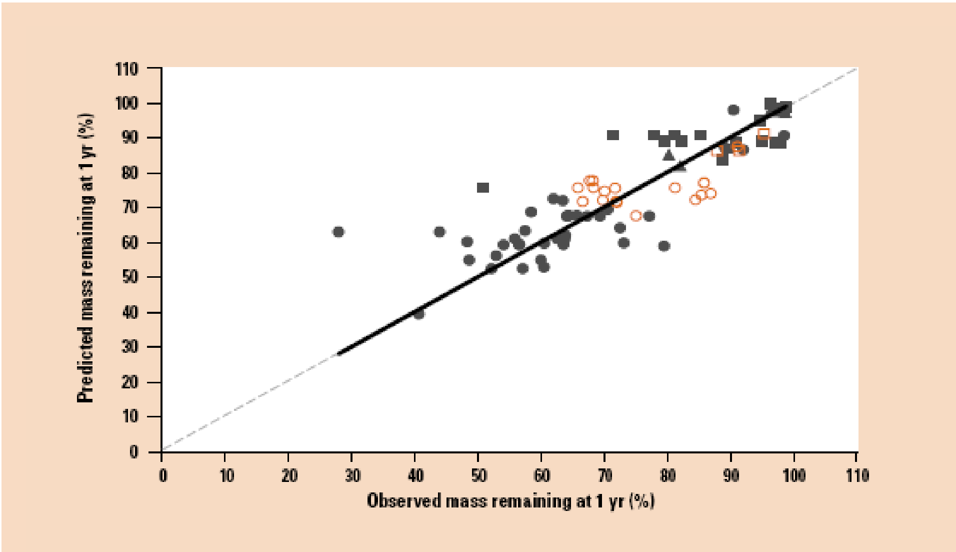
Dashed line represents the 1:1 line. Solid line represents the linear function of best fit when forced through the origin (Slope=1.00, R^2=0.60, n=83). MEF and MSE were 0.70 and 80 g^2 100 g^{-2}, respectively.



Validation of simulated data outputs were also performed using field measured data on long term litter accumulation (Paul *et al.* 2004). The model predicted litter accumulation between 4 and 100+ years with an MEF of 0.65 and a MSE of 15 t^2 ha^{-2} (Paul *et al.* 2004). The line of best fit between measured and simulated litter mass had a slope near unity (1.06) and an R^2 of 0.67 (Figure 6.B.5).

Figure 6.B.5 Relationship between observed mass of eucalypt leaf (●), eucalypt bark (▲), eucalypt dead wood (■) and pine needles (○) and that predicted using *CAMFor.*

Dashed line represents the 1:1 line. Solid line represents the linear function of best fit when forced through the origin (Slope=1.06, R^2=0.67, n=95). MEF and MSE were 0.65 and 15 t^2 ha^{-2}, respectively.



6.B.4 Estimating Changes in Crop and Pasture Biomass and Debris

6.B.4.1 Biomass

The model uses crop and pasture yield data and the proportional allocation of dry matter to different plant components to estimate annual dry matter accumulation in agricultural ecosystems.

An earlier analysis (Unkovich *et al.* 2009) defined the relevant crops for carbon accounting purposes (Table 6.B.2) at the Australian Statistical Geography Standard, statistical area level 2 (SA2) boundaries (Pink 2010).

Table 6.B.1 Field crops accounting for ≥95% (●), and additional crops for ≥99% (○) of field crop sowings for Australia as a whole, and in each Australian State in 2006 (from Unkovich et al. 2009).

Crop	Aust.	NSW	Vic.	Qld	SA	WA	Tas.
Wheat (*Triticum spp*)	●	●	●	●	●	●	●
Barley (*Hordeum vulgare*)	●	●	●	●	●	●	●
Narrow-leaf lupin (*Lupinus angustifolius*)	●	○	○		○	●	
Canola (*Brassica napus*)	●	●	●		●	●	
Oat (*Avena sativa*)	●	●	●	○	●	○	●
Sorghum (Sorghum vulgare)	●	●		●			
Sugarcane (*Saccarum officinarum*)	●	○		●			
Cotton (*Gossypium hirsutum*)	●			●			
Triticale (*Triticum durum x Secale cereale*)	●	●	●		●		●
Chickpea (*Cicer arietinum*)	○	○	○	●			
Field Pea (*Pisum sativum*)	○		●		●	○	
Faba bean (*Vicia faba*)	○	○	○		○		
Rice (*Oryza sativa*)	○	●					
Sunflower (*Heliantus annus*)	○	○		●			
Lentil (*Lens culinaris*)	○		●				
Maize (Zea mays)		○		○			
Vetch (*Vicia sativa*)			○		○		
Mung bean (*Phaseolus aureus*)				○			
Peanut (*Arachis hypogaea*)				○			
Soybean (*Glycine max*)				○			
Millet (*Pennisetum spp*)				○			
Oil Poppies (*Papaver somniferum*)							●

The available data have been reviewed to develop appropriate harvest indices for each plant type to enable conversion from mass of saleable product to total plant mass (Unkovich *et al.* 2010). The proportional allocation of dry matter to plant components were determined from estimates by expert field agronomists and include allocation to roots, GBF (grains, buds and fruit), stalks and leaves, coarse roots and fine roots. The crop types and plant partitioning used in the model are shown in Table 6.B.2.

The crop and pasture yield data for each cropping system, SA2 region and soil type are estimated in *FullCAM* (see Appendix 6.E.5)

Table 6.B.2 Plant partitioning by crop and pasture type

Species 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)
Annual & perennial (incl. Mulga)	0.00	0.00	0.50	0.00	0.50
Annual grass	0.00	0.00	0.50	0.00	0.50
Annual legume	0.00	0.00	0.50	0.00	0.50
Annual legume irrigated	0.00	0.00	0.50	0.00	0.50
Annual weeds	0.00	0.00	0.50	0.00	0.50
Aristida-Bothriochloa	0.00	0.00	0.50	0.00	0.50
Barley	0.00	0.30	0.40	0.00	0.30
Black speargrass	0.00	0.00	0.50	0.00	0.50
Blady grass	0.00	0.00	0.50	0.00	0.50
Blue lupin	0.00	0.23	0.55	0.00	0.22
Bluebush/Saltbush	0.00	0.00	0.50	0.00	0.50
Bluegrass-browntop	0.00	0.00	0.50	0.00	0.50
Canola	0.00	0.27	0.51	0.00	0.22
Chickpea	0.00	0.30	0.48	0.00	0.22
Cotton - irrigated	0.25	0.25	0.30	0.10	0.10
Cotton - rainfed	0.25	0.25	0.30	0.10	0.10
Faba bean	0.00	0.30	0.48	0.00	0.22
Field pea	0.00	0.30	0.48	0.00	0.22
Grass only - brigalow/gidyea	0.00	0.00	0.50	0.00	0.50
Grazed cereal	0.00	0.00	0.60	0.00	0.40
Grazed cereal - irrigated	0.00	0.26	0.44	0.00	0.30
Grazed vetch	0.00	0.30	0.48	0.00	0.22
Lentil	0.00	0.30	0.48	0.00	0.22
Lucerne	0.00	0.00	0.50	0.00	0.50
Lucerne irrigated	0.00	0.00	0.50	0.00	0.50
Maize	0.32	0.34	0.09	0.00	0.25
Millet	0.00	0.26	0.43	0.00	0.31
Mitchell grass	0.00	0.00	0.50	0.00	0.50
Monsoonal annual	0.00	0.00	0.50	0.00	0.50
Monsoonal perennial	0.00	0.00	0.50	0.00	0.50
Mung bean	0.00	0.30	0.48	0.00	0.22
Narrow-leaf lupin	0.00	0.23	0.55	0.00	0.22
Native annual	0.00	0.00	0.50	0.00	0.50
Native annual improved	0.00	0.00	0.50	0.00	0.50
Native perennial	0.00	0.00	0.50	0.00	0.50
Native perennial improved	0.00	0.00	0.50	0.00	0.50
Oat	0.00	0.26	0.43	0.00	0.31
Oil poppies	0.00	0.40	0.40	0.00	0.20

Species 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)
Peanut	0.00	0.35	0.35	0.00	0.30
Perennial grass	0.00	0.00	0.50	0.00	0.50
Perennial grass Irrigated	0.00	0.00	0.50	0.00	0.50
Perennial grass/clover	0.00	0.00	0.50	0.00	0.50
Perennial legume	0.00	0.00	0.50	0.00	0.50
Queensland bluegrass	0.00	0.00	0.50	0.00	0.50
Rice	0.00	0.26	0.43	0.00	0.31
Samphire	0.00	0.00	0.50	0.00	0.50
Sorghum	0.00	0.29	0.41	0.00	0.30
Soybean	0.00	0.30	0.48	0.00	0.22
Spinifex	0.00	0.00	0.50	0.00	0.50
Sugarcane	0.75	0.00	0.15	0.00	0.10
Sunflower	0.39	0.32	0.19	0.00	0.10
Triticale	0.00	0.26	0.43	0.00	0.31
Tropical grass	0.00	0.00	0.50	0.00	0.50
Vetch	0.00	0.30	0.48	0.00	0.22
Weeds annual	0.00	0.00	0.50	0.00	0.50
Weeds perennial	0.00	0.00	0.50	0.00	0.50
Wheat	0.00	0.26	0.44	0.00	0.30

Carbon contents of crop and grass species

Plant dry matter is converted to carbon using a crop carbon content value that is specific to the species in use, in the model. These average values for crop species were determined from an analysis of plant materials obtained from around the country, using a dry combustion method and published in the Technical Report series.

6.B.4.2 Debris

The amount of plant residue generated by a crop or grass species is dependent on both the plant growth and management practice. As well as containing the crop/pasture growth and species data, the relational database describes the agricultural management practices, (e.g., stubble management) applied to each crop/pasture (see section 6.E.4). These data are used to determine how much of the crop mass becomes residue for incorporation and decomposition to litter and soil carbon pools, how much is taken offsite and how much is burnt.

Initial crop litter mass and decomposition rates

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 6.B.3

Table 6.B.3 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 low for each monthly simulation step given the sigmoidal growth response of agricultural plant species, including pastures (Table 6.B.4), 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.

Table 6.B.4 Turnover rates applied to crop and pasture systems

Plant Component	Turnover Rates yr^{-1}	
	Pasture species	Annual crop species
Grains, Buds, Fruit	0.4	0.10
Stalks	0.4	0.10
Leaves	0.4	0.10
Coarse Roots	0.4	0.10
Fine Roots	0.4	0.10

6.B.5 Estimating Changes in Soil Carbon

The Rothamsted soil carbon model (*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, groundcover and evaporation. *Roth-C* is used in conjunction with both *CAMFor* and *CAMAg* to model soil carbon stocks in the national account.

Soil inputs to the model are soil type (for fractionation), clay content and the initial topsoil 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.

6.B.5.1 Model Calibration, Validation and Verification

Calibration of *Roth-C* was undertaken using available long-term field trial data, 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 validation and verification (Skjemstad and Spouncer, 2002).

Appendix

Calibration and validation

Two agricultural and seven forestry long term trial sites were selected for estimating changes in soil carbon. One agricultural site was located on a monsoonal subtropical environment with heavy clay soil and the other was located in a temperate Mediterranean climate with a light textured soil. At each agricultural site, archival soil samples (0-30 cm depth) collected throughout the life of the trials were fractionated into particulate organic carbon (POC), charcoal (char-C) and humic (HUM) pools (Skjemstad and Spouncer, 2003).

The soil carbon model (Roth-C) used to calculate changes in soil carbon stocks caused by shifts in agricultural practice was independently calibrated and validated (Skjemstad and Spouncer 2003). The results were found to be sensitive to the partitioning of carbon between the various soil fractions (Janik *et al.* 2002; Skjemstad *et al.* 2004; Paul and Polglase, 2004b).

Testing of the seven forestry sites and two agricultural sites confirmed the model calibrations for soil carbon pool allocations for both forestry and agricultural sites. Details of the calibration and testing of the model are provided in Paul *et al.* (2002b and 2003b).

Model validation used existing time-series data and new paired-site comparisons to test model predictions of change. Calibration of the model demonstrated that the measured soil carbon fractions (POC, HUM and Char-C pools) fitted well with the modelled carbon pools (RPM, HUM and IOM) as defined in *FullCAM*, A full description of the model calibration and validation results for agriculture can be found in Skjemstad and Spouncer (2003).

In general terms the coefficient of variation for modelled outputs of soil carbon is around 5% (Janik *et al.* 2002), whereas the coefficient of variation for measured soil carbon is 15-40% (McKenzie et al. 2000a and b; Janik *et al.* 2002). Further details are provided in Murphy *et al.* (2002), Harms and Dalal, (2003) and Griffin *et al.* (2002).

More recently Chappell and Baldock (2013) were commissioned by the Department of the Environment to enhance the reliability of soil carbon change estimates provided by the *FullCAM* framework. A local optimisation was performed separately for each of the 103 plots of the calibration and verification sites (Skjemstad and Spouncer 2003) allowing optimisation of three initial stocks of SOC pools (RPM, HUM and IOM) and the decomposition parameters (RPM and HUM). The optimised values of the initial soil carbon pools were then used in a separate global optimisation of the same measurement data but with optimisation of only the decomposition parameters (RPM and HUM).

The results are shown in (Table 6.B.5).

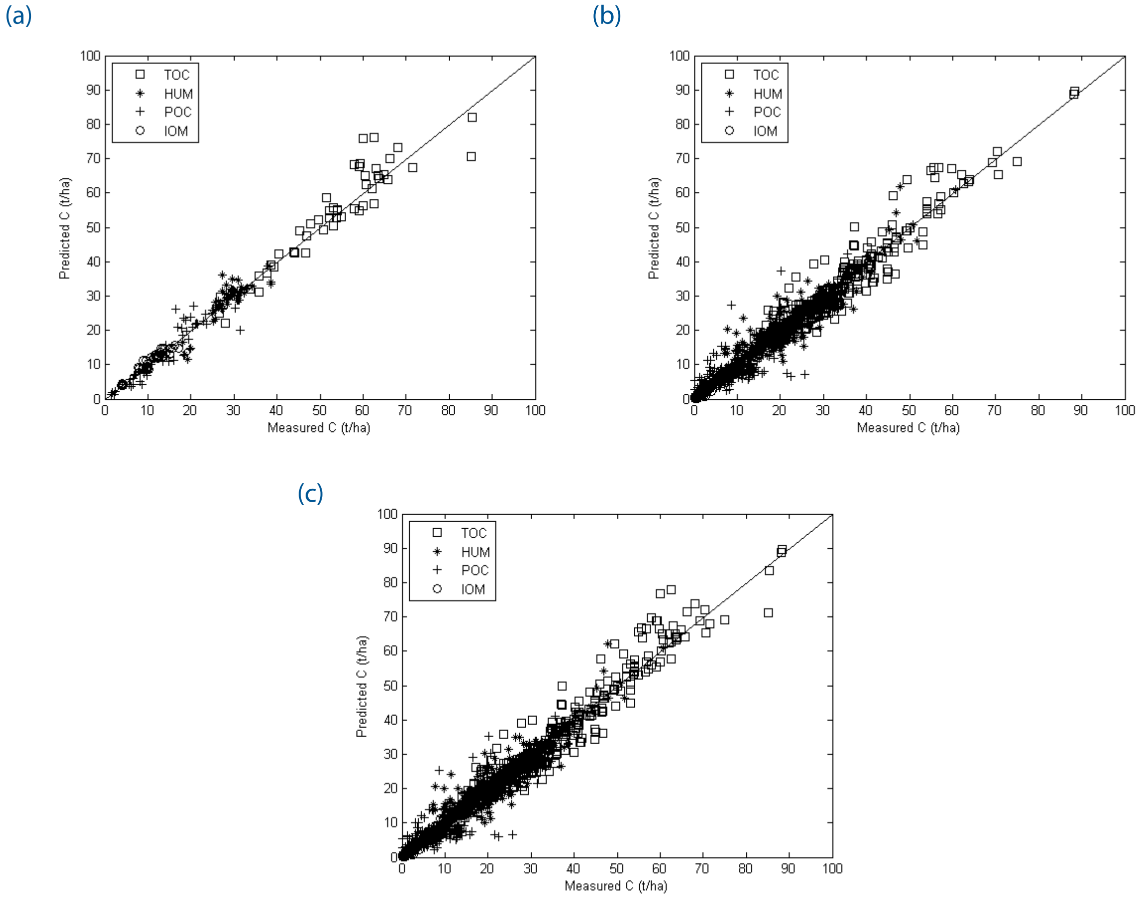
Table 6.B.5 Roth-C model including soil redistribution globally fitted decomposition rates and their goodness of fit.

Global optimistation	RPM y^{-1}	HUM y^{-1}	RMSE ($C\ t\ ha^{-1}$)
Calibration sites	0.202	0.018	0.212
Verification sites	0.154	0.024	0.092
All sites	0.174	0.023	0.086

Source: Chappell and Baldock (2013)

Figure 6.B.6a shows a plot of measured C for all site data of Brigalow and Tarlee against Roth-C predicted C using the optimised values of the decomposition parameters RPM=0.202 y^{-1} and HUM=0.018 y^{-1}. The RMSE of the global model fitting was 0.212 (C t/ha) which describes the error associated with model predictions using the parameter values calibrated against these data.

Figure 6.B.6 Global optimisation of the Roth-C model (using decomposition parameters for RPM and HUM) against the measured C of the RPM, HUM and IOM pools of the calibration site Brigalow and Tarlee (a), the verification sites only (b) and the calibration and verification sites combined (c).



Note: Global optimisation of the Roth-C model (using decomposition parameters for RPM and HUM) against the measured C of the RPM, HUM and IOM pools of the calibration site Brigalow and Tarlee (a), the verification sites only (b) and the calibration and verification sites combined (c)

Figure 6.B.6b shows a plot of measured C for all site verification data against Roth-C predicted C using the optimised values of the decomposition parameters RPM=0.154 y^{-1} and HUM=0.024 y^{-1}. The RMSE of the global model fitting was 0.092 (C t/ha). Figure 6.B.7c shows a plot of measured C for all sites (calibration and verification) data against Roth-C predicted C using the optimised values of the decomposition parameters RPM=0.174 y^{-1} and HUM=0.023 y^{-1}. The RMSE of the global model fitting was 0.086 (C t/ha). Evidently, the previously recommended values of RPM = 0.15 y^{-1} and HUM = 0.02 y^{-1} are within the variation found across the plots and sites around Australia but these values are smaller than the globally fitted decomposition rates. As such the decomposition parameters have been adjusted to reflect this latest research and provide the most robust calibration of *FullCAM*.

Appendix

Verification:

Subsequent to the implementation of the baseline map of organic carbon in Australian soil (Viscarra Rossel; *et al*, 2014), the Australian three-dimensional soil grid (Clay) (Viscarra Rossel; *et al*, 2015), updated species (Table 6.B.2) and management practices (section 6.E.4) as well as the optimisation of the decomposition rates (*Calibration and Validation*), the Department of Environment undertook a modelling exercise in which the FullCAM was used to simulate the effects on soil carbon of changes in practices to manage stubble, tillage and the amount of crop biomass as well as estimate the effects of a change in land use from a continuous cropping to a pasture system and a continuous pasture to rotational cropping system.

Given the impact of climate and soil properties on the technical potential of soil carbon enhancement and the uncertainty distribution around the technical potential, seven sites were selected to reflect four main temperature and moisture regimes (Cool-Wet; Cool-Dry; Warm-Wet; Warm-Dry) defined in accordance with the 2006 IPCC Guidelines. For each of the sites selected, the Australian Statistical Geography Standard, statistical area level 2 (SA2) boundaries (Pink 2010) in which the site is located was identified.

For each of the seven selected sites, statistics (minimum, mean and maximum values and standard deviations of the values) for the percentage of soil that is clay by weight and total were determined for the SA2 in which the selected sites were located and regression analysis on the percentage of soil that is clay by weight and total soil carbon for the SA2s was carried out to determine the correlation coefficient between the two key soil properties.

The minimum, mean and maximum values, and standard deviations for the percentage of soil that is clay by weight and total soil carbon were applied as risk variables in the Monte-Carlo analysis using @Risk (Palisade Corporation, 2005). Parameterisation was designed to ensure that values that would not occur within the SA2 of the selected site were not used in the Monte-Carlo analysis. This approach ensures regional specificity by removing/reducing skew/bias and normalises the outputs according the input data so that the outcomes are truly reflective of that particular SA2, while allowing for the inherent variability in climate and soil type across the Australian landscape and, more specifically, the SA2.

The correlation between the percentage of soil that is clay by weight and total carbon, (including the 1:1 correlation between the soil fractions and the total soil carbon) was applied in the Monte-Carlo simulation correlation matrix to ensure proportionality of soil fractions and clay were observed.

A truncated normal distribution was applied to the Monte-Carlo simulations to ensure the probability distribution of the output value for soil carbon stock is bounded above and below by the minimum and maximum values for the input risk variables.

The Monte-Carlo simulations were run for a full 1000 simulations as opposed to ceasing when convergence was met. This repeated sampling enabled the output value for soil carbon stock to converge on as close to the most probable technical potential value attainable for the SA2.

Factual (baseline) and counter-factual (scenario) simulations of selected activities identified in the 2006 IPCC Guidelines and the 2013 IPCC Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol (KP) Supplement were run in *FullCAM*.

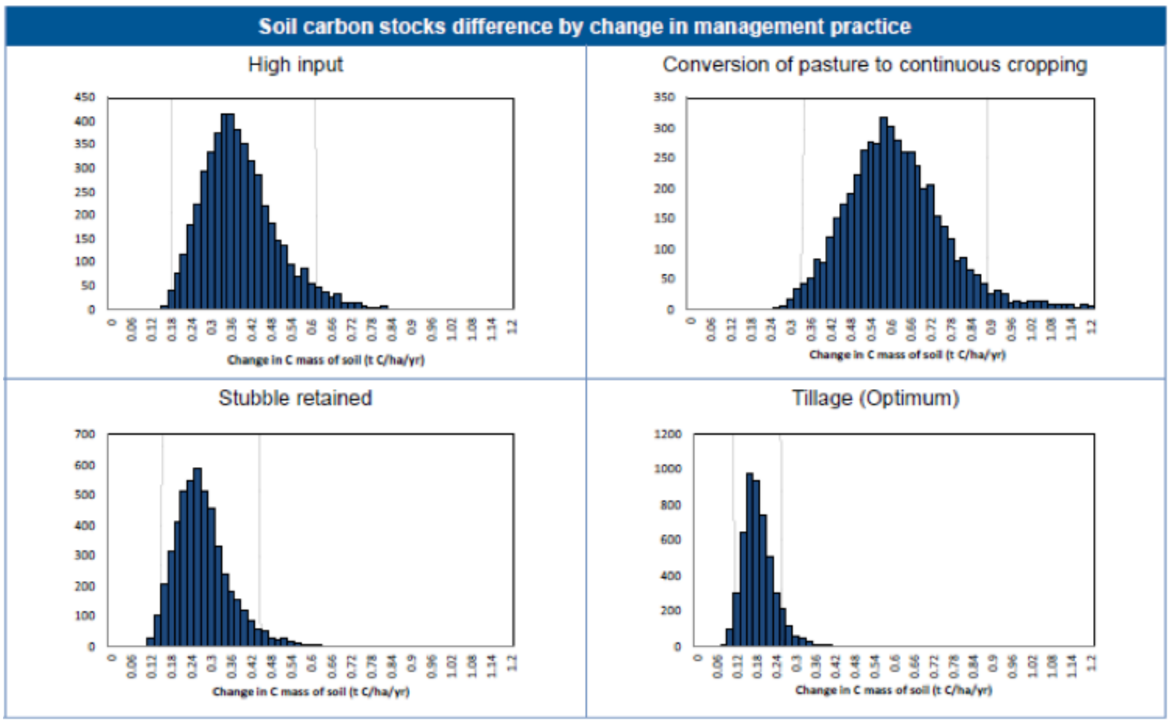
Table 6.B.6 Sensitivity analysis of soil carbon values in *FullCAM*

Scenario	Lower bound at 95%	Lower bound at 40%	Median	Mean	Upper bound at 95%
High inputs management	0.22	0.34	0.36	0.49	0.93
Change from continuous cropping to continuous pasture	0.35	0.40	0.45	0.50	1.00
Change from continuous pasture to rotational cropping	0.10	0.14	0.21	0.25	0.53
Stubble retention	0.06	0.10	0.13	0.18	0.40
Destocking	0.06	0.10	0.14	0.18	0.36
Tillage (Optimum)	0.09	0.12	0.17	0.22	0.43

Note: Soil carbon counter-factual (scenario) values compared to the factual (baseline) expressed as an average annual absolute change (t C ha^{-1} yr^{-1}) at the 95% and 60% confidence interval (CI) after 25 years.

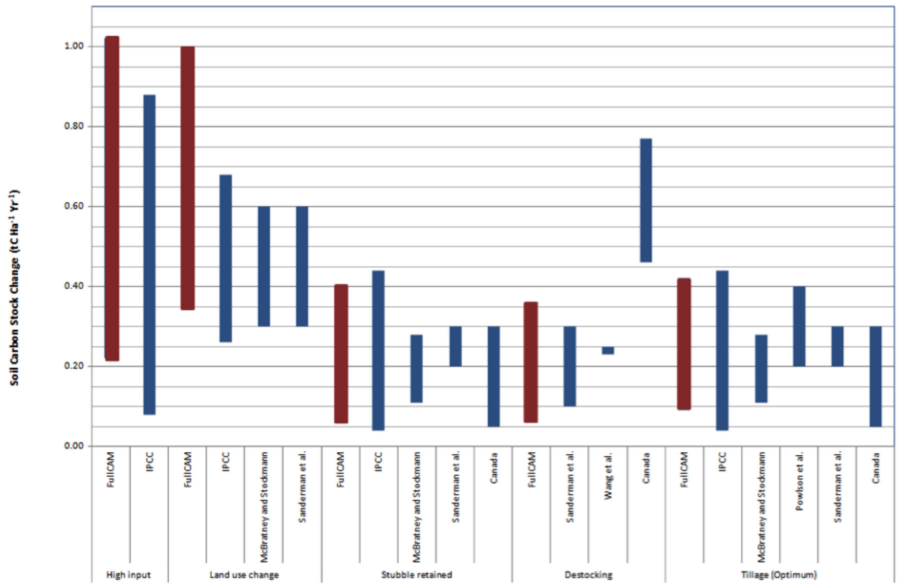
National values for the estimated response of soil carbon to changes in various management practices are presented in (Table 6.B 6). The results are within expected ranges and, as demonstrated below in Figure 6.B.7 consistent with empirical literature and international practice. The model does not generate a single value, but a range of values, as shown in (Table 6.B 7) where the distribution of values generated by the model is presented for each of the changes in management practices. The distribution of values demonstrates the variability in outcomes modeled by *FullCAM*, mainly reflecting spatial variations in soil quality, which is entirely expected from empirical experience across Australia. Figure 6.B.9 illustrates the variation in outcomes, depending on location, of differences in soil carbon sequestration and/or reduction in the rate of losses in a sensitivity scenario where the yields were increased by 20 per cent over a period of years.

Figure 6.B.8 Sensitivity analysis of soil carbon values in *FullCAM*: Monte carlo simulations



Note: Probability distribution for the average annual change (tC Ha^{-1} Yr^{-1}) in the carbon mass of soil for the difference between the counter-factual (scenario) and factual (baseline) values as a result of each of the enhancement activities selected.

Figure 6.B.9 Comparison for soil carbon response to changes in management practices for *FullCAM* and from domestic empirical literature and international practice



6.B.6 Planned Improvements

The methods for the cropland and grassland categories are continually being reviewed for consistency with 2006 IPCC Guidelines requirements. A key planned improvement is to improve the way that *FullCAM* estimates the impact of management changes on emissions and removals.

Through the process of updating the management database to support the 2006 IPCC Guidelines requirements a data gap in the empirical literature relating to temporal pasture management practice across Australia and in particular grazing pressures. The Department of the Environment will be commissioning CSIRO to conduct a more in depth analysis of the literature and national statistics to potentially close the data gap.

In conjunction with CSIRO the Department of the Environment is investigating enhancements to *FullCAM* to develop and improve the treatment of perennial grasses in the model.

An additional area the Department has been investigating is the options for utilising the GENDEC module in *FullCAM* to better model the impacts of management strategies on the entry of crop residues into the soil as well as additions of various organic amendments derived from offsite. CSIRO has proposed a schema consisting of "Standing debris" that is not in contact with the soil, and a "Mulch" layer that is in contact with the soil. The "Standing debris" will include standing stubble that will transition to either the Mulch pools on events such as rolling and trampling by grazing, or into the soil pools on incorporation through events such as cultivation and sowing operations. In addition to residues on the soil surface after harvest or events that knock standing stubble onto the ground, the "Mulch" layer will receive offsite additions of organic amendments. A "Root debris" pool receives dead root material that is greater than 2 mm in size, whilst fine roots less than 2 mm enter the soil organic matter pools as previously. The proposed "Standing debris" and "Mulch" layers do not represent a significant departure from the use of 'Agricultural debris' currently in FullCAM and the optional mulch layer represented by GENDEC. Further work is required to assemble the data required to build, test and run the proposed system.

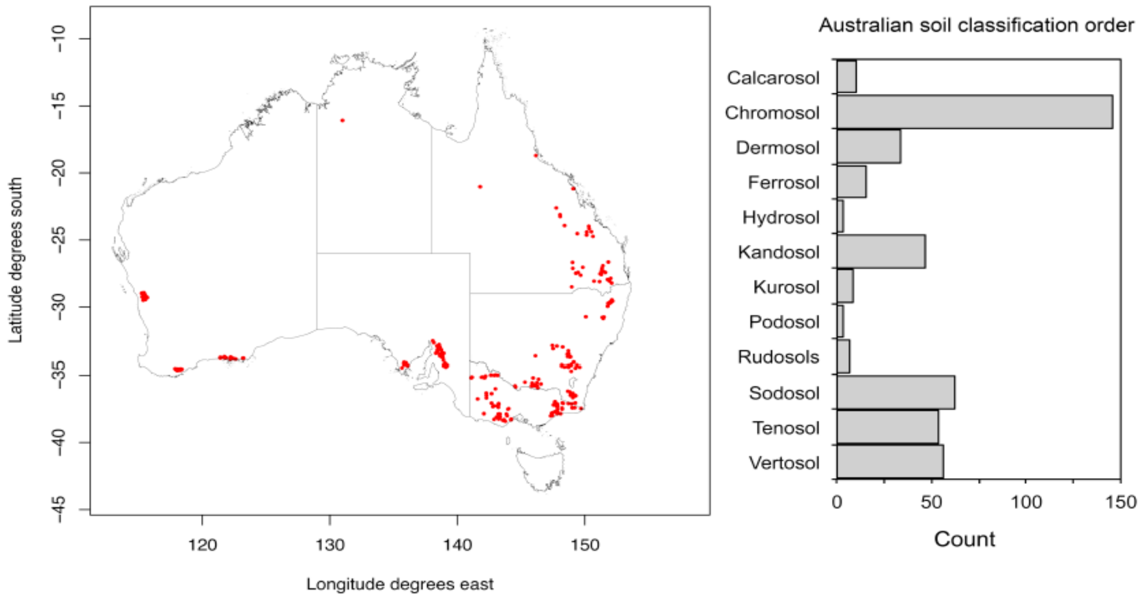
Soil carbon fractions

Fine spatial resolution continental maps of the soil carbon fractions (particulate organic carbon (POC), humic organic carbon (HOC) and resistant organic carbon (ROC)) are currently being generated by CSIRO using a methodology that is similar to that used to derive the baseline map of organic carbon in Australian soil (Viscarra-Rossel et al. (2014).

There were 400 soil data with measurements of POC, HOC, ROC. Largely, these data originated from the Soil Carbon Research Program (SCaRP), and a small number are from two smaller projects that were funded under the Department of Agriculture (DA) Filling the Research Gap (FTRG) Programs. The data represented all Australian Soil Classification Orders but they were sparsely distributed across Australia and represented soil that is mostly under agriculture, but also forests. The spatial distribution of the data is shown in Figure 6.B.9.

The visible–near infrared and mid-infrared spectra of the 400 soil samples were recorded and spectroscopic calibrations were derived to predict POC, HOC and ROC of other soil samples for which data on the organic carbon fractions were not available. The calibrations were used to predict the fractions of around 4000 soil samples that cover the extent of Australia and represent all land use types, and all climatic and bio-geographical regions.

Figure 6.B.10 Spatial distribution of soil organic carbon fractions (POC, HOC, ROC) and the number of observations per Australian Soil Classification order.



Once the spectroscopic predictions were made, the spatial modelling of the data was performed by combining the bootstrap, a decision tree with piecewise regression on environmental variables and geostatistical modelling of residuals. The spatial models will be validated with an independent data set and once complete the Department of Environment will incorporate the fine spatial resolution continental maps of the soil carbon fractions in FullCAM to ensure internal consistency of spatial soil inputs.

Appendix

Appendix 6.C: The Forest Productivity Index

To derive the spatial and temporal patterns of forest growth the simplified 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[17]) at a 1 km grid scale on a monthly basis since 1970. The site-based, multi-temporal productivity indices are used to support a generalised empirical growth model. All modelling is done on the basis of aboveground biomass with subsequent factors to account for belowground (fine and coarse root) material.

A truncated version of the *3-PG* model (Landsberg and Waring 1997), retaining the essential features of biomass net primary production (*NPP*) estimation, without the carbon partitioning procedures is used to provides a site index of plant productivity that is independent of the type of forest present.

The essence of the model is the calculation of the amount of photosynthetically active radiation absorbed by plant canopies (*APAR*). *APAR* is calculated (Equation 6C_1) as half the amount of short-wave (global) incoming radiation (*SWRadn*) absorbed by plant canopies.

$$APAR = SWRadn \times 0.5 \times (1-e^{(-0.5 \times LAI)}) \times \text{days in month} \quad (6C\_1)$$

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 *ln*(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 substantial 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 output from the model is 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 zero (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).

The modifying factors are:

Soil fertility: Because of natural variation and the considerable uncertainty surrounding soil fertility values, only three levels of soil 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).

17 A generic model of Net Primary Productivity derived a classification of productivity, on a scale of 1-30. Temporal and spatial variability is identified by a change in classification. This is not a linear relationship with biomass growth increment.

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 (6C_2) used is:

$$VPDmod = e^{(-0.05 \times VPD)} \quad \text{(6C\_2)}$$

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 6C_6) in the root zone of plants. Plant water use (Equation 6C_4) is calculated from the equation for equilibrium evaporation (Equation 6C_3, see Landsberg and Gower 1997; p. 79), modified by feed-back from current soil water content, and a conventional water balance equation (Equation 6C_5):

$$EqEvapn = ((0.67 \times NetRadn *(1-0.05)) / 2.47) \times \text{days in month} \quad \text{(6C\_3)}$$

$$Transpiration = EqEvapn_j \times SWmod_{j-1} \quad \text{(6C\_4)}$$

$$WaterBal = (Rain \times (1\text{-}interception)) - Transpiration \quad \text{(6C\_5)}$$

$$SoilWaterContent_j = SoilWaterContent_{j-1} + WaterBal_j \quad \text{(6C\_6)}$$

Initial Soil Water Content was taken as 0.75 x SWcapacity. Soil Water Content carries over from one time step to the next. The soil moisture calculation sequence was run for 3 years, after which Soil Water Content had essentially equilibrated to stable monthly values. Soil Water Content values in year 3 were therefore used in the analysis. The soil water modifier (*Swmod*, Equation 6C_8) was calculated from the moisture ratio (*MoistRatio*, Equation 6C_7), which is Soil Water Content normalised to SWcapacity. The equation describes the variable effect of MoistRatio across the range from wet soil (MoistRatio ≈1) to dry soil (MoistRatio ≈0).

$$MoistRatio = SoilWaterContent/SWcapacity \quad \text{(6C\_7)}$$

$$SWmod = 1 / (1 + ((1\text{-}MoistRatio)/0.6)^{0.7}) \quad \text{(6C\_8)}$$

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 (6C_9) describing the effect of temperature is:

$$T_{mod} = ((T_{av} - T_{low}) / (T_{opt} - T_{low})) \times ((T_{high} - T_{av}) / (T_{high} - T_{opt})) \quad \text{(6C\_9)}$$

T_{av} is the average monthly temperature, T_{min} is the monthly average temperature below which plant growth stops, T_{max} is the monthly average temperature above which plant growth stops and T_{opt} is the optimum temperature for growth $(T_{min} + T_{max})/2$. The temperature modifier (T_{mod}) is 1 when $T_{av} = T_{opt}$.

Equation (6C_9) gives a hyperbolic response curve, with $T_{mod} = 0$ when $T_{av} = T_{min}$ or T_{max}. T_{min} is set to ½ the minimum temperature of the coldest month (if the minimum temperature of the coldest month is greater than or equal to 0oC, T_{min} was set to the minimum temperature of the coldest month plus ½ the minimum temperature of the coldest month if the minimum temperature of the coldest month is less than 0oC). T_{max} is set to 5oC above the maximum temperature of the hottest month of the year and T_{opt} as equal to the average of T_{min} and Tmax. Consequently, T_{mod} generally had relatively small effects on the calculation of NPP.

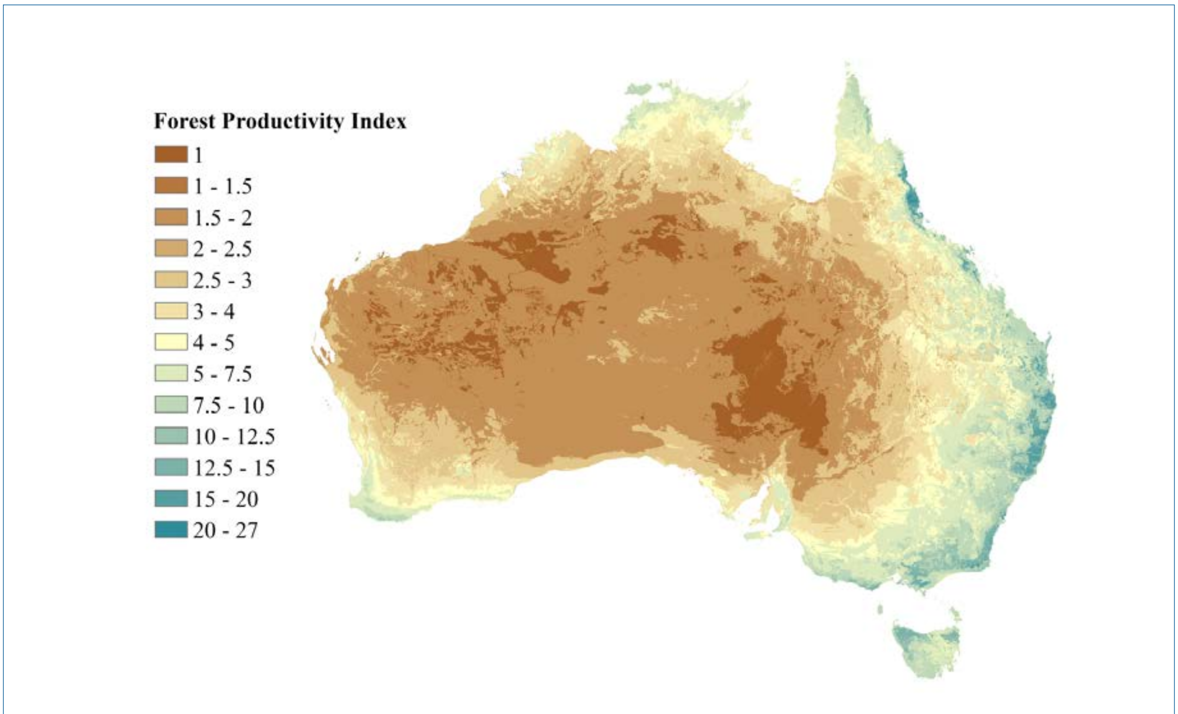
A frost modifier is included, using the simple assumption that frost temporarily inactivates the photosynthetic mechanism in foliage, so there is no growth on a frost day. The modifier is, therefore, simply the ratio of number of frost days/month to the number of days in the month.

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 Appendix E. A further 250 m long-term average FPI is also calculated, using a slope and aspect corrected APAR calculation (Figure 6.C.1).

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

Figure 6.C.1 250m slope and aspect corrected productivity index map



Appendix

Appendix 6.D: Initial Forest Biomass

The initial forest biomass layer is used to estimate the initial biomass of forests on lands that is incremented in the following sub categories:

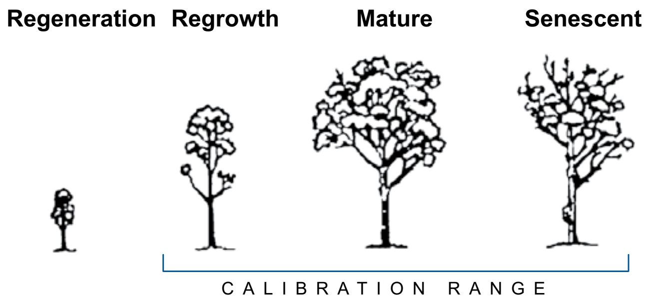
- Forest land converted to Cropland; and
- Forest land converted to Grassland.

An estimate of biomass (the assumed initial biomass) of mature forests is required to estimate emissions due to first time clearing events. The assumed initial biomass is applied to all first time clearing events whenever they occur. The assumed initial biomass for a pixel is calculated based on a regression model of the relationship between the Forest Productivity Index and measured biomass (Raison *et al.* 2003; Richards and Brack, 2004a).

Calibration data

Biomass measurements used in the calibration include all forest conditions except those with visible evidence of recent disturbance such as clearing, harvest or fire since 1970. The lands may, however, have an ongoing low level disturbance such as grazing and low intensity fires. The calibration data covers the mix of age classes from regrowth to senescent (old-growth) (Figure 6.D.1) and therefore the potential variation in field biomass conditions.

Figure 6.D.1 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 forest 'gaps' contained in some field measurements. Plots taken as part of fixed-grid or transect systems could potentially fall in gaps in sparse forests. As the remote sensing programme 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.

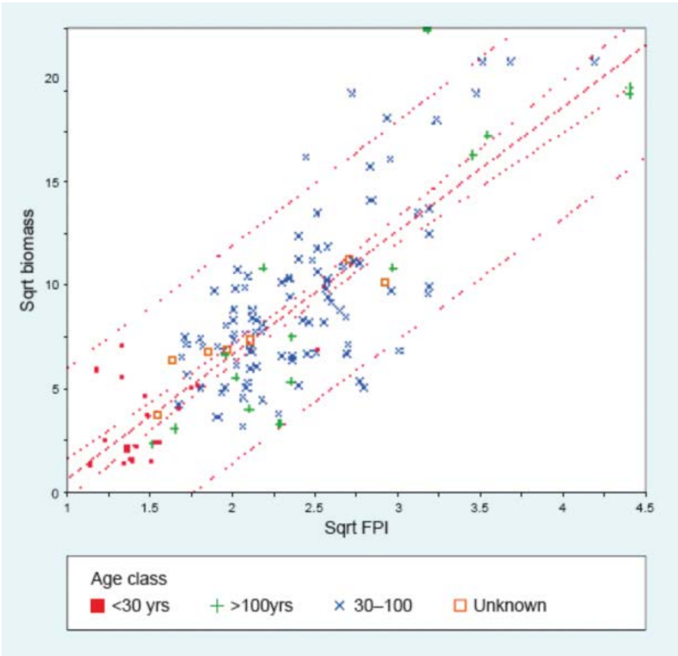
Assumed initial biomass relationship

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 6.D.2 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 measures (*M*) and the Long-Term Forest Productivity Index (*P*) (Equation 6D_1). A square root transformation was required to meet assumptions of normality and homogeneity (Figure 6.D.2).

$$M = (6.011 \times \sqrt{P} - 5.291)^2 \qquad (6D\_1)$$

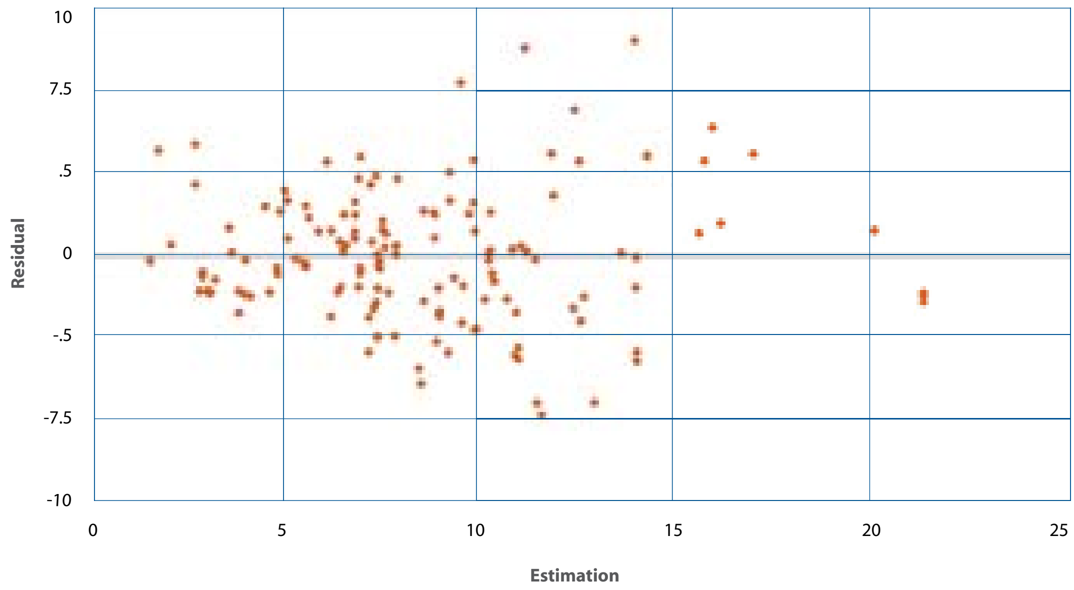
Figure 6.D.2 The assumed initial biomass relationship



The goodness of fit of Equation (6D_1) to the measured data ($r^2 = 0.68$, $p < 0.01$) 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 (6C_1) to the FPI mapping (Appendix 6.C). While the goodness of fit and lack of bias in error estimates (Figure 6.D.3) provides confidence in the application of Equation (6C_1) 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 6.D.3 Error distribution for equation 6.D.1.

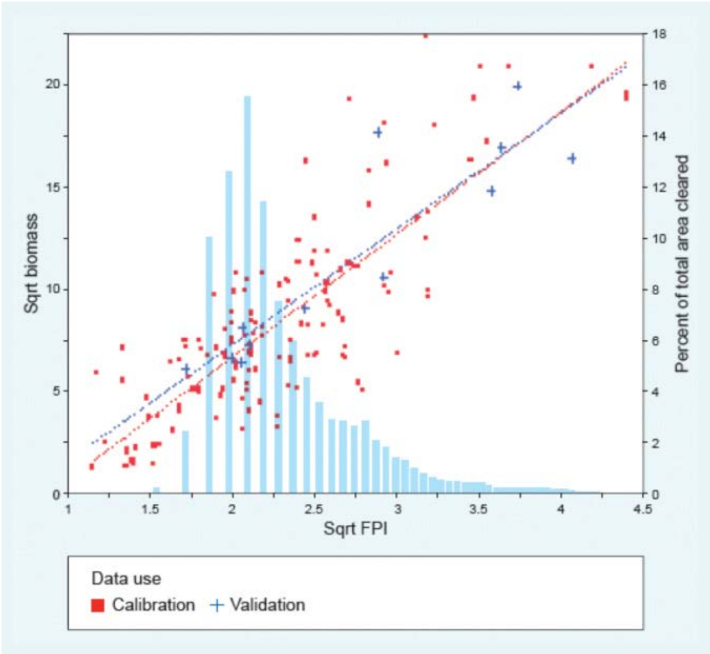


Validation and verification of assumed initial biomass

Calibration of the initial assumed above ground biomass regression model has been validated by using independent research and field studies of biomass estimates, excluding forest areas with young regrowth. The Department of the Environment commissioned a research project to weigh all trees at three forest sites of varying productivity but with similar disturbance histories (Ximenes *et al.* 2005, 2006). Since the relationship was first developed, data collection from 15 new field sites has since been completed (Snowdon *et al.* 2002) and are available for validation. These data points cover a wide range of forest types and represent forests that are either near maturity or at maturity with little evidence of recent disturbance. Validation tests show no significant difference between the validation and calibration data (Figure 6.D.4). 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.

Appendix

Figure 6.D.4 Calibration and validation data for the initial assumed biomass estimates.



Note: The background histogram represents percentage of the area reported under forest land converted to cropland and grassland by forest productivity index.

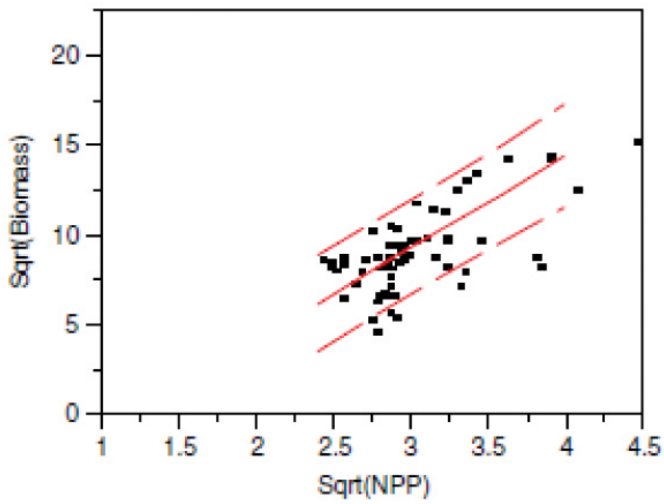
The Department of the Environment also utilises data collected by other agencies for verifying the biomass relationship. This data is typically of a lower quality (i.e., no direct biomass measurements) that precludes its use in calibration or validation. A key example of this verification approach is outlined in Brack *et al.* (2006). As part of a separate study funded by the Bureau of Rural Sciences (BRS) to estimate stem volume, MBAC Consulting conducted a field inventory of south-east Queensland. Brack *et al.* (2006) converted this basic inventory data to biomass estimate using a generalized allometric equation from Snowdon *et al* (2002) to verify the biomass relationship. The biomass data had several limitations:

1. the disturbance history of the plots was unclear and many appeared to be younger regrowth;
2. many of the plots had large gaps where no trees existed, which would lead to an underestimation of biomass;
3. the applicability of the allometric equation to the sites was not tested; and
4. the sites only covered a small range of the FPI values.

Despite these limitations, there was still a significant relationship between the FPI and biomass (Figure 6.D.5). The equation produced lower initial biomass estimates than the biomass equation defined by Richards and Brack (2004) but this is likely a function of the points listed above.

Further verification work is planned and Department of the Environment is actively working with state agencies and research agencies to collect and collate additional data.

Figure 6.D.5 Regression of FPI and biomass (t ha-1) with 90% confidence interval. Biomass estimated from Snowdon et al. (2000) allometrics and MBAC Consultants (2003) inventory data.



Source: Brack *et al.* (2006)

Appendix 6.E: Other *FullCAM* input data

6.E.1 Soil carbon input data

Initial soil carbon layer

To estimate soil carbon stock changes *FullCAM* requires spatial soil data including soil type, clay content and a pre-disturbance or initial soil carbon content. The soil type data is used to derive water holding capacity which along with soil clay content determines the rate of decomposition of plant residues and the allocation of carbon to the different soil pools (Richards, 2001; Webb, 2002).

Viscarra-Rossel *et al* (2014) has derived spatially explicit estimates, and their uncertainty, of the distribution and stock of organic carbon in the soil of Australia. This was achieved through the assembly and harmonisation of data from Australia's National Soil Carbon Research Program (SCaRP), the National Geochemical Survey of Australia (NGSA) and the Australian Soil Resource Information System (ASRIS) to produce the most comprehensive set of data on the current stock of organic carbon in soil of the continent.

A fine spatial resolution baseline map of organic carbon at the continental scale was produced by combining the bootstrap, a decision tree with piecewise regression on environmental variables, and geostatistical modelling of residuals. Values of stock were predicted at the nodes of a 3-arc-sec (approximately 90 m) grid and mapped together with their uncertainties. Baselines of soil organic carbon storage over the whole of Australia, its states and territories, and regions that define bioclimatic zones, vegetation classes and land use were then calculated.

Viscarra-Rossel *et al* (2014) determined that the average amount of organic carbon in Australian topsoil is estimated to be 29.7 t ha^{-1} with 95% confidence limits of 22.6 and 37.9 t ha^{-1} The total stock of organic carbon in the 0–30 cm layer of soil for the continent is 24.97 Gt with 95% confidence limits of 19.04 and 31.83 Gt.

Figure 6.E.1 shows the baseline map of organic soil carbon in Australian soil to support national carbon accounting and monitoring under climate change. Soil carbon content was corrected to methodological standards where the initial method of measurement was known; otherwise the data were considered unusable and were not included in the final product.

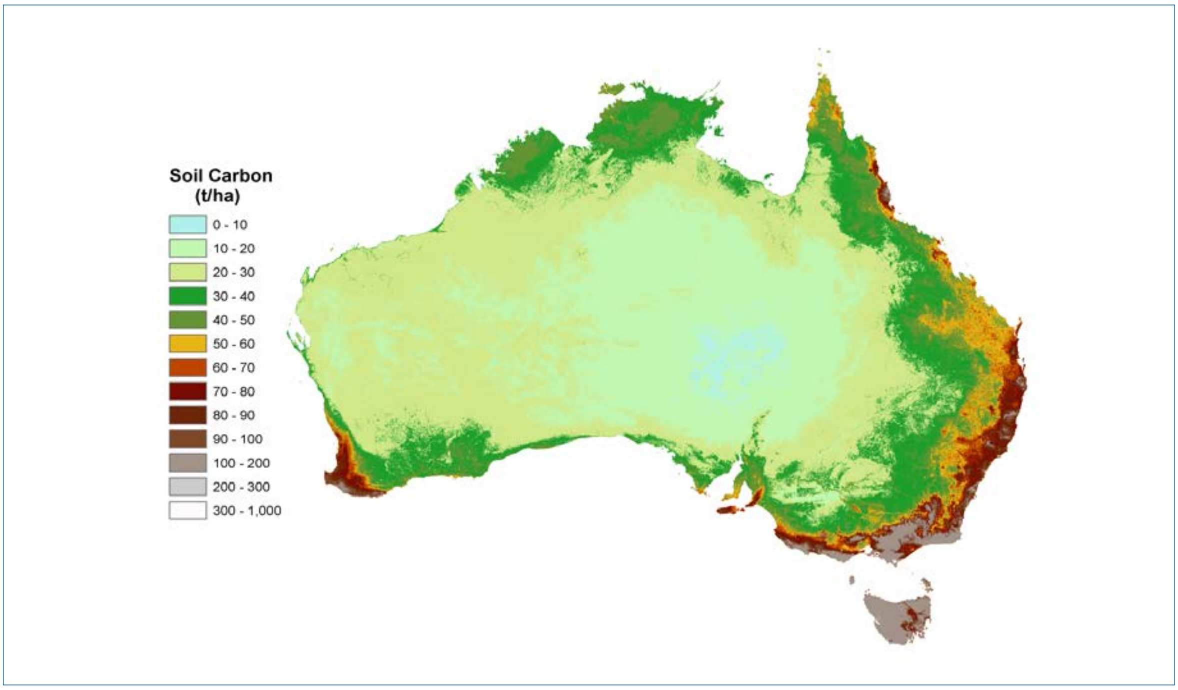
Soil carbon fractions

The process of developing the earlier pre-clearing spatial dataset is described in Webb (2002), allowed for the initial soil carbon values from the mapping to be partitioned into the carbon pools used by the carbon model via a relational database. These pools are defined by their differences in turnover times (i.e. the resistant versus decomposable). 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.

Soil clay content

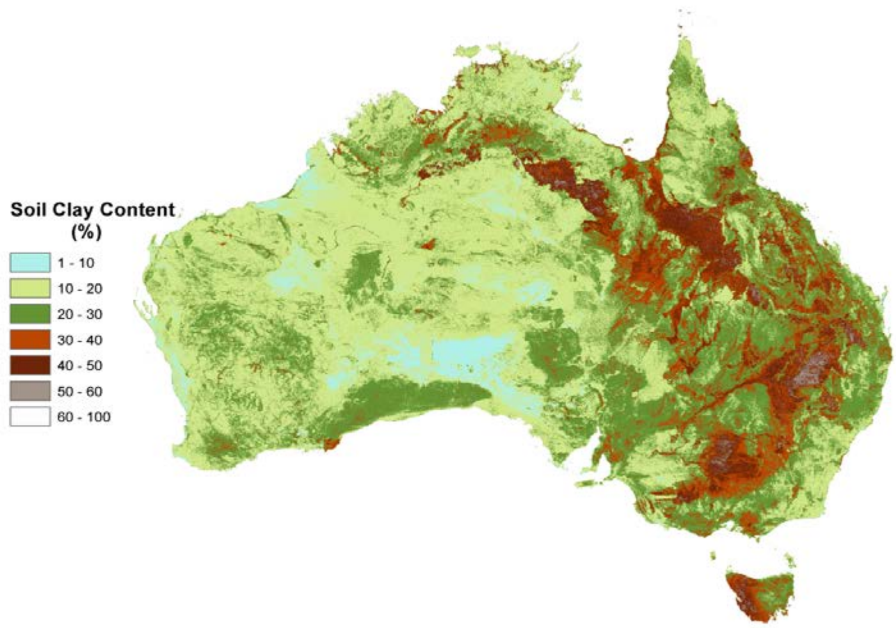
A map of clay content was also developed (Figure 6.E.2) by Viscarra-Rosel *et al* (2015). The Soil and Landscape Grid of Australia-wide Soil Attribute Maps were generated using measured soil attribute data from existing databases in the national soil site data collation and spectroscopic estimates made with the CSIRO's National spectroscopic database (Viscarra Rossel & Webster, 2012). The spatial modelling was performed using decision trees with piecewise linear models and kriging of residuals. Fifty environmental covariates that represent climate, biota, terrain, and soil and parent material were used in the modelling. Uncertainty was derived using a bootstrap (Monte Carlo-type) approach to derive for each pixel a probability density function (pdf), from which we derived 90% confidence limits. The approach is described in Viscarra Rossel *et al.* (2015a).

Figure 6.E.1 Baseline map of organic carbon in Australian Soil (Viscarra-Rossel *et al.* 2014).



Appendix

Figure 6.E.2 The Australian three-dimensional soil grid (Clay): Australia's contribution to the GlobalSoilMap project (Viscarra-Rossel, submitted).



6.E.3 Climate data

Model sensitivity testing identified that inter-annual 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 account for the effects of climate both spatially and temporally over the modelled period, 1970-2008, weather station data from the Bureau of Meteorology for rainfall, minimum and maximum temperature, evaporation and solar radiation were obtained. Monthly climate surfaces (maps) at 1 km resolution for each variable were then 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 stations 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 resolution) 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.

Appendix

Derived Outputs

The weather station climate data are interpolated (modelled) using mathematical (multivariate 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 (Kesteven *et al.* 2004). The list of outputs and their resolution is shown in Table 6.E.2. Figures 6.E.3 to 6.E.4 illustrate national long-term average annual climate maps generated using the ANUCLIM software.

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 6.E.1 List of climate and productivity maps developed for land sector reporting in the National Inventory System

Climate Variable	Description
Rainfall	1 km resolution continentally, monthly 1968-2012
Temperature	1 km resolution min., max., and average continentally, monthly 1968-2012
Evaporation	1 km resolution continentally, monthly 1968-2012
Frost Days	1 km resolution continentally, monthly 1968-2012
Solar Radiation	1 km continentally, monthly direct and diffuse 1968-2012, 250 m resolution continentally, slope and aspect corrected diffuse and direct
Long-term productivity	250 m resolution
Annual productivity	(sum of monthly) 1 km resolution (1970-2012)

Figure 6.E.3 Long-term average annual evaporation

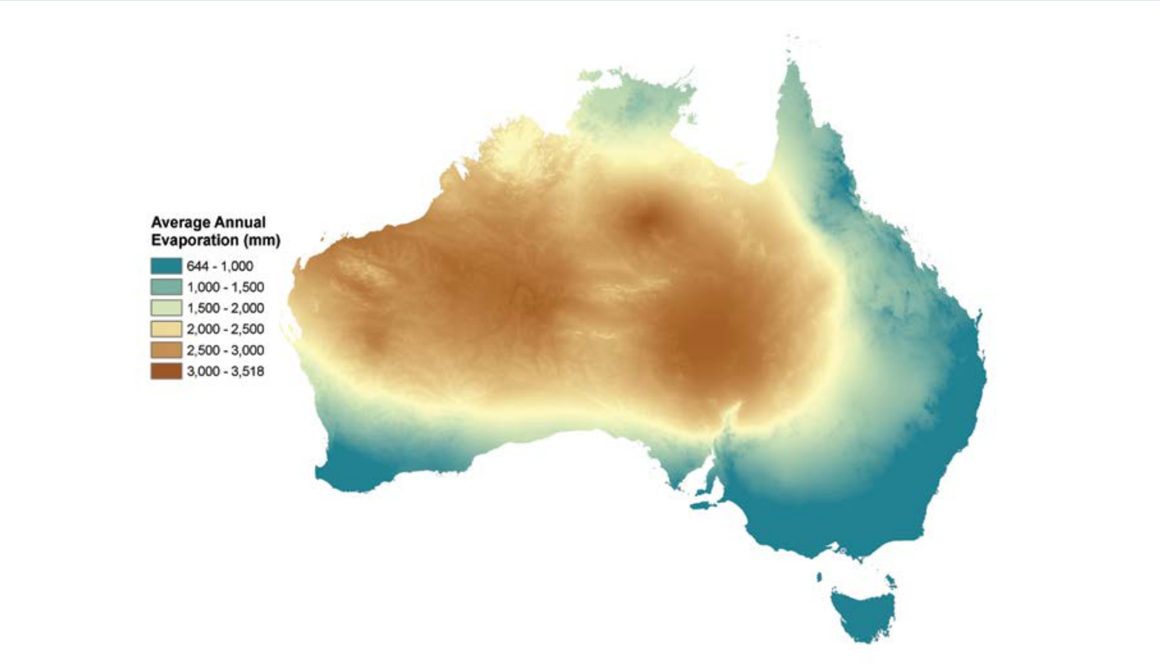
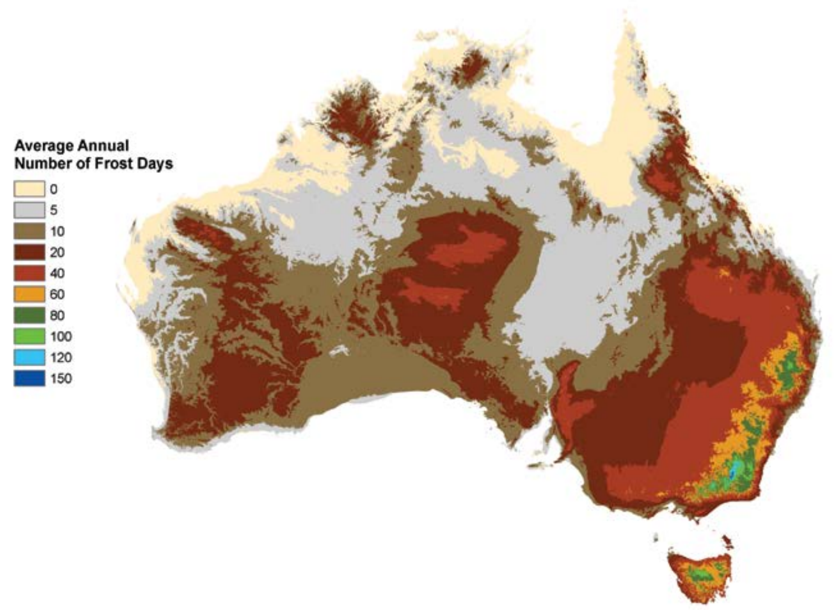


Figure 6.E.4 Long-term average number of frost days per year



6.E.4 Land use and land management

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. In 2014 the Department of Environment commissioned CSIRO to collate all available information regarding agricultural management systems to ensure a consistent, nationally available compilation of this information.

For the forest management data programme, 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 Raison and Squire (2008).

Cropping systems

For cropping systems the crop species identified by Unkovich et al. (2009) (section 6.B.4.1) were sourced from the Australian Bureau of Statistics agricultural census small area data in electronic format.

The collated datasets were concorded to the new, Australian Statistical Geography Standard, statistical area level 2 (SA2) boundaries (Pink 2010). All years between 1983 and 1997 were concorded to 1996 statistical local area boundaries (Australian Bureau of Statistics 2000), the 2001 at 2001 statistical local area boundaries (Australian Bureau of Statistics 2002), the 2006 at 2006 statistical local area boundaries (Australian Bureau of Statistics 2008) and for 2011 on 2011 statistical local area boundaries (Australian Bureau of Statistics 2013). This concordance ensured spatial representation consistency throughout the time series.

The datasets were used to extract the area of each of the crops listed in Table 6.E.2 for each SA2 to construct a time series dataset from 1983 to 2011 to cover 99% of total crop sowing areas in each Australian State. Since the

Appendix

ABS has more recently (post 2001) changed from annual agricultural censuses to five yearly census, five yearly data blocks, in synchrony with the recent censuses were used to represent management epochs (Table 6.E.2).

Table 6.E.2 Agricultural census year data used to provide crop representation for five year time periods

Census Year	Applied to
1983	1970-1984
1986	1985-1989
1991	1990-1994
1996	1995-1999
2001	2000-2004
2006	2005-2009
2011	2010-2014

The year 1983 is the earliest time that data are available electronically and this is thus used to populate the time series back to the 1970 start point.

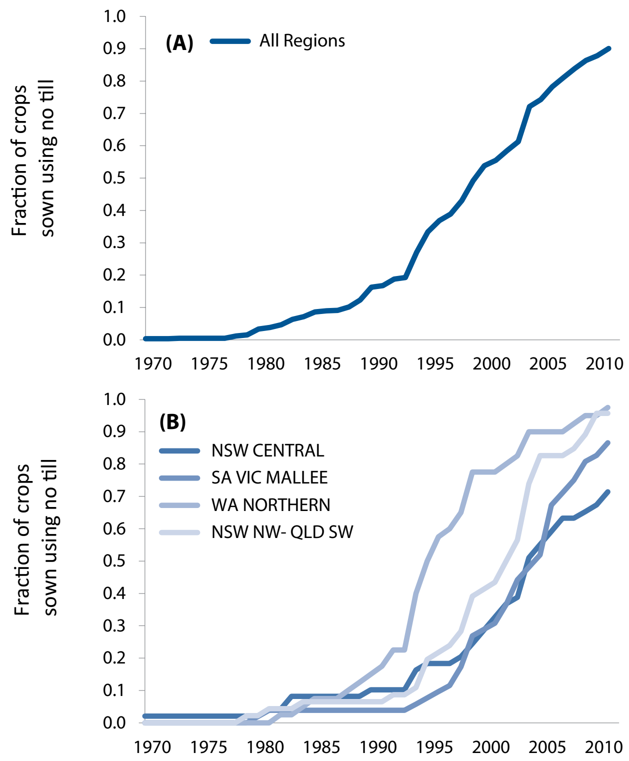
Cropping systems have evolved over time with the use herbicides to control weeds instead of tillage and sowing machinery adapted to sow into standing stubble of antecedent crops. This means that there has been a significant change over time in the extent of tillage and the incorporation of crop residues into soils which might influence carbon return to soils, carbon cycling and soil carbon stocks.

Two datasets assisted in informing these changes in management over time.

Time series data on the adoption of no till practices on a region by region basis is available through a survey in 2008 of the "Adoption of no-till cropping practices in Australian grain growing regions" (Llewellyn and D'Emden 2009; Llewellyn et al. 2012), and includes farmer estimates of the historical adoption of no-till seeding systems, back to 1960. This dataset is the only available resource describing the adoption of no till seeding systems across the Australian grain cropping zone on a temporal and spatial basis. This dataset, updated in 2014, provides opportunity to describe changes in the intensity of tillage on croplands over time. A second dataset, available from the Australian Bureau of Statistics, provides detailed information at SA2 scale on the management of crop stubbles in 2010-2011. Using these two data sources a time series dataset of tillage x stubble management at SA2 scale has been developed.

Details of the survey and the broad outcomes are given in Llewellyn and D'Emden (2009) and Llewellyn *et al.* (2012). The dataset provides information on the fraction crops established using "no till" seeding systems on a "regional" basis. In this case the regions were clusters of Statistical Local Areas (Trewin 2005). These regional data were used to populate an SA2 level dataset.

Figure 6.E.5 Adoption of changed tillage practices in Australia: 1970-2013

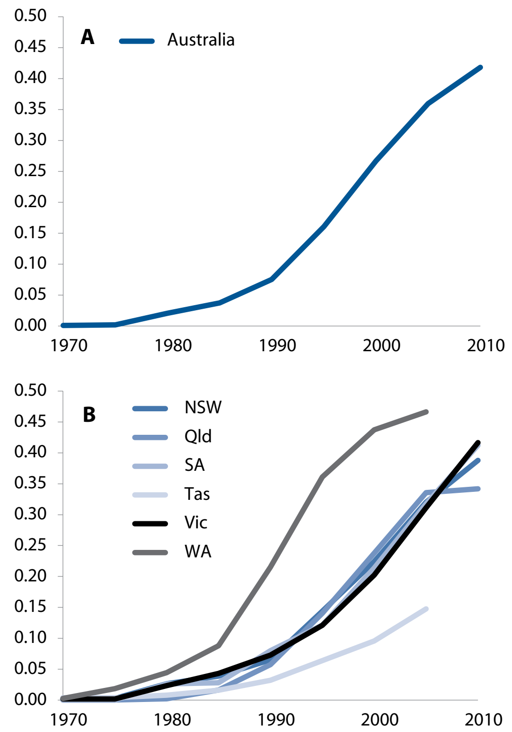


Note: Fraction of crops sown with no till (single pass) seeding technology across (A) the Australian grain belt, and (B) for four of thirteen regional areas Calculated from a revised dataset of Llewellyn et al. (2012)

The Llewellyn *et al* (2012) dataset was used to produce regional scalars (0-1) describing the adoption of no till crop established from 1970 until 2010[18]. This was then applied against the 2011 ABS point census to created SA2 level data back in time. As a result the data of Figure 6.E.6 were normalised such that the value for 2010 was 1.0, and the preceding years scaled proportionately. These time series values were then applied to the 2011 ABS SA2 level census data to provide the historical no till fraction. The national and state level trends are shown in Figure 2 to be about half that apparent in the Llewellyn et al. (2012) dataset.

18 When the data of Figure 6.E.5 and 6.E.6were compared with the ABS survey of land management (2011) it was found that the fraction of crops sown with "no till" were very much higher in the Llewellyn et al. (2012) dataset than that apparent in the ABS census of 2011. This may be because the ABS census was for all cropping land, whereas the Llewellyn survey was very much skewed toward farmers who were primarily grain growers. It is likely that dedicated grain growers have larger cropping areas and invest in efficient no-till systems compared to mixed farmers or farmers with relatively small holdings. The ABS survey data was explicitly for the total area sown within an SA2.

Figure 6.E.6 Adoption of changed tillage practices in Australia by state: 1970-2013



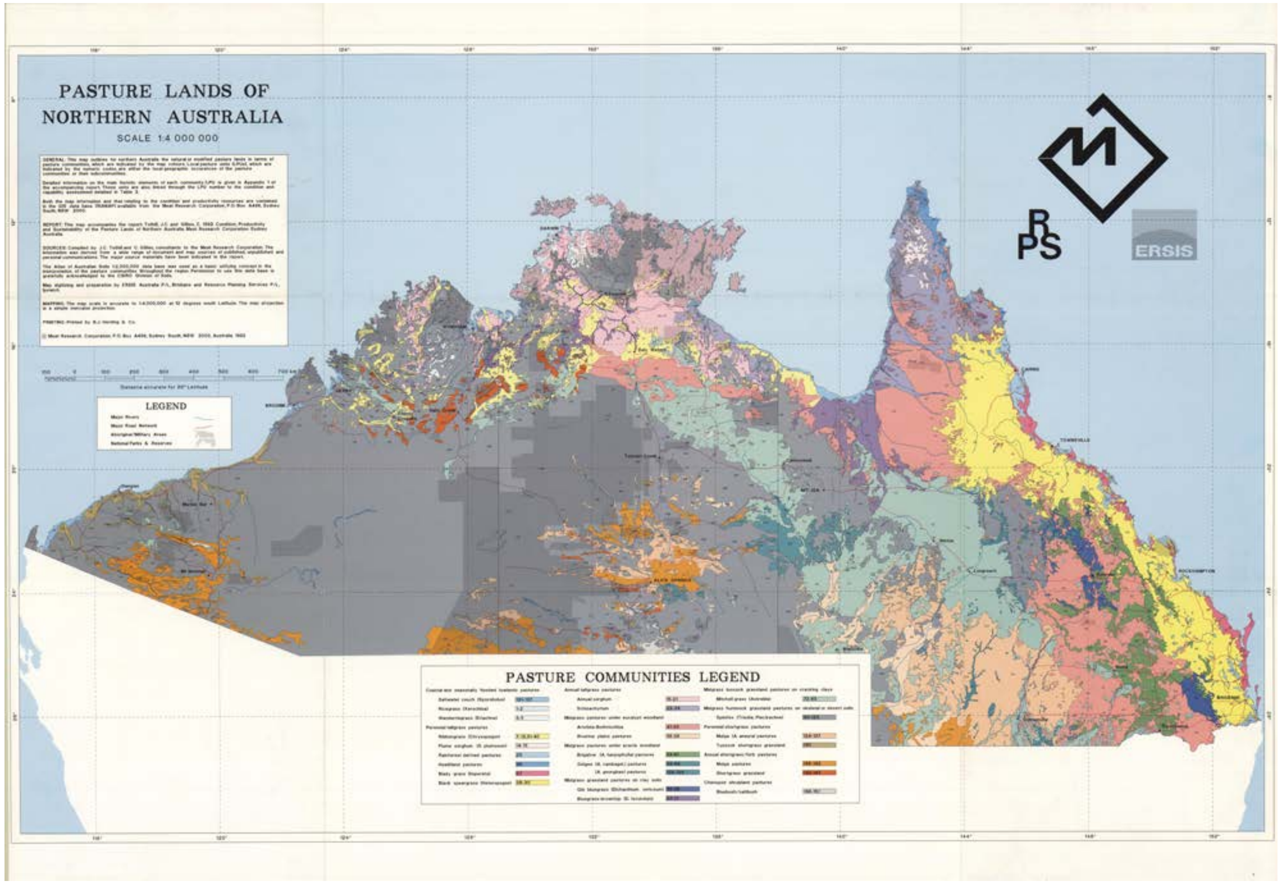
Note: Estimated fraction of crops sown with no till (single pass) seeding technology across (A) the Australian grain belt, and (B) for each of the primary Australian cropping States, calculated by scaling the 2011 ABS census data according to the data of Figure 6.E.7

Grazing Systems

As with the data preparation for cropping systems, the pasture species identified in Table 6.B 8 were concorded to the new, Australian Statistical Geography Standard, statistical area level 2 (SA2) boundaries (Pink 2010) and the recent ABS censuses were used to represent management epochs (Table 6.E.4). The species and management data were, however, collated from a number of sources.Grassland types in southern Australia after 2000 were sourced from Donald (2012) and, prior to 2000, were obtained from the Australian Temperate Pastures Database (Hill et al, 1998). The digitised map (Figure 6.E.7) of the pasture lands of Northern Australia (Tothill and Gillies 1992) provided data for northern Australia for all years and grassland types.

Appendix

Figure 6.E.7 Pasture Lands of Northern Australia



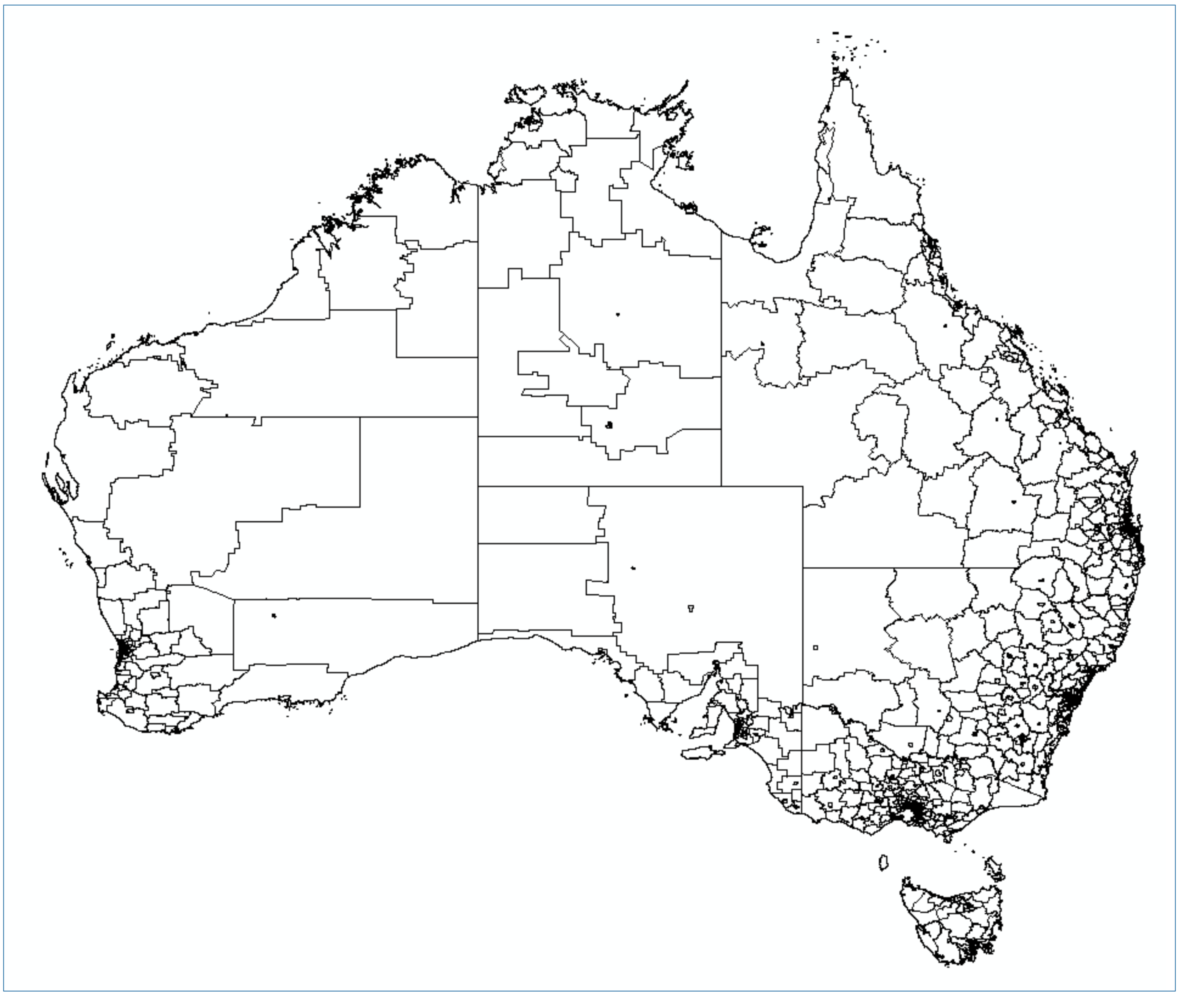
The information collected describes 527 grazing and cropping systems, with associated management practice data also held within the *FullCAM* model relational database. Table 6.E.3 provides an example of the data collected. Allocation to a land use and management system is designated according to the relative frequency of land use and management for each soil type in each SA2 region in each year. For each of these systems the key management practices, such as the use of fire, when grazing is applied (months and intensity), ploughing and herbicide treatment, were implemented in the model.

Appendix

Table 6.E.3 Example land use table

SA2	Start Year	End Year	Agriculture Species	Management practice
31173	2010	2014	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 122, 10y, Grazing - Normal, 1 burn
71050	1990	1994	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 122, 2y, Grazing - Normal, 0 burns
71055	1990	1994	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 244, 2y, Grazing - Normal, 0 burns
31177	2010	2014	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 244, 5y, Grazing - Normal, 1 burn
31503	1985	1989	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 30, 1y, Grazing - Normal, 0 burns
51207	1990	1994	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 305, 2y, Grazing - Heavy, 0 burns
71068	2000	2004	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 305, 2y, Grazing - Normal, 0 burns
71065	2005	2009	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 305, 2y, Grazing - Very Heavy, 0 burns
71068	2000	2004	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 335, 10y, Grazing - Heavy, 8 burns
31406	2000	2004	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 335, 10y, Grazing - Normal, 8 burns
71055	2000	2004	Aristida-Bothriochloa	Aristida-Bothriochloa, Estab 335, 10y, Grazing - Very Heavy, 8 burns
11238	2000	2004	Barley	Barley, No till, stubble cool burn
31282	2010	2014	Barley	Barley, No till, stubble hot burn
11271	1990	1994	Barley	Barley, No till, stubble mulched
41149	1995	1999	Barley	Barley, No till, stubble ploughed
51237	2005	2009	Barley	Barley, No till, stubble removed
21100	2000	2004	Barley	Barley, No till, stubble standing
11198	2005	2009	Barley	Barley, Tilled, stubble cool burn
11175	1995	1999	Barley	Barley, Tilled, stubble hot burn
11098	2005	2009	Barley	Barley, Tilled, stubble mulched
11286	1990	1994	Barley	Barley, Tilled, stubble ploughed
41155	1990	1994	Barley	Barley, Tilled, stubble removed
61003	2010	2014	Barley	Barley, Tilled, stubble standing
31186	2010	2014	Black speargrass	Black speargrass, Estab 122, 10y, Grazing - Normal, 1 burn
31522	1995	1999	Black speargrass	Black speargrass, Estab 244, 2y, Grazing - Normal, 0 burns
31376	2000	2004	Black speargrass	Black speargrass, Estab 244, 5y, Grazing - Normal, 1 burn
31254	1985	1989	Black speargrass	Black speargrass, Estab 30, 1y, Grazing - Normal, 0 burns
71068	1990	1994	Black speargrass	Black speargrass, Estab 305, 2y, Grazing - Heavy, 0 burns
71068	1970	1984	Black speargrass	Black speargrass, Estab 305, 2y, Grazing - Normal, 0 burns
71068	2000	2004	Black speargrass	Black speargrass, Estab 305, 2y, Grazing - Very Heavy, 0 burns
71068	2005	2009	Black speargrass	Black speargrass, Estab 335, 10y, Grazing - Heavy, 8 burns
71068	1970	1984	Black speargrass	Black speargrass, Estab 335, 10y, Grazing - Normal, 8 burns
71068	2000	2004	Black speargrass	Black speargrass, Estab 335, 10y, Grazing - Very Heavy, 8 burns

Figure 6.E.8 Australian Statistical Geography Standard, statistical area level 2 (SA2) boundaries (Pink 2010)



6.E.5 Crop and Pasture Yield

Crop/pasture growth model

FullCAM uses the crop and pasture yield data in the estimation of biomass accumulation in agricultural systems. Yield data is estimated in *FullCAM* using a simple crop/pasture growth model to estimate yields based on rainfall availability during the growth period (Unkovich *et al*.. 2009). The model uses the *FullCAM* water balance routine to estimate daily evapotranspiration, using fixed crop x region specific splits for bare soil evaporation or crop water use (transpiration) to estimate crop and pasture productivity. Two plant production modules are used, one to accommodate annual crops and pastures (Figure 6.E.9), and the other for perennial pasture systems across the continent (Figure 6.E.10). The two modules cover summer and winter grain and forage crops, sugarcane, sown and native pastures, and grass growth in rangeland ecosystems.

Figure 6.E.9 Conceptual model of annual crop growth module

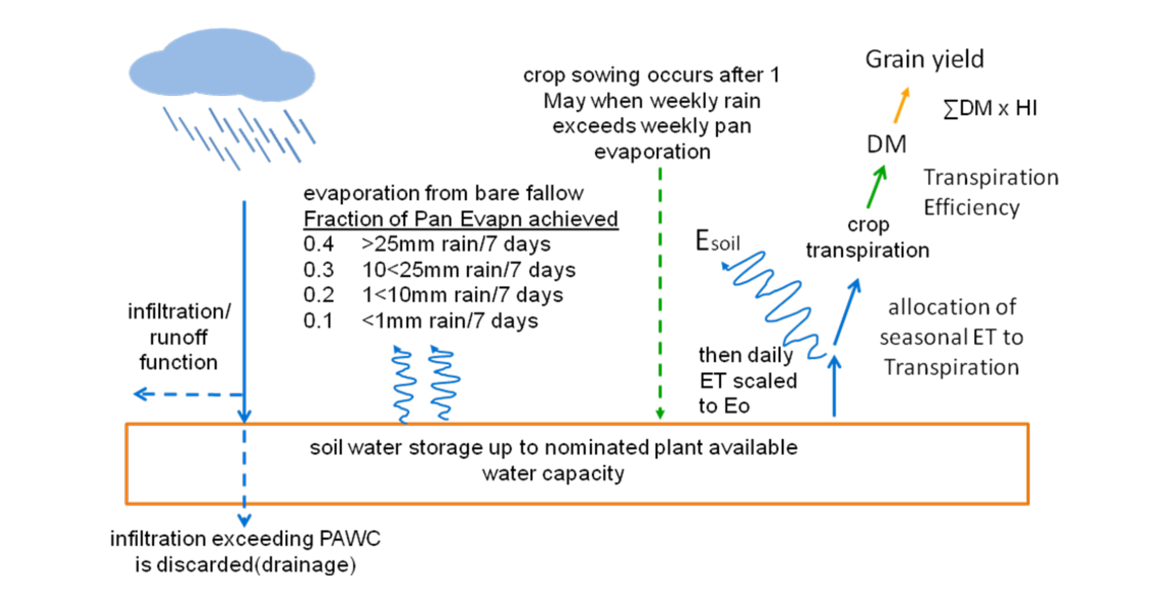
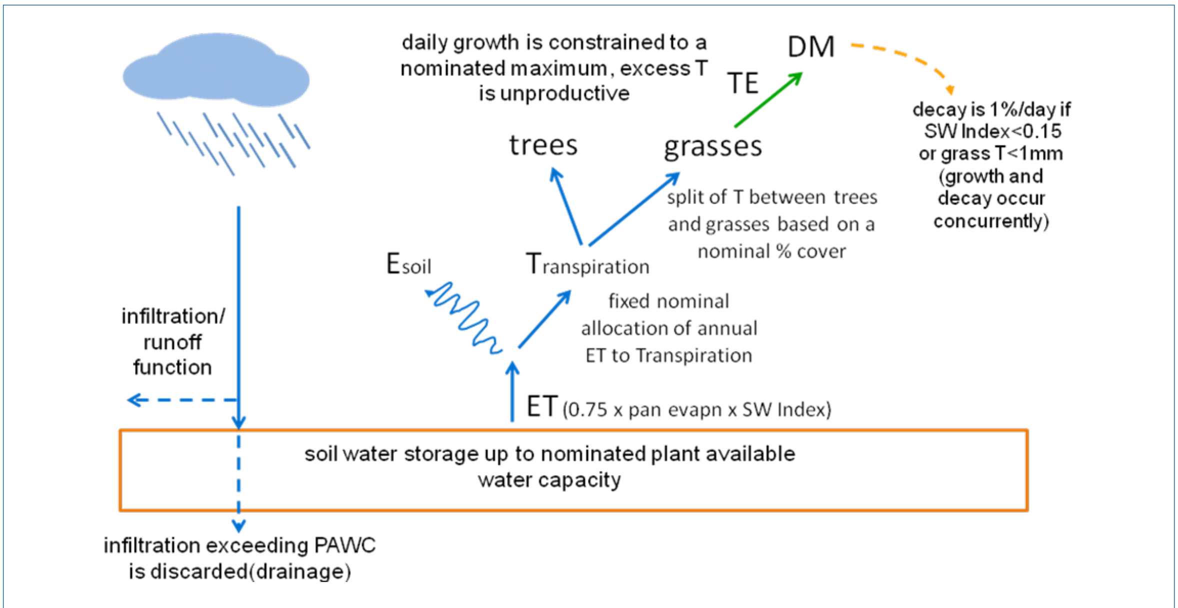


Figure 6.E.10 Conceptual model of perennial grass/pasture module



Productivity improvement trends

As the model of crop growth is based on recent agricultural management practices it is necessary to scale the modelled dry matter production backwards in time according to long term trends in farm crop productivity. Taking 2000 as the base year, modelled yields have been scaled, both backwards and forwards, from this time at the indicative rate (1.36% pa) for the 1970-2010 time period. While this rate of change also includes yield increases due to improvements in crop harvest index (Unkovich *et al.* 2010) these have not removed from the dry matter productivity increases because HI is currently held constant in *FullCAM*.

Testing the model

CSIRO has tested the model construct output against a database of crop yield data (Unkovich *et al.* 2014) and, in general (regional) testing, the modules accounted for about 50% of the variance in annual crop grain yield or of shoot dry matter of perennial pastures on any given day. In site specific tests the annual grain crop model was able to explain up to 80% of the variance in crop yield.

Appendix

Appendix 6.F: Post-1990 Plantations – Forest Growth Model

Forest growth model

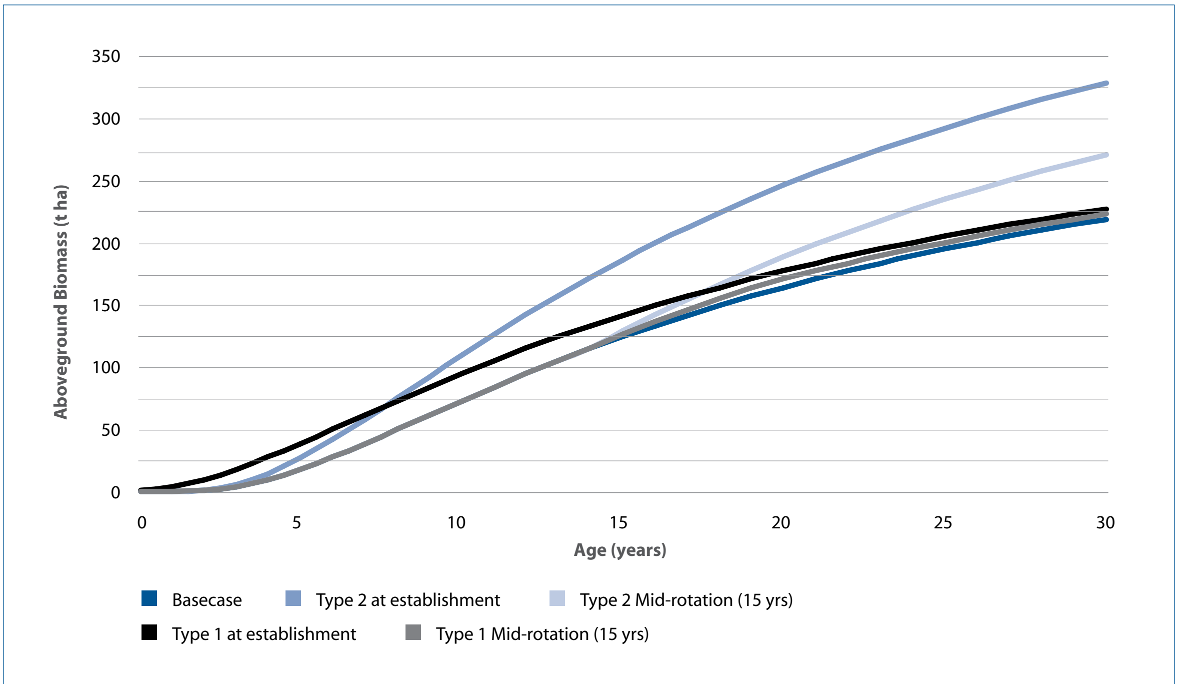
Plantations commonly produce more biomass than native forest systems in Australia, at least in the short to medium term (15-40 years). For example, Baker and Attiwill (1985) showed that *Pinus radiata* achieved 70-100% of the biomass of an 80 year old native forest, grown under similar conditions, in only 20 to 24 years. These growth differences are driven by factors such as nutrient addition, reduction in insect herbivory associated with the use of non-endemic species or through control of pests, site-specific species matching and management, and possibly greater physiological efficiency in utilising site resources by the introduced species.

The initial assumed biomass model (Appendix 6.D) and methods to estimate removals, due to regrowth post clearing, represent forest systems without significant management input and is well suited to the *forest land converted to grassland* and *cropland* sub-categories. However, in plantation systems with significant management inputs, such as fertiliser application or intensive site preparation, and species specific site matching, additional model parameters are needed to accurately estimate forest growth.

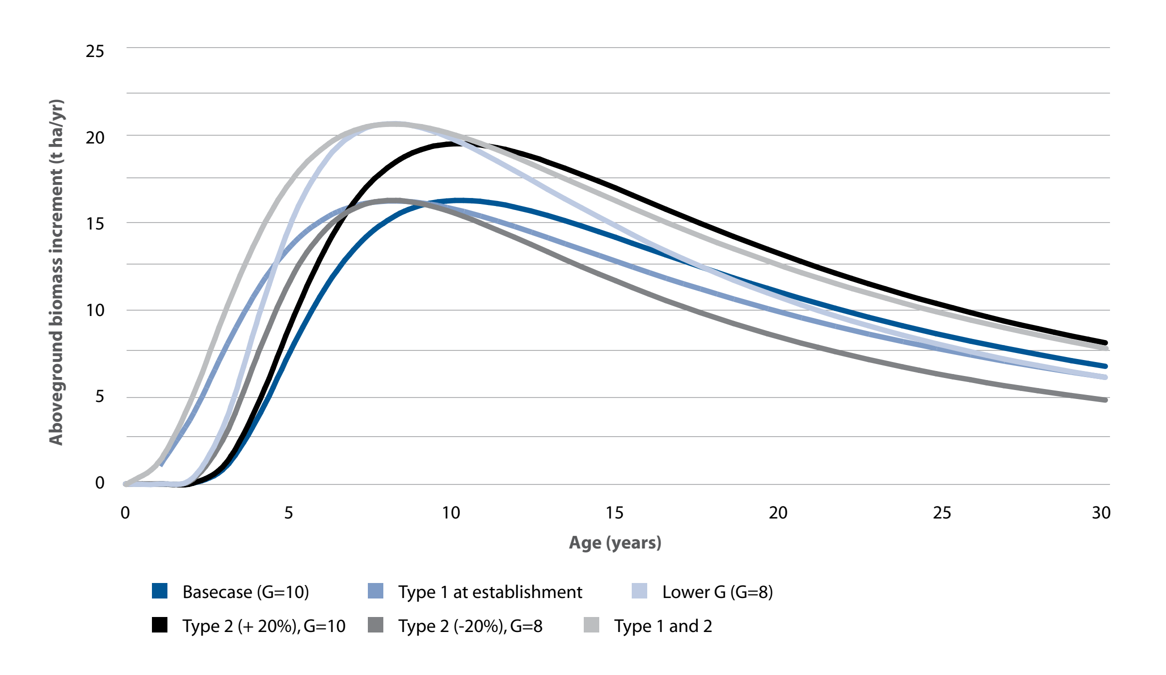
To account for the effects of management practices on growth the native forest regrowth model (the Tree Yield Formula, Appendix 6.B) is supplemented to include functions that represent Type 1 and Type 2 growth responses (Snowdon and Waring, 1984) (Figure 6.G1). Type 1 management practices advance or retard stand development (effectively age), but do not increase underlying site productivity over the life of the rotation. Weed control at establishment, and nitrogen fertiliser application after thinning, are examples of Type 1 responses (Snowdon, 2002). Type 2 treatments increase (or decrease) a site's carrying capacity in the longer term. Phosphorus application, which in Australia can lead to long-term increase in site productivity (i.e., over several rotations) (Snowdon, 2002) is an example of a Type 2 response.

Figure 6.G.1 Effect of Type 1 and Type 2 management practices on (a) cumulative and (b) annual growth

(a)



(b)



Snowdon (2002) developed methods for including Type 1 and 2 effects in hybrid growth models. These have been implemented in the forest growth component of the *FullCAM* model. In the model, Type 1 forest treatment events are simulated by varying the developmental stage or age of the stand, moving the forest back and forth along the growth curve depending on the degree of treatment (see Equation 3). Type 2 treatments simply change the asymptote (i.e., *M*; see Equation 6G_4) from the time the treatment is applied. These methods lend themselves well to application in the hybrid empirical-process based structure of *FullCAM*.

A further effect that must be accounted for is the impact of establishing regionally non-endemic plantation species. This effect is expressed through a plantation species multiplier (*r*; see Equation 6G_1). It is similar to a Type 2 response being applied from the time a species is planted until final harvest. The *r* multiplier is based on the long term average Forest Productivity Index (*P*; see Appendix 6.C) for each point, the type of plantation established and is stratified by State and National Plantation Inventory (NPI) region (Figure 6.16). This allows the model to account for variations in growth between regions that cannot be accounted for easily from climatic and broad scale site information (e.g., Sheriff *et al.* 1996; Turner *et al.* 2001), while still accounting for the significant variation that occurs within each region due to site factors.

Calculation of r

The plantation species multiplier (*r*) was determined for each major plantation species on a regional basis. Regional long-term forest productivity index values of plantation areas in each National Plantation Inventory (NPI) region and State were determined by overlaying the long-term forest productivity index (*P*) spatial data, with areas of hardwood and softwood plantation as identified by the plantation type mapping from the remote sensing programme. The average Mean Annual Volume Increment (MAVI) data for each plantation species in each State and NPI region was obtained from Turner and James (1997), Turner and James (2002), Snowdon and James (2008) and Ferguson *et al.* (2002). The values are either based on or represent the data used in Australia's National Forest Inventory (NFI). Minimum and maximum MAVI values that are not available in the NFI data were estimated for each species and NPI region, based on Snowdon and James (2008) and the following assumptions:

1. MAVI values of the NFI are the average for the region, not the most common growth rate;
2. Minimum MAVI values are effectively set by commercial viability. These are generally not lower than 12 m^3 ha^{-1} yr^{-1}, (although this may vary for certain species within regions, such as Pinus pinaster in dry regions in West Australia); and
3. Maximum MAVI values are unlikely to exceed 30 m3 ha^{-1} yr^{-1} in long rotation systems and 35 m^3 ha^{-1} yr^{-1} in short rotation systems.

Environmental plantings are considered similar to regenerating native forest and assigned an *r* value of 1 (no management/species effect). The distribution of plantations according to plantation typing was mapped to the *P* data to verify that the minimum and maximum values were reasonable given the assumptions applied. For the calculation of *r*, the minimum and maximum *P* values were assumed to be the 5% and 95% of the total distribution of area for each plant type. As species is not identified in the plantation type data, where a plantation type (i.e., hardwood/softwood) consisted of different species with distinct productivity ranges (e.g., *P. pinaster* and *P. radiata* in Western Australia are both softwoods but *P. pinaster* is commonly established in low rainfall areas), the *P* for the dominant species was set values from regions with similar species and conditions, with the other species ranging from the minimum P value to the lowest P value of the dominant species. The MAVI and *P* data used for calibrating *r* are shown in Table 6.G1.

The *r* value required to adjust the base case native forest growth model to the documented plantation MAVI growth rates and the estimated minimum and maximum MAI's for each State, NPI region and species was calculated based on assumptions of species characteristics and forest management (Equation 6G_1). As the MAVI growth data is not spatially explicit it was assumed that low *P* values represent low MAVI values and high *P* values represent high MAVI values. This is justified through the strong relationship between *P* data and native forest biomass stocks (see Appendix 6.D), and studies using the productivity data in plantation systems that show relationships between *P* and stand height and basal area, but with significant regional variation (Ford, 2004). Expansion factors at final harvest were calculated using the equations from Snowdon et al (2000) and the average rotation length. While the expansion factor data show considerable variability at young ages, there is little variation in older stands, providing a high degree of certainty in these values. Species specific basic wood density values at maturity were obtained from Illic *et al.* (2000) and Polglase *et al.* (2004). Similar to the expansion factors, the range of density values decreases as the stands mature. For species in which management typically includes a thinning prior to final harvest, typically longer rotation sawlog plantations, the basic density value was reduced by 10% to account for the age-related effects and the thinned volume added to the final total harvest biomass. The percentage of maximum potential biomass achieved by final harvest was calculated based on estimates of age of maximum biomass increment, described in the next section.

Table 6.G.1 Range of FPI (P) values on which plantation types occur, the minimum, average and maximum growth rates (Mean Annual Volume Increment, $m^3\ ha^{-1}\ yr^{-1}$) and rotation length.

NPI	Plantation type	Species	FPI low	FPI mean	FPI high	Min MAI	Average MAI	Max MAI	Rotation length
Western Australia	Softwood	Pinus radiata	5.0	7.0	11.2	12	20	30	30
Western Australia	Softwood	Pinus pinaster	3.8	5.5	8.0	6	11	16	35
Western Australia	Hardwood	Eucalyptus globulus SR	4.0	6.7	11.9	12	17	30	12
Western Australia	Hardwood	Eucalyptus globulus LR	5.0	7.0	11.9	12	18	27	25
Tasmania	Softwood	Pinus radiata	5.3	10.0	15.3	12	19	30	30
Tasmania	Hardwood	Eucalyptus globulus SR	6.0	11.5	15.5	14	23	30	10
Tasmania	Hardwood	Eucalyptus nitens SR	5.3	10.0	14.5	12	15	27	15
Tasmania	Hardwood	Eucalyptus nitens LR	6.0	11.5	15.5	14	19	27	25
Green Triangle	Softwood	Pinus radiata	4.8	7.4	11.5	12	21	30	35
Green Triangle	Hardwood	Eucalyptus globulus SR	4.8	7.7	11.5	12	17	27	12
Green Triangle	Hardwood	Eucalyptus globulus LR	6.0	8.2	11.5	14	20	25	25
South Australia - Lofty Block	Softwood	Pinus radiata	5.3	6.6	10.6	12	21	27	35
South Australia - Lofty Block	Hardwood	Eucalyptus globulus SR	4.3	6.5	10.4	12	17	27	12
South Australia - Lofty Block	Hardwood	Eucalyptus globulus LR	5.0	7.5	10.4	12	20	25	25
Central Victoria	Softwood	Pinus radiata	5.5	8.0	14.1	12	18	27	35
Central Victoria	Hardwood	Eucalyptus globulus SR	5.3	7.3	13.9	12	18	27	12
Central Victoria	Hardwood	Eucalyptus globulus LR	6.0	8.0	13.9	14	18	25	25
Murray Valley	Softwood	Pinus radiata	5.3	9.4	12.4	12	20	27	30
Murray Valley	Hardwood	Eucalyptus globulus SR	5.3	8.6	13.0	12	16	25	13
Murray Valley	Hardwood	Eucalyptus globulus LR	6.5	9.0	13.0	12	18	25	25
Central Gippsland	Softwood	Pinus radiata	5.9	9.0	16.6	12	20	30	30
Central Gippsland	Hardwood	Eucalyptus globulus SR	5.8	10.4	16.9	12	18	27	12
Central Gippsland	Hardwood	Eucalyptus nitens LR	7.0	13.0	16.9	12	18	27	25
Bombala-East Gippsland	Softwood	Pinus radiata	6.4	11.0	14.9	12	16	27	35
Bombala-East Gippsland	Hardwood	Eucalyptus globulus SR	6.4	9.5	15.1	12	19	27	12
Southern Tablelands	Softwood	Pinus radiata	5.1	7.0	12.4	12	16	27	30
Central Tablelands	Softwood	Pinus radiata	5.3	9.0	11.7	12	16	25	30
Northern Tablelands	Softwood	Pinus radiata	6.2	9.9	16.6	12	16	25	30
Northern Tablelands	Hardwood	Eucalyptus globulus SR	4.7	8.4	16.1	12	16	25	14
Northern Tablelands	Hardwood	Nth Coast Eucs LR	7.4	11.7	16.1	12	14	20	30
North Coast	Softwood	SouthernPines	8.1	12.5	22.3	12	15	25	30
North Coast	Softwood	Hoop pine	8.1	12.5	22.3	9	13	20	40
North Coast	Hardwood	Nth Coast Eucs SR	7.6	10.8	19.6	12	18	27	12
North Coast	Hardwood	Nth Coast Eucs LR	8.0	10.8	19.6	12	18	25	35
South East Queensland	Softwood	SouthernPines	6.3	11.1	21.2	12	13	25	30
South East Queensland	Softwood	Hoop pine	6.3	11.1	21.2	8	13.4	20	40
South East Queensland	Hardwood	Nth Coast Eucs SR	6.0	9.0	21.0	12	18	27	12
South East Queensland	Hardwood	Nth Coast Eucs LR	7.0	11.5	21.0	12	18	25	35
Northern Queensland	Softwood	SouthernPines	6.7	10.4	17.5	12	13	25	30
Northern Queensland	Softwood	Hoop pine	6.7	11.8	25.0	8	13.4	20	50
Northern Queensland	Hardwood	Nth Coast Eucs SR	6.6	10.2	20.9	12	18	27	12
Northern Queensland	Hardwood	Nth Coast Eucs LR	9.0	15.0	20.9	12	18	25	35
Northern Territory	Hardwood	Acacia	6.4	8.4	11.0	20	25	35	8
Northern Territory	Hardwood	NT eucs	6.4	8.5	11.0	8	12	20	30

r = (MAVI x Rotation Length x Basic Density x Expansion Factor) / M .... (6G_ 1)

A $\log_e$-$\log_e$ (ln-ln) model was then fitted to the r and P data by plantation type (hardwood/softwood) (Figure 6.G2) (Equation 7G_2). Residuals were homogenously distributed. P, NPI region and rotation length (short or long) were found to be significant effects. A separate model based on state was also developed using the same regression to allow predictions for the small area (< 5%) of hardwood and softwood plantations identified outside the NPI regions. There was no significant interaction between NPI and rotation length and no apparent bias in the results.

$\ln(r) = b_{0} + b_{1} * \ln(P_{av})$ .... (6G_2)

Where:

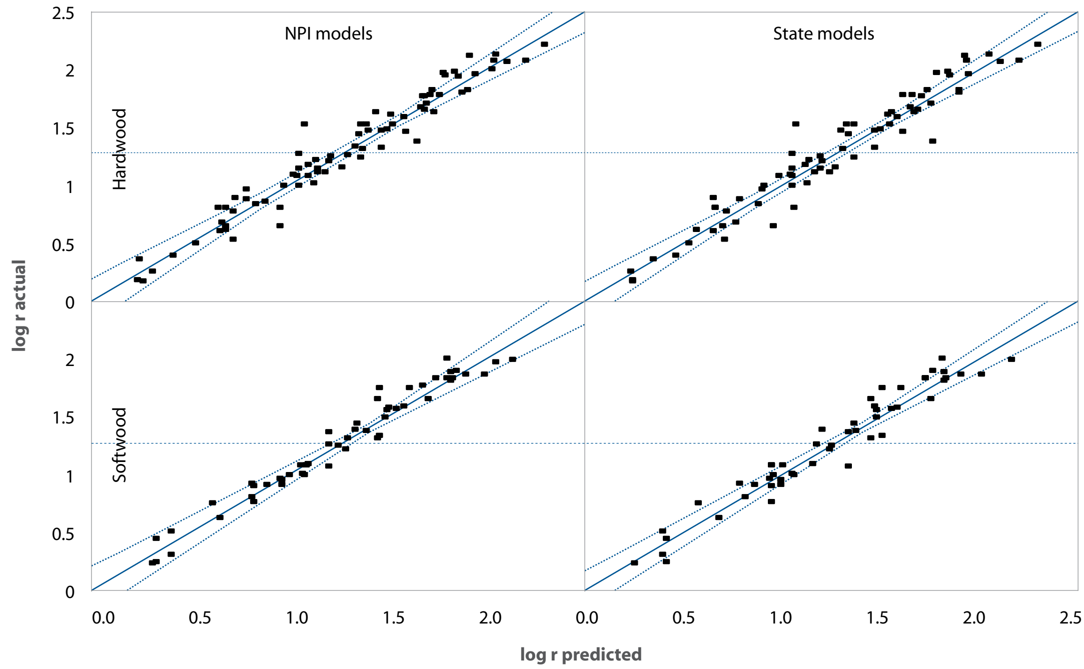
r = non-endemic species multiplier

b_0 = value based on NPI region and rotation length (long or short)

b_1 = value based on if the plantation occurs in an NPI region or a state.

P = long-term average FPI value.

Figure 6.G.2 Actual vs predicted r values for hardwood and softwood plantations by State and NPI



The analysis showed that plantation forests established on sites with high *P* values require lower *r* values than those on sites with lower *P* values. This was expected, as plantations on low quality sites will often respond better, in percentage response, to good site preparation methods and adequate fertilizer addition (Turner, 1984; Snowdon and James, 2008), leading to a more 'even' range of carbon uptake rates compared with native systems.

The age of maximum biomass increment

The age and magnitude of maximum current annual biomass increment (Max I_B) varies with species, site productivity and management. The age of Max I_B is not typically reported in forest growth studies as it generally occurs before the age of first commercial thinning when direct measurements of stem volume are less commercially important and, hence, less frequent. However, it is generally considered that the age of Max I_B occurs at or around the time of canopy closure (Gower *et al.* 1994; Ryan *et al.* 1997; Law *et al.* 2003). For the purpose of calibrating the model this was assumed to be the case.

In addition to underlying site conditions (soils and climate), fertilisation and improvements in establishment techniques over the past 30 years have reduced the age of canopy closure and promoted early growth in long-rotation plantation systems (Boomsma and Hunter, 1990; Snowdon and James, 2008). Management systems which aim for high biomass outputs with a lower concern for stemwood quality and form (i.e., short rotation pulpwood plantations) will also tend to lower the age of maximum biomass increment through high stocking rates and more intensive initial management.

In *FullCAM* the age of maximum biomass increment can be modified through direct manipulation of *G* or through applying Type 1 effects prior to *G* (see Appendix 6.B; Equation 6G_5). Varying *G* affects both the age and magnitude of Max I_B. Where a Type 1 response is applied prior to *G* (i.e. between ages 0 and *G*), the effective age of Max I_B is lowered without affecting the magnitude of growth. The majority of management effects on early age growth, such as weed control and good site establishment methods, are modelled by applying Type 1 effects at planting. This also provides extra flexibility in adjusting stand growth based on specific management regimes. Hence, the unaffected *G* value (i.e., that with little or no management) can be calculated based on the actual age of Max I_B and the sum of Type 1 effects on early age growth due to management (Equation 6G_3):

$$G = G_{man} + T1_{pre\text{-}g} \qquad (6G\_3)$$

Where:

G_{man} = age of maximum biomass increment with management

G = age of maximum biomass increment assuming no management

$T1_{pre\text{-}g}$= sum of the Type 1 age advance events applied prior to *G*

For native ecosystems an age of maximum current annual growth increment (CAI) of ten years is applied. Many commercial plantations are managed for aggressive early growth that shortens the period to harvest. This is most evident in short rotation (approximately ten year) pulpwood plantations. Silviculture, in particular a dense stocking rate of trees per hectare, is used to supply this early growth. In some instances this can bring the age of maximum current annual increment to being as low as 2-3 years after establishment. Each plantation type/management regime combination is assigned a specific age of maximum current annual increment based on location.

Calibration of G

Values for G were calibrated for each species within each NPI region based on rotation length and the approximate sum of Type 1 effects at planting. Canopy closure (effectively G_{man} in the model) in *P. radiata* plantations established over the last 20 years generally occurs between the ages of seven and 12 years depending on site quality and management (Snowdon and James 2008). On poor quality sites with little management or site improvement it may take even longer. Improved establishment and early age management practices adopted in the last 20 to 30 years, in particular after the late 1970's, have reduced the age of canopy closure by about two to three years (Boomsma and Hunter, 1990; Snowdon and James, 2008) and were modelled as Type 1 effects. Equation (6G_4) was calibrated based on 'unaffected stands' by adding 2 years of Type 1 effect to the current age of canopy closure (Equation 6G_3), resulting in a range of nine to 14 years for *G*. Regionally specific data for *G* and G_{man} was not available so this range was applied for all long rotation systems. However G_{man} DEs vary by region and time depending on management practices. Long-rotation eucalypt plantations are still relatively uncommon and little is known about their future management and prospects. Given the paucity of data it was assumed that long-rotation eucalypt plantations are similar in management to other long rotation systems, although they may reach canopy closure slightly earlier depending on growth conditions, as discussed below. To account for the effect of site productivity on *G* a simple linear relationship between *G* and *M* was included (Equation 6G_4). The results of the calibration are shown in Waterworth *et al.* (2007).

Canopy closure tends to occur much earlier in short rotation plantations due to species characteristics, higher stocking rates, more intensive management and better site/species matching. *Eucalyptus* species tend to reach canopy closure much more quickly than *Pinus* species given suitable conditions, and hence increase in mass much faster during the early stages of development (Myers *et al.* 1996). Therefore G for short rotation plantations was set 2 to 3 years earlier than for long rotation systems

Final model form used for post-1990 plantations

$G = s \times M + c$.. (6G_ 4)

Where:

G = age of maximum biomass increment of unaffected stand

s = multiplier to account for site productivity

M = unadjusted maximum biomass value

c = region/species dependant intercept

The modified tree yield formula that is used to calculate forest growth for the post-1990 *plantations* sub-category is therefore:

$Ia = r \times M \times ((y2 \times e\text{-}k/d) - (y1 \times e\text{-}k/d\text{-}1)) \times (P/Pav)$ ....*(6G- 5)*6G- 5)

Where:

I_a =Aboveground mass increment of the trees, in t DM ha^{-1}

a = Age of trees

r = non-endemic species multiplier

M = maximum aboveground biomass (calculated from P)

y_1 =Type 2 site multiplier at age, a

y_2 = Type 2 site multiplier at age, a-1

$k = 2 * G$

Where, G = Tree age of maximum growth

d = Adjusted age of the trees, in years

= a + sum over each treatment of

0	if a <= W
v * (a – W) / U	if a >= W and a <= W + V
v	if a > W +U

Where, *for each Type 1 treatment,*

v = the age advance due to the treatment, either positive or negative, in years

U = the advancement period, in years

W = the age, a, at which the treatment was applied, in years.

P= the actual FPI over the period d_a to d_{a-1}

P_{av} =Long term average FPI value

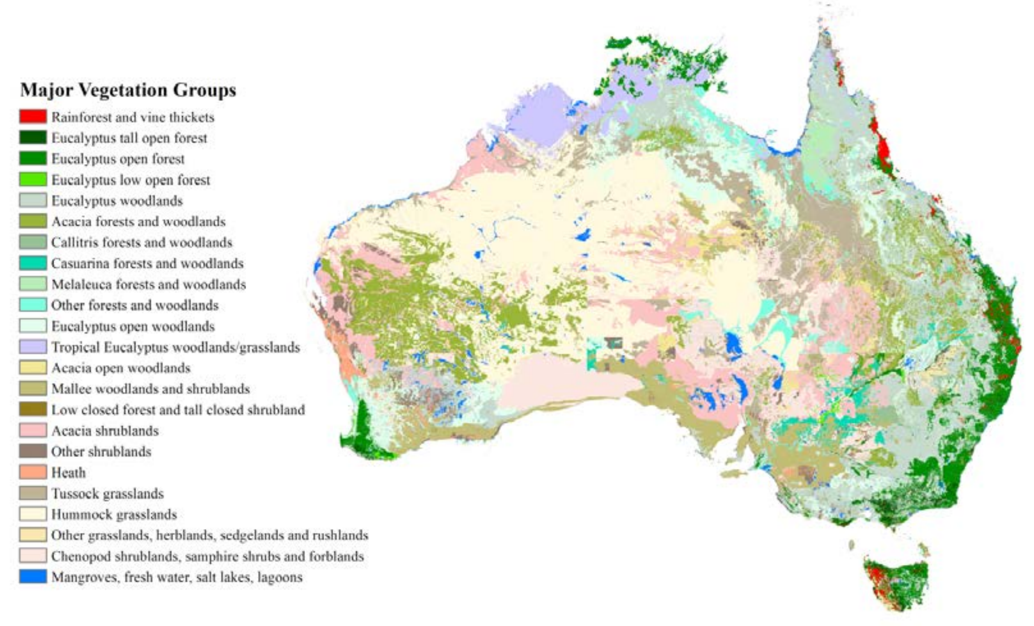
Appendix

Appendix 6.G: Major Vegetation Groupings Classified by the National Vegetation Information System

The Major Vegetation Groups (MVG) (Figure 6.H1) are used to specify the biomass allocations of *forest land converted to cropland* or *grassland*. In additional the MVG are used to spatially disaggregated the land included in the *forest land converted to cropland* or *grassland* classifications in the CRF tables.

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 *forest land converted to 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. For the purposes of carbon accounting the Level III MVG categories were applied. These vegetation types are described in below.

Figure 6.H.1 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 Australia's land cover change programme 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.

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 Forest

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 Forest

This group is widespread along the sub-coastal plains, 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 Woodland

This group is 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 Forest and Woodland

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. Callitris Forest and Woodland

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 Forest and Woodland

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 Woodland/Grassland

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 do 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.

Appendix

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 Shrubland

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 Forest and Closed Shrubland

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 Shrubland

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. Other Shrubland

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 Grassland, 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 dominate 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. There can be widespread clearing or infilling of mangroves and tidal mudflats in coastal areas near urban major centres for industrial uses or urban developments.

Appendix 6.H Tier 2 Forest Conversion Model

Forest land converted to cropland and *grassland* emissions estimates are based on the Tier 3 Approach 3 model and national time-series of Landsat satellite data. Verification of the use of the Tier 3 model to estimate emissions from this sub-category was performed through comparison with a Tier 2, Approach 2 method. The Tier 2 model was developed as an excel spreadsheet model. This model formed the basis for reporting emissions prior to the implementation of the Tier 3, Approach 3 methods and has been subsequently enhanced. The Tier 2 model is used to estimate changes in biomass from the conversion of 'mature' forest, the regrowth of forest on previously cleared land, the growth of crops and grasses on cleared land, and the subsequent re-clearing of a proportion of this regrowth.

The model also calculates changes in the dead organic matter (DOM) and soil pools and emissions (CO_2 and non-CO_2) associated with burning;

The annual area converted or re-cleared (activity data) were the same as those used as input to the Tier 3 model for Forest land converted to Cropland and Grassland.

In the Tier 2 model land clearing is stratified into three broad forest classes:

1. closed (tropical forest);
2. open (predominantly eucalypt forest); and
3. woodland forest

This stratification was undertaken by overlaying the areas cleared from the remote sensing analysis on the major vegetation groups of the National Vegetation Information System (NVIS; see Appendix 6.H).

Figure 6.I.1 Initial assumed biomass of land cleared post-1989 which has entered Australia's deforestation accounts.

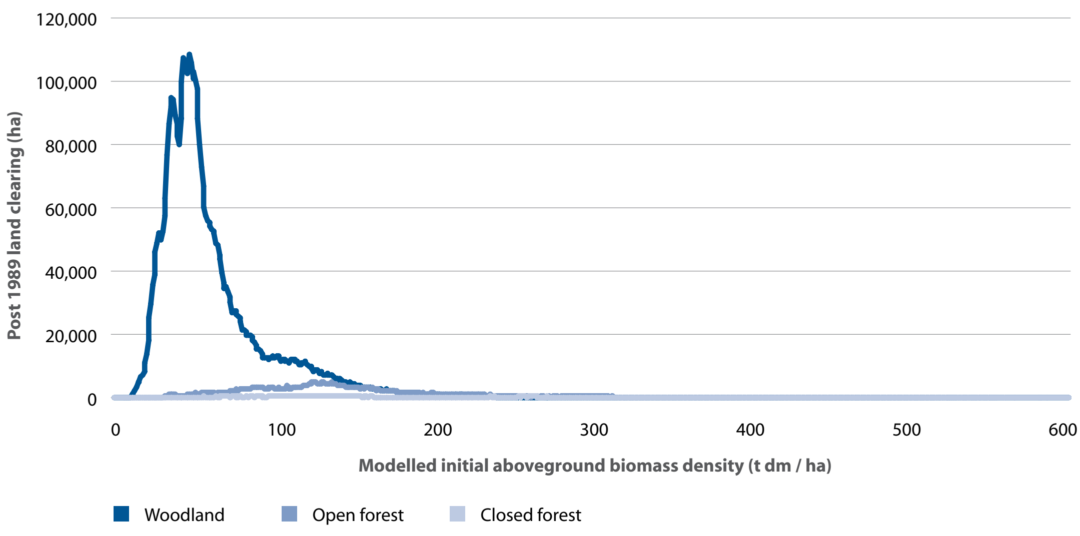


Figure 6.I.1 shows that the majority of land clearing since 1989 has occurred in woodland forests. This information was used in the Tier 2 model to allocate the area cleared in each year to clearing of woodland, open forest and closed forest (Table 6.I.1).

Carbon pools

Biomass – aboveground and below ground trees

To determine the biomass of each forest class that is used in the Tier 2 model, analysis was undertaken of the initial assumed above ground biomass of the lands that are within Australia's deforestation account. To undertake this analysis the simulated cells layer for lands within the deforestation account were intersected with the initial assumed above ground biomass surface. Table 6.I.1shows the results of this analysis. The estimates are expressed as averages within three forest types – closed forest, open forest and woodland. The area converted from forest land to cropland and grassland areas were allocated to the three forest types by matching their locations to the locations of Australia's major vegetation groups.

Table 6.I.1 Tier 2 forest coefficients used to estimate emissions and removals from first time forest clearing

	Closed Forest	Open Forest	Woodland Forest
Proportion of annual clearing (%)	2	10	88
Initial biomass of forests(a)(b) (t dm ha^{-1})	198.7	152.8	67.6
Root : shoot ratio	0.25	0.25	0.40
Debris onsite mass(b) (t dm ha^{-1})	100	75	50
Initial soil carbon (t C ha^{-1})	70	73	60
Proportion of area subject to forest regrowth (%)	25	25	25

(a) Aboveground biomass.

(b) Used for all States and Territories.

Areas of previously cleared land that re-grew to forest are assumed to achieve their original biomass in 25 years. The biomass of forest subject to reclearing is 32% of the mature biomass.

Biomass – above ground and below ground herbaceous species

Sequestration associated with the growth of crop and grass species is included in the model on land which is not subject to forest regrowth. Table 6.I.2 provides the biomass increment parameters applied to estimate this variable. These parameters are multiplied by the total area of clearing recorded each year to estimate the biomass accumulated by crop and grass species on cleared land.

Table 6.I.2 Biomass accumulated by crop and grass species on cleared land

	Crops	Grasses
Proportion of cleared land (%)	15	60
Above ground mass, including debris (tdm ha-1)	4.0	4.2
Root : shoot ratio	0.5	0.5

Dead organic matter

The forest debris onsite prior to forest clearing is presented in Table 6.I.1. Debris associated with crops and grasses is included with living biomass (Table 6.I.2). Forest debris, including initial debris and debris remaining after forest conversion, was assumed to decay over a period of 10 years (IPCC, 2003).

Appendix

Soil carbon

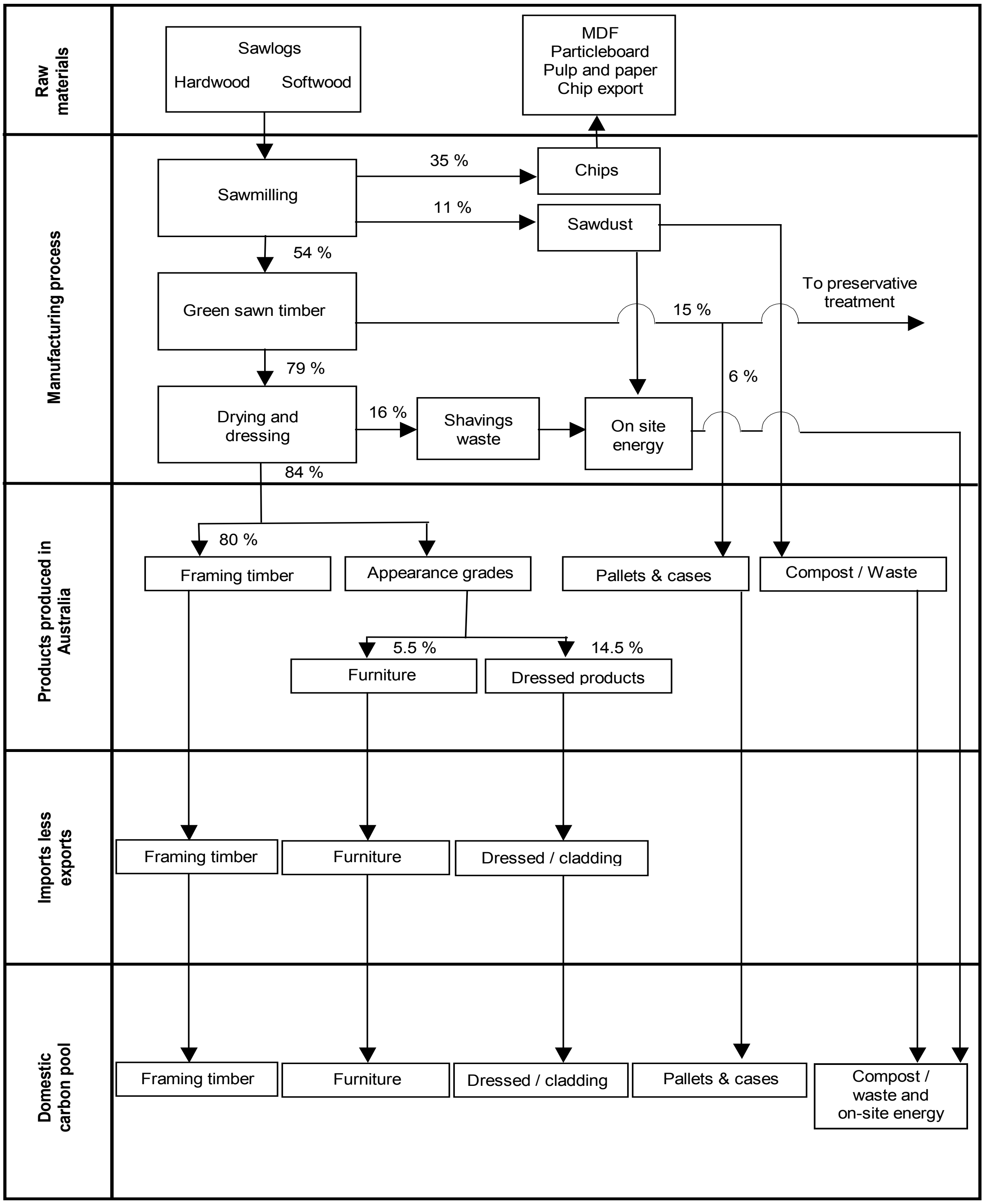
Emissions of soil carbon following conversion are estimated by applying the Roth C model for all first time cleared land (See Appendix 6.B). The Roth C model was parameterised with climate data (rainfall, temperature, open pan evaporation) from a representative site in central Queensland.

Non CO_2 emissions

Non-CO_2 (CH_4 and N_2O) emissions were estimated by multiplying the CO_2 emissions from onsite burning and onsite burning of debris with a 'non-CO_2 to CO_2' coefficient. The non-CO_2 to CO_2 coefficient incorporates the ratio of mass of non-CO_2 gas to the mass of carbon it contains, the ratio of non-CO_2 gas emitted to carbon emitted, the ratio of the amount of CO_2 with equivalent greenhouse gas effect to an amount of non-CO_2 gas and the fraction of CO_2 that is carbon by weight.

Appendix 6.I: Wood Flows By Sector

Figure 6.J.1 National Inventory Model - Sawmilling wood flows *



* percentages shown for softwood sawmilling, refer to model for hardwood and cypress pine

Figure 6.J.2 National Inventory Model for Wood Products - Wood flows in preservative treated products

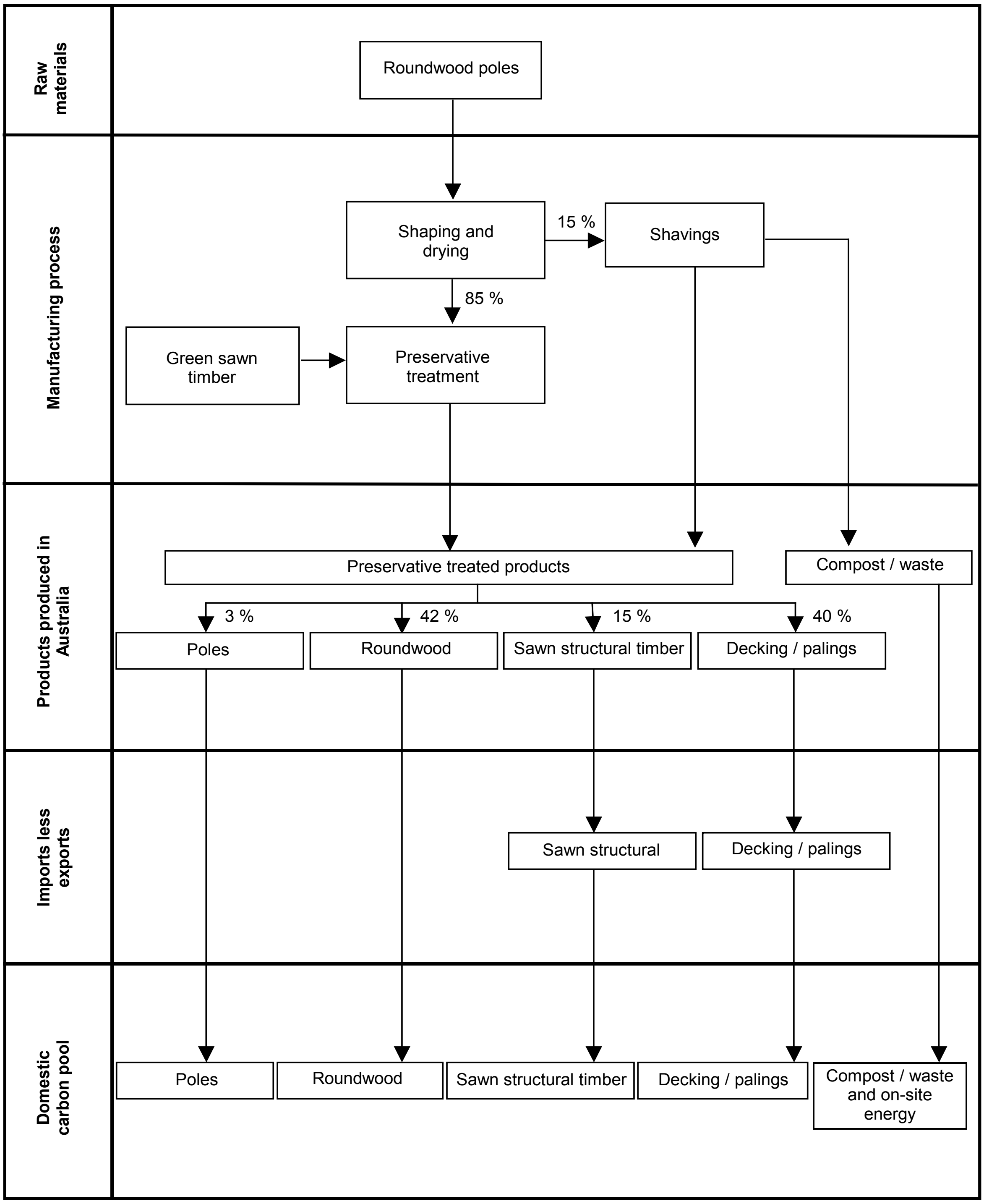
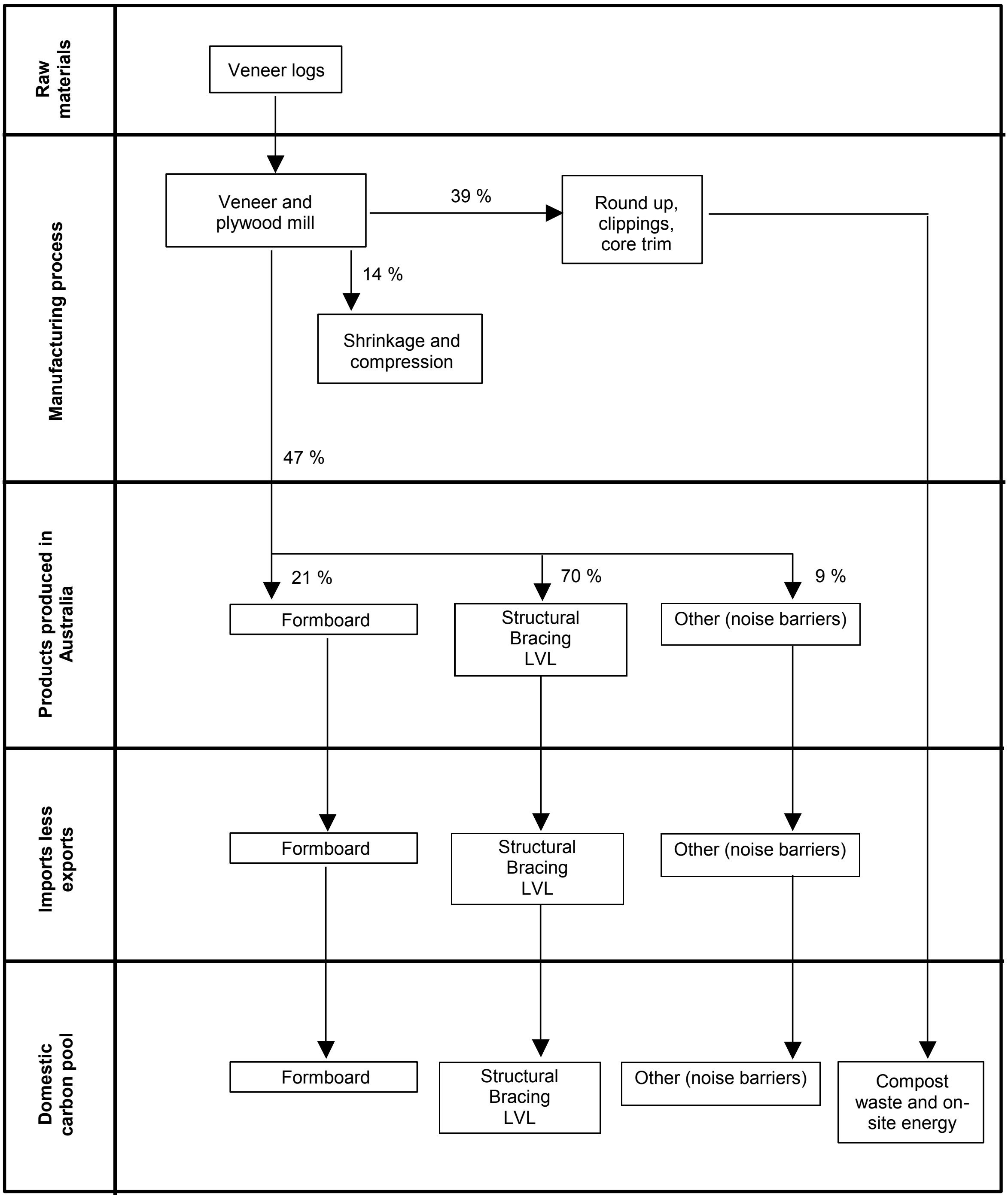


Figure 6.J.3 National Carbon Accounting Model for Wood Products – Wood Flows in plywood production



Appendix

Figure 6.J.4 National Inventory Model for Wood Products - Wood flows in MDF and particleboard manufacture

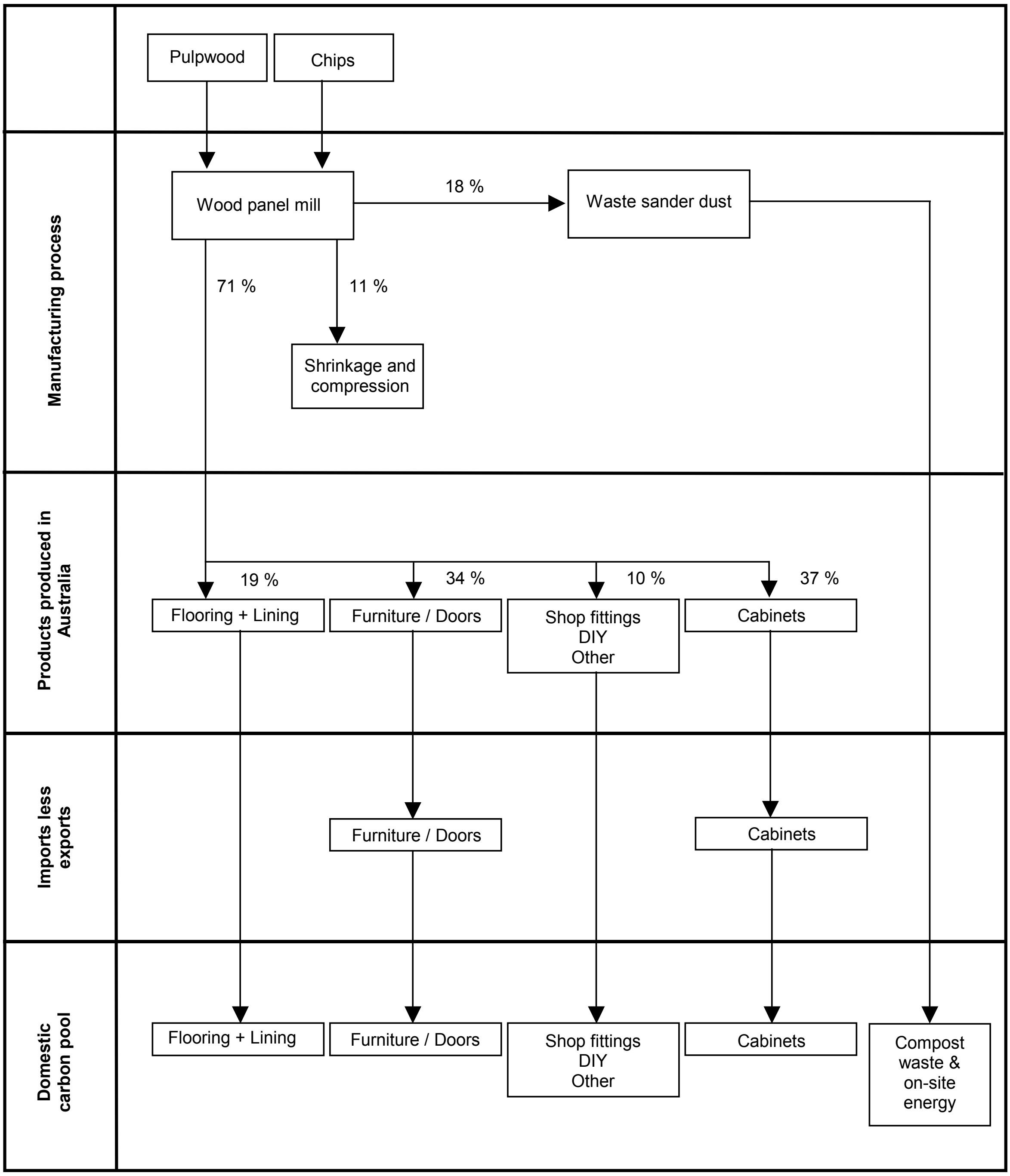
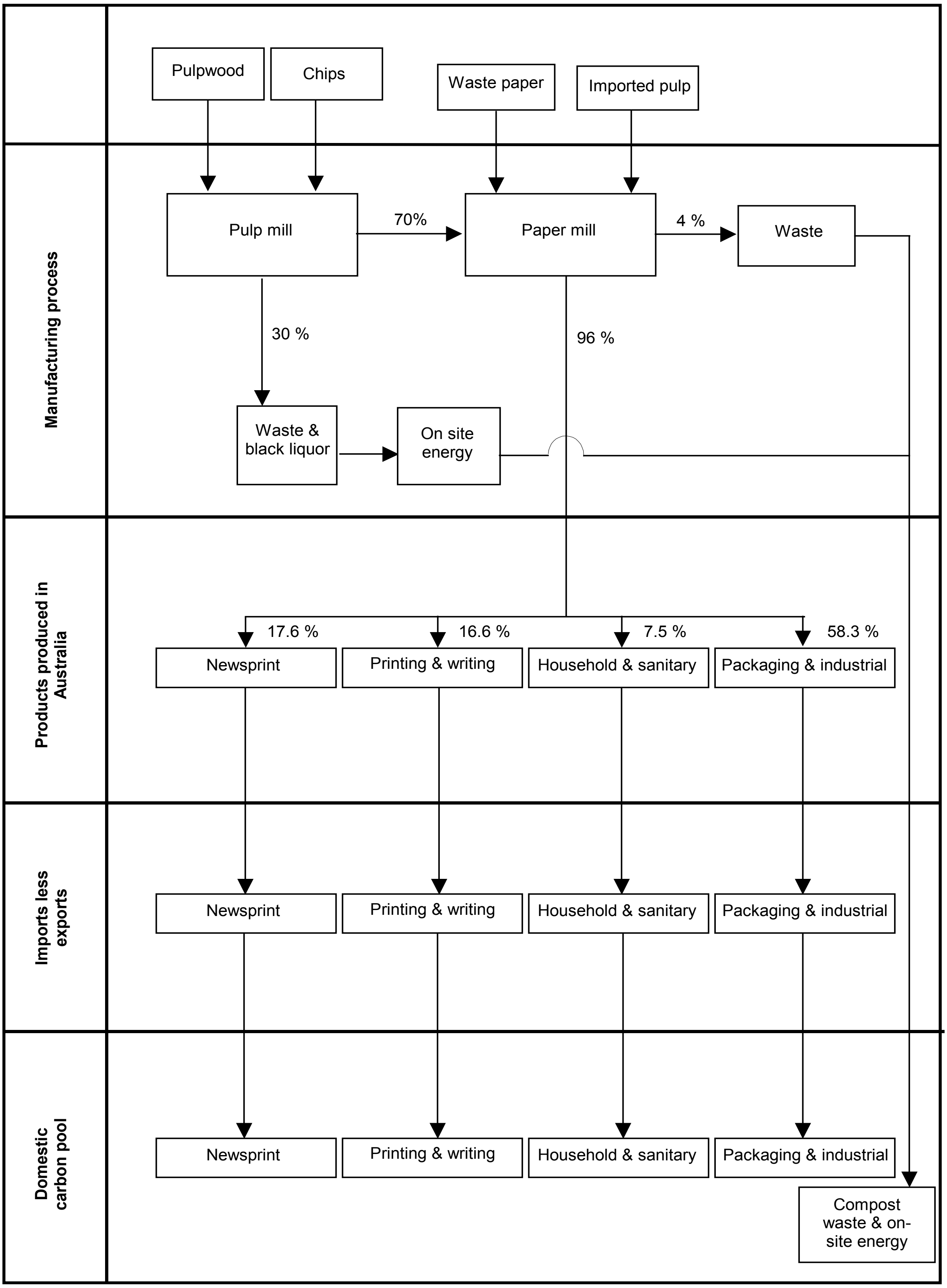
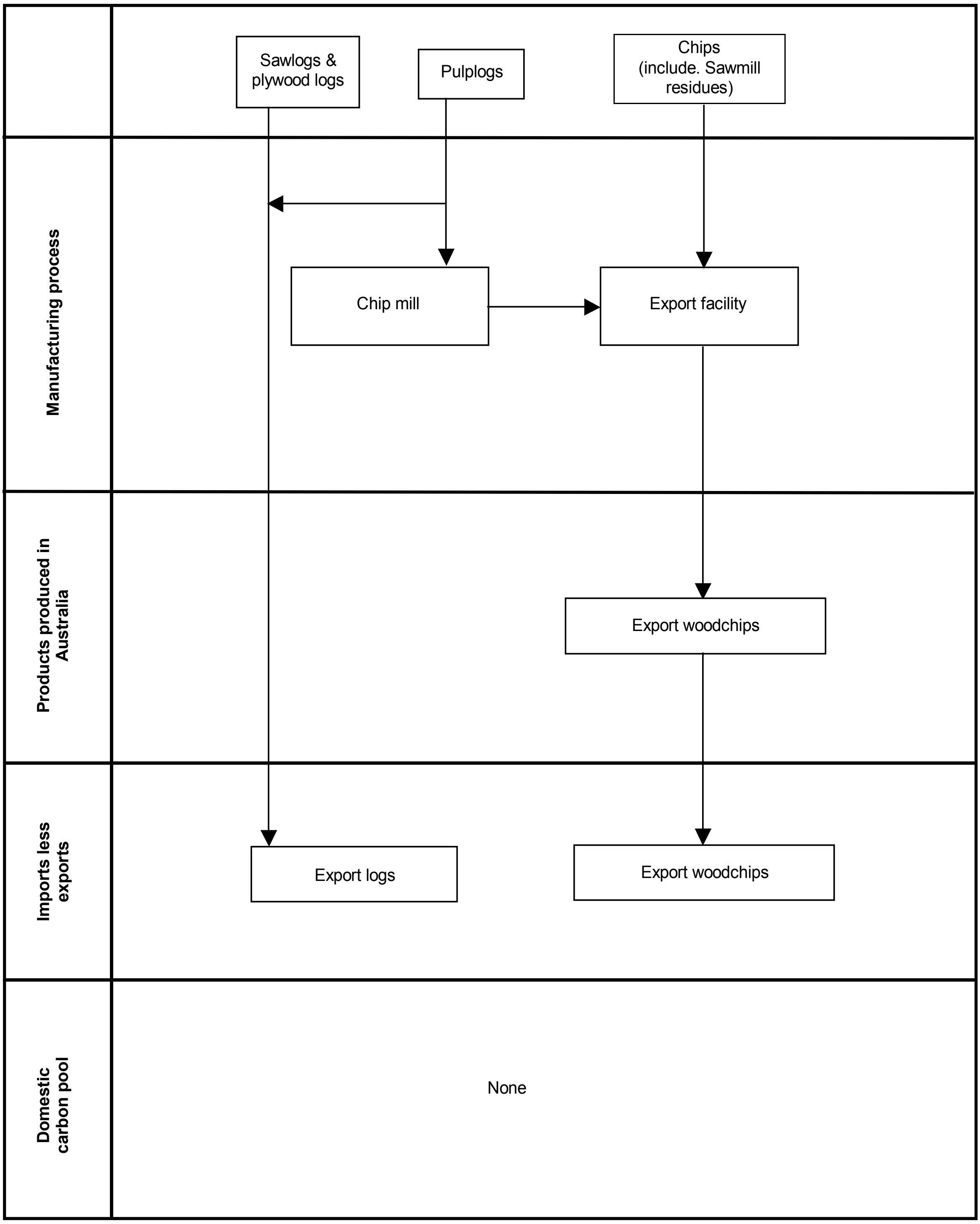


Figure 6.J.5 National Inventory Model for Wood Products - Wood flows in pulp and paper manufacture *



* percentages shown for particleboard manufacture – see model for details on MDF

Figure 6.J.6 National Inventory Model for Wood Products - Wood flows in export wood chips and logs



7 Waste

7.1 Overview

Total estimated waste emissions for 2013 were 13.4 Mt CO_2-e, or 2.5% of total net national emissions (excluding LULUCF) (Table 7.1). The majority of these emissions were from solid waste disposal, contributing 10.4 Mt CO_2-e or 77.8% of waste emissions. *Wastewater treatment and discharge* contributed a further 2.8 Mt CO_2-e (21.1%) of waste emissions while waste incineration and biological treatment of solid waste contributed 0.03 Mt CO_2-e (0.2%) and 0.1 Mt CO_2-e (0.8%) respectively. *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.

Table 7.1 Waste CO2-e emissions, 2013

Greenhouse gas source and sink categories	CO_2-e emissions (Gg)			
	CO_2	CH_4	N_2O	Total
5 WASTE	30	12,913	417	13,360
A. Solid waste disposal	NA	10,394	NA	10,394
B. Biological treatment of solid waste	NA	102	11	113
C. Incineration and open burning of waste	30	NA	NE	30
D. Wastewater treatment and discharge	NA	2,416	406	2,823

7.1.1 Trends

Waste emissions were 35.8% (7.4 Mt CO_2-e) lower in 2013 than they were in 1990 and 5.3% (0.8 Mt CO_2-e) lower than in 2012.

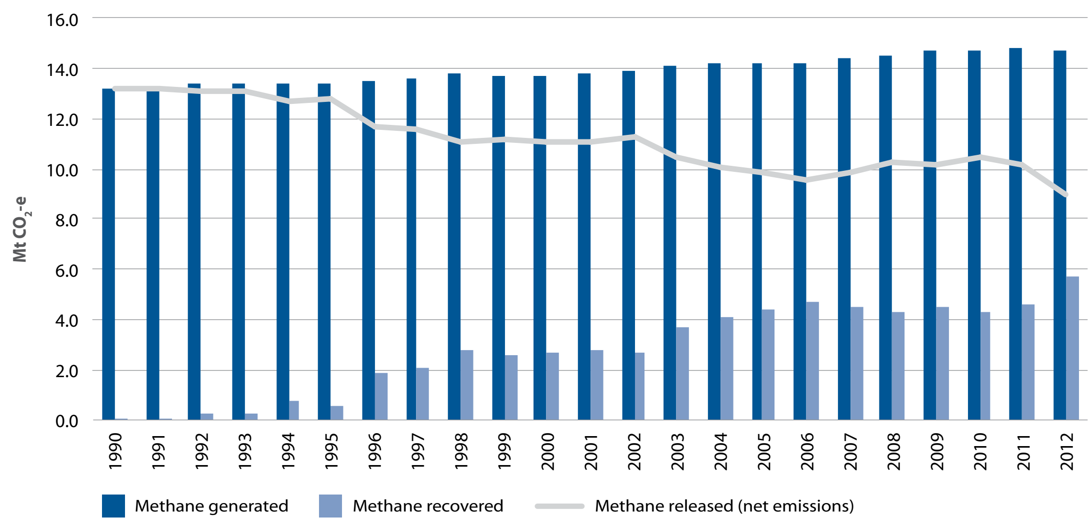
Emissions from municipal *solid waste disposal* decreased by 36.1% (5.9 Mt CO_2-e) over the period 1990 to 2013 (Figure 7.1) and were 6.7% (0.7 Mt CO_2-e) lower than in 2012. This decline is mainly due to increases in methane recovery over the time-series. It is also notable that in recent years, as rates of recycling have increased, paper disposal in particular has declined as a share of total waste disposed. Total waste disposal has also declined in recent years as alternative waste treatment options are becoming more viable, driven by state and territory waste management policy. As waste degradation is a slow process, estimates of methane generation for 2013 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 7.6 Mt CO_2-e of methane in 2013.

Emissions from the *Biological treatment of solid waste* have increased by 1.9% (0.002 Mt CO_2-e) since 2012. Emissions of CO_2 from the incineration of solvents and clinical waste decreased by 64.8% (0.1 Mt) between 1990 and 2013.

Wastewater treatment and discharge emissions decreased by 36.3% (1.6 Mt CO_2-e) over the period 1990 to 2013, with a decrease of 0.4% (0.01 Mt CO_2-e) since 2012. Changes in estimates for *wastewater treatment and discharge* emissions are largely driven by changes in industry production, population loads on centralised treatment systems and the amount of methane recovered for combustion or flaring.

Figure 7.1 Emissions from solid waste disposal, 1990–2013



7.2 Overview of Source Category Description and Methodology – Waste

Table 7.2 Summary of methods and emission factors used to estimate emissions from waste

Greenhouse Gas Source And Sink Categories	CO2		CH4		N2O	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
5. Waste	T2	CS	T2	CS,D	CS	D
A. Solid waste disposal	NA	NA	T2/3	D	NA	NA
B. Biological treatment of solid waste	NA	NA	T1	CS	T1	CS
C. Incineration and open burning of waste	T2	CS	NE	NA	T2	CS
D. Wastewater treatment and discharge	NA	NA	T2/3	CS,D	CS	D

T1= Tier 1, T2 = Tier 2, CS = country specific, M = model, D = default, NE = not estimated, NA = not applicable

7.3 Source Category 5.A Solid Waste Disposal

7.3.1 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. CO_2 produced from the flaring of methane from waste is also considered as having been derived from biomass sources.

Solid waste treatment in Australia

Common with the practice in many other developed economies, solid waste is processed in Australia via four main mechanisms:

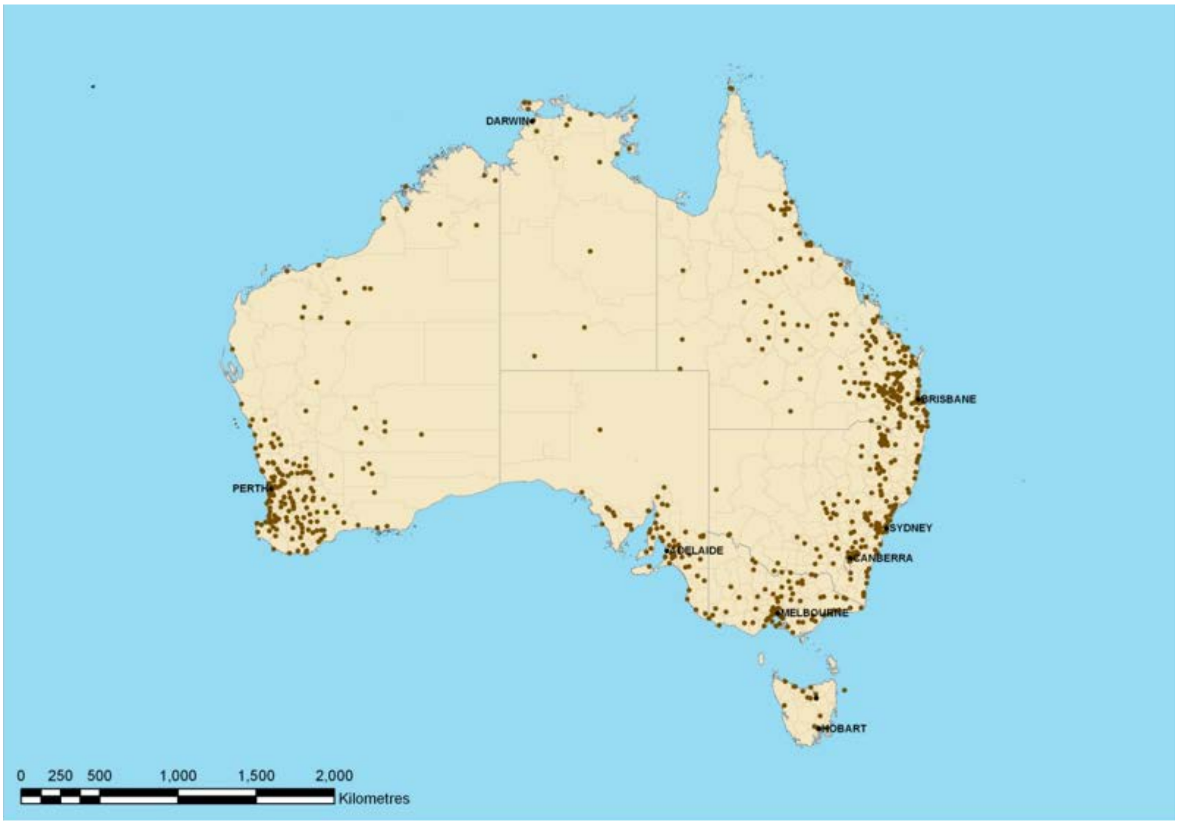
- landfill;
- biological treatment/composting;
- incineration; and
- recycling/reuse.

DEWHA (2009) reported that there are at least 665 operating landfills in Australia receiving around 21 Mt of waste. This amount equates to approximately 48% of the estimated total waste generated (44 Mt). The balance of waste, 52% of waste material generated, is recycled or reprocessed (including biological treatment/composting) while a negligible amount is treated thermally (incinerated) (DEWHA 2009). Figure 7.2 shows the physical locations of the major landfills in Australia. The map shows that landfills are clustered around the large population centres around Australia's coastline.

A landfill industry survey conducted by the Waste Management Association of Australia (WMAA) in 2007 found that a relatively small number of sites are responsible for the bulk of the waste received in Australia. Of the landfills surveyed, 39 process more than 200 kt of waste per year, 24 process between 100 kt and 200 kt per year, 32 process between 50 kt and 100 kt per year, 38 process between 25 kt and 50 kt per year, 61 process between 10 kt and 25 kt per year and the remainder (around 55% of the total number of landfills) process less than 10 kt each per year.

Overall, these statistics show the concentrated nature of the landfill industry in Australia. The top 8% of landfills (i.e. the top 39) manage over 55% of total waste received while almost 90% of solid waste sent to landfill in Australia is received in 133 large landfills with capacity to process 25 kt or more of waste each year. In terms of waste management practices in place at Australian landfills, 11% of landfills have a landfill gas collection system in place. However, in the larger scale landfills, this practice is more common meaning that around 30% of the methane generated is collected for either flaring or energy generation.

Figure 7.2 Australian landfill locations



Source: Geoscience Australia

Common management practices amongst larger landfills include the use of leachate collection systems (38% of landfills). Landfill designs include 38% of landfills with clay cell liners in place, 9% use HDPE cell liners while 7% use GCL liners. In terms of capping practices, 59% of landfills use clay capping, whilst 12% of landfills use either HDPE, GCL or evapotranspiration caps.

7.3.2 Activity data

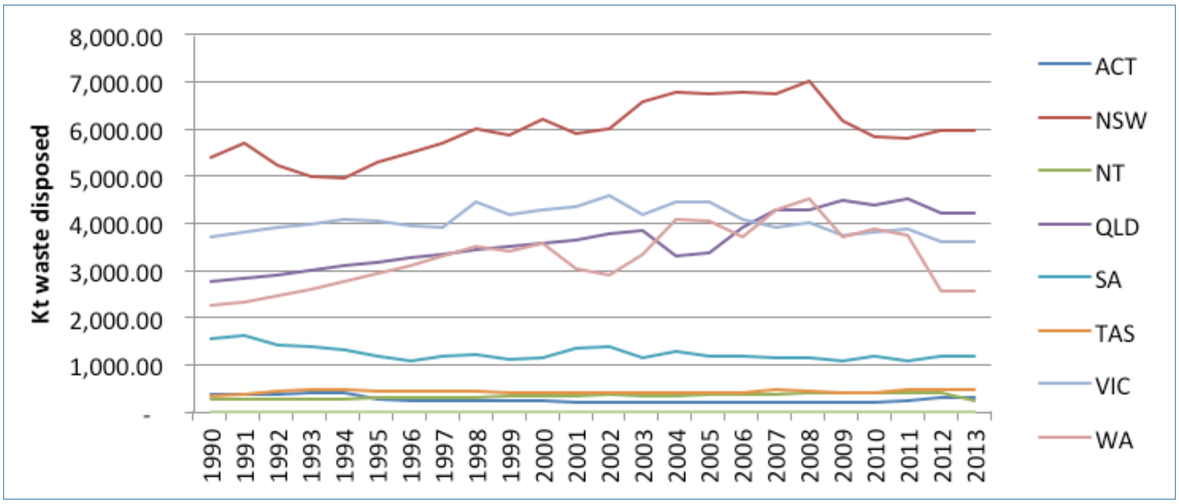
The Australian methodology for calculating greenhouse gas emissions from solid waste is consistent with the IPCC tier 2 First Order Decay (FOD) Model (IPCC 2006). The methodology deployed utilises a dynamic model driven by landfill data provided by the relevant State/Territory Government agencies responsible for waste management together with facility-level data obtained under the NGER (2009 onwards) system. 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 6.

7.3.3 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 and the impact of

State government policies on waste management (Figure 7.3). In addition to total disposal in each State/Territory, disposal at individual landfills is obtained under the NGER system (2009 onwards) for landfills meeting the reporting thresholds. Approximately 50% of total disposal is covered by NGER facility data. The residual disposal not covered by the NGER system (2009 onwards)is calculated as the total disposal reported for each state and territory minus the sum of NGER disposal in each State and Territory. It is important to note that activity data reported in this NIR and the accompanying CRF tables are for waste disposal to landfill as opposed to waste generated. State and Territory landfill levy schemes are applied specifically to waste disposed and the NGER system (2009 onwards) reporting requirements have also been designed to be consistent with this principle.

Figure 7.3 Solid waste to landfill by state



Sources: NSW Department of Environment Climate Change and Water; Sustainability Victoria; QLD Department of Environment and Resource Management; SA Environment Protection Authority; WA Department of Environment and Conservation; Tasmanian Department of Primary Industries, Parks, Water and Environment; ACT Department of Territory and Municipal Services and NGER 2009-2012.

7.3.3.1 Waste streams

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 and NGER (2009 onwards) data have been used to determine the stream percentages. Where disaggregated historical data cease, the stream shares have been held constant back to 1940 (Table 7.16).

Table 7.3 Waste streams: municipal, commercial and industrial, construction and demolition: percentages by State: 2013

	NSW[(a)]	VIC[(b)]	QLD[(c)]	NT[(d)]	SA[(e)]	WA[(f)]	TAS[(g)]	ACT[(h)]
Municipal Solid Waste	28%	38%	32%	42%	34%	43%	37%	37%
Commercial and Industrial	45%	37%	33%	19%	27%	28%	56%	52%
Construction and Demolition	27%	24%	35%	39%	38%	30%	7%	11%

Sources: (a) NSW Department of Environment Climate Change and Water; (b) Sustainability Victoria; (c) QLD Department of Environment and Resource Management; (d) SA Environment Protection Authority; (e) WA Department of Environment and Conservation; (f) Tasmanian Department of Primary Industries; (g) Department of Territory and Municipal Services and NGER 2012

Note: External Territories waste stream breakdown is assumed to be the same as QLD.

Some States include clean fill (uncontaminated inert solid material) 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.

7.3.3.2 Individual waste types

Each waste stream is further disaggregated into a mix of individual waste type categories that contain significant fractions of biodegradable carbon. The categories considered are as follows:

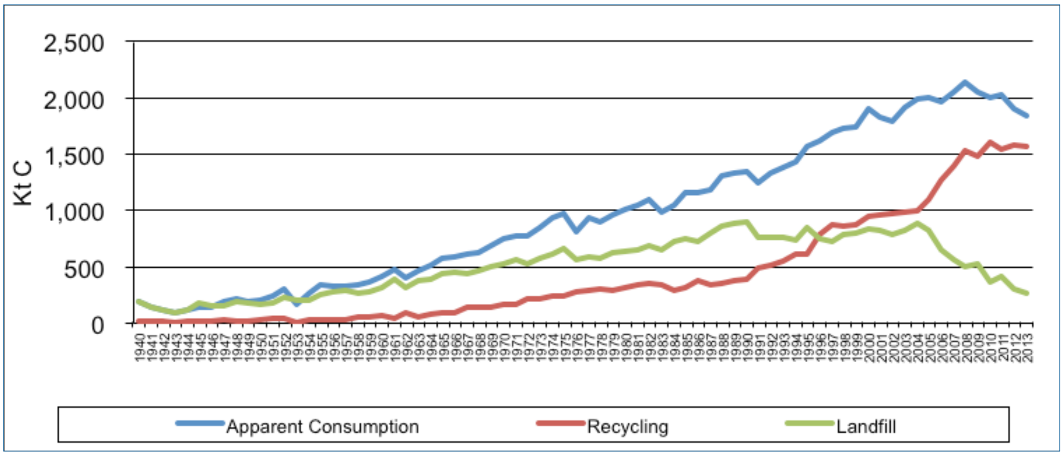
- Food;
- Paper;
- Garden and green;
- Wood;
- Wastes from the production of harvested wood products;
- Textiles;
- Sludge (including biosolids);
- Nappies;
- Rubber and leather; and,
- Inert (concrete, metal, plastics, glass, soil etc).

Harvested wood products - Paper, wood and wood waste generation and disposal

The solid waste disposal estimates and composition are integrated with the wood, wood waste and paper disposal estimates output from the harvested wood products model. These quantities of disposal are used to adjust the waste mix percentages for the non-NGER residual proportion of the waste load going to landfill. This adjustment is undertaken to ensure that the total wood, wood waste and paper disposed to all Australian landfills is consistent with the output of the harvested wood products model.

The amount of paper disposed 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 shift in disposal from landfill to recycling that has occurred since the late 1980s (Figure 7.4). Data on paper and wood reaching the end of their useful life is relatively robust given the long data series available for paper and wood product production, trade and consumption and the assumptions about lifetimes of products reported in Appendix 7.I. This function is a constrained form of the function specified in Section 12.2.2 in IPCC 2006.

Figure 7 4 Paper consumption, recycling and disposal to landfill - Australia: 1940-2013



Source: Refer to Table 7 6

Over time the amount of paper waste generated for disposal will be consistent with the amount of paper consumption given the short life time assumed for this product. Overall paper consumption is estimated to have risen from 380 kt in 1940 to reach 3,685 kt in 2013 (ABARES 2014a) reflecting both increasing population and increasing per capita consumption levels. In terms of carbon, these consumption estimates translate into an estimated 190 kt C in 1940 and 1,843 kt C in 2013 (Table 7.5). Per capita consumption of paper has increased from an estimated 26 kg C per person in the 1940s to 81 kg C per person in 2013. Reflecting the growth in paper consumption, waste paper generation is estimated to have increased from 245 kt C in 1940 to 1,887 kt C in 2013.

The proportion of paper waste generated that reaches landfill depends critically on the amount of paper diverted to other disposal paths. In Australia, an increasing trend to paper recycling has led 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 30% in 1990 to 83% in 2013, with a sharp jump recorded in 2006 reflecting in part the effectiveness of a number of State Government waste management initiatives. The share of paper disposed to landfill has declined commensurately.

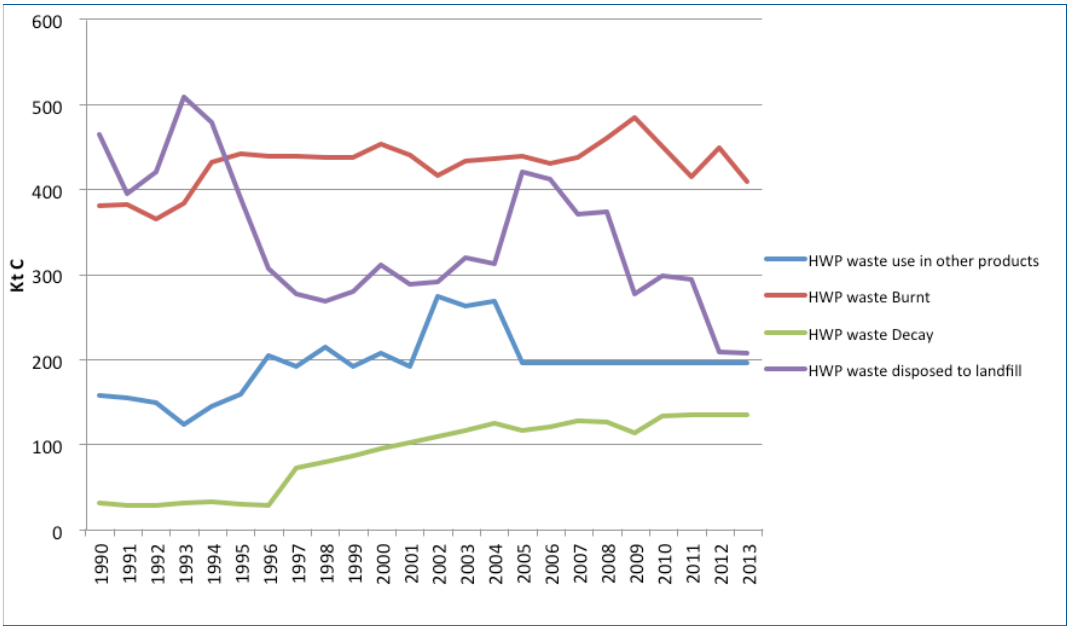
The generation of wastes from the production of harvested wood products, mainly sawmill residues and commercial offcuts, is also a significant source of waste generation and reflects two conflicting trends. The overall production of harvested wood products, particularly sawnwood from hardwoods, increased 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. In 1940, the ratio of waste generated to wood and paper product produced was 52%. By 2013, this ratio had fallen to 22%.

The amount of wastes generated from the production of harvested wood products that are disposed to landfill depends critically on how much of the wastes are estimated to have been diverted to other disposal paths or uses including the quantities combusted for energy [19], the quantities of fibre used in the production of other products

19 Non-CO2 emissions associated with the combustion of HWP wastes are accounted for in the energy sector. CO2 emissions are reported as a memo item.

(paper) and the quantities disposed to aerobic treatment processes. Of these three possible alternative disposal options, there has been rapid growth in the disposal of wastes to aerobic treatment processes in recent years with a concomitant reduction in wood wastes going to landfill (Figure 7.5).

Figure 7.5 Estimated wood product wastes production, recycling, aerobic treatment processes and disposal to landfill - Australia: 1990-2013



Source: Refer to Table 7.6

Table 7.4 Paper consumption, waste generation and disposal: Australia

	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 landfill as share of total disposal
	kt C	kg C/head	kt C	kt C	kt C	kt C		
1940	190	26	200	245	27	204	0.14	0.83
1990	1,350	80	747	1,338	400	898	0.30	0.67
2000	1,904	100	1,034	1,839	947	837	0.51	0.46
2005	2,007	99	1,111	1,989	1,103	826	0.55	0.42
2008	2,142	100	1,175	2,094	1,529	502	0.73	0.24
2009	2,049	93	1,151	2,073	1,484	527	0.72	0.25
2010	2,000	90	1,120	2,031	1,610	361	0.79	0.18
2011	2,036	91	1,126	2,030	1,552	417	0.76	0.21
2012	1,912	84	1,081	1,957	1,591	308	0.81	0.16
2013	1,843	81	1,036	1,887	1,571	260	0.83	0.14

Source: DE estimates: derived from ABARES 2013, Department of National Development 1969, Jaakko Pöyry Consulting 2000, Recycled Organics Unit 2009. See Table 7.6.

Table 7.5 Wood product production, waste generation and disposal: Australia

	HWP production (a)	HWP waste generation	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 disposed to aerobic treatment	Share of HWP waste used in other products
	kt C	kt C					
1940	1,782	931	0.52	0.30	0.67	0.03	0.00
1990	3,914	1,036	0.26	0.37	0.45	0.03	0.15
2000	5,246	1,068	0.20	0.43	0.29	0.09	0.19
2005	5,928	1,175	0.20	0.37	0.36	0.10	0.17
2008	6,134	1,159	0.19	0.40	0.32	0.11	0.17
2009	5,628	1,073	0.19	0.45	0.26	0.11	0.18
2010	5,519	1,081	0.20	0.42	0.28	0.12	0.18
2011	5,502	1,043	0.19	0.40	0.28	0.13	0.19
2012	5,043	992	0.20	0.45	0.21	0.14	0.20
2013	4,326	950	0.22	0.43	0.22	0.14	0.21

(a) Includes waste generation but excludes roundwood log and woodchip exports.
Source: DE: derived from ABARES 2013, Department of National Development 1969, Jaakko Pöyry 2000. See Table 7.6.

Table 7.6 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	ABARES 2013; Jaakko Pöyry 2000, Department of National Development 1969.	Not applicable.	ABARES 2013; 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.I).	Not applicable.	End of useful life function specified in Jaakko Pöyry 2000 (See Appendix 7.I).
(3) Waste generation	Derived from (1) and (2).	Jaakko Pöyry 2000 (See Appendix 7.I).	Derived from (1) and (2).
Method of disposal			
Landfill	Balance of paper waste generation (3) and paper disposed through recycling, combustion and aerobic decay.	Balance of HWP production waste generation (3) and wastes disposed through recycling, combustion and aerobic decay.	Determined exogenously based on GHD (2008) and Hyder Consulting (2008).
Recycling	Source: ABARES 2013, Jaakko Pöyry 2000.	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 aerobic decay.
Combusted for energy / waste incineration	0% assumed combusted for energy or incineration.	Derived as the balance of wood and wood waste combusted by manufacturing industry (Source: BREE 2013a and ABARES 2013) and assumptions on combustion of wood. No data is available on waste incineration.	Combusted for energy: 5% of product disposal (see Appendix 7.I). Source: Jaakko Pöyry 2000. Zero percent of product disposal assumed to be incinerated (i.e. not for energy).
Aerobic treatment processes	3% of product assumed to decay due to aerobic processes based on expert judgement. Source: Jaakko Pöyry 2000.	Source: Recycled Organics Unit (2009). Prior to 1995, 3% of product assumed to decay due to aerobic processes. Source: Jaakko Pöyry 2000.	Decay assumed to be 0% based on expert judgement. Source: Jaakko Pöyry 2000.

The key data sources and assumptions made in relation to the estimation of the data presented in Table 7.4 and Table 7.5 are reported in Table 7.6. 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 aerobic treatment processes. This estimator ensures completeness and consistency with the estimates of the stock of harvested wood products presented in Appendix 7.I and is considered to produce robust estimates because of the high quality of the available data on apparent paper consumption (ABARES 2014a and the Department of National Development 1969) and paper recycling (ABARES 2014a). 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 (ABARES 2014a and the Department of National Development 1969) and on the combustion of wood and wood waste (BREE 2014). Data on the amount of wastes disposed to aerobic treatment processes is available from the Recycled Organics Unit of the University of New South Wales. The other important assumption set out in Table 7.6 concerns the percentage of wastes lost through incineration. No data is currently available on the amount of waste incinerated as opposed to combusted for energy. Obtaining more accurate data on this variable 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 assumption on incineration, indicating that there is limited risk of the estimates of waste disposed to landfill used in the inventory being underestimates.

Table 7.7 Additions and deductions from harvested wood products: 2013

	kt C
Additions to the HWP carbon stock	
Apparent consumption of HWP	3,445
Generation of HWP wastes	950
Total additions	4,395
Deductions from the HWP carbon stock	
Disposal to landfill	830
Disposal through combustion for energy/ waste incineration	526
Disposal through aerobic decay	192
Recycling/use in other products	1,856
Total deductions	3,404
Net increment in HWP stock	**992**

Combustion of HWP for energy reduces the amount of the HWP stock and is effectively recorded as a reduction in stock (or, equivalently, a source of emissions). In 2013, the reduction in carbon stock from combustion for energy of HWP and wastes generated from HWP production is estimated at

526 ktC. This source of emissions is effectively recorded within the HWP category. Non-CO_2 emissions from the combustion of these products are recorded in Fuel Combustion 1.A. Similarly, the disposal of HWP to landfill reduces the stock of product and is also effectively recorded as a reduction in stock (or source of emissions) against the HWP category. In 2013, the reduction in carbon stock from disposal to landfill is estimated at 830 ktC. Half of this carbon will also eventually be converted to methane in the landfills (effectively, the carbon is counted twice).

Back casting of total waste disposed to landfill

The data available from State Government agencies on total waste disposed to landfill does not extend to the period prior to 1990. Nor are there any possibilities for filling in the gaps with future surveys. In these circumstances, IPCC 2006 notes that a range of splicing and extrapolation techniques are available. The technique chosen to determine the historical time series was a surrogate-data technique where the drivers used to determine total waste to landfill were the amount of waste generated from paper consumption and the estimated amount of waste generated from the production of harvested wood products. These data were chosen because published datasets of production and consumption of these variables, which are closely related to disposal, were available back to 1936. The surrogate technique applied was to assume that the total waste to landfill is perfectly correlated with the sum of paper and wood wastes disposed to landfill for years prior to 1990. This assumption ensures that the more general underlying influences affecting waste generation impact these estimates since a) rising per capita incomes and rising population are reflected in rising demand for paper consumption and consequent waste generation and b) changes in production functions over time (improvements in efficiency) are reflected in the amount of waste generated in HWP.

For disposal data reported under the NGER (2009 onwards) system, information is available on the entire operational life of the landfills extending to the pre-1990 period. Where these disposal data available, they have been used. However, it must be noted that this represents only a small proportion of currently operating landfills.

Waste mixes disposed to landfill

Waste composition is determined in two ways. For landfills covered by the NGER (2009 onwards) system, their reported waste composition is used directly. Where these data are not available, country-specific waste mix percentages are used. These waste mix percentages are obtained as outlined below.

The base waste mix percentages are derived as a simple average of waste mixes presented in studies conducted by GHD (2008) and Hyder Consulting (2008), 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 7.8 Actual waste mix percentages change over time as the amount of wood waste and paper entering landfills vary – percentages for 2013 are reported in Table 7.88.

Table 7.8 Individual waste type mix: percentage share of individual waste streams disposed to landfill 2013

	Municipal Solid Waste	Commercial & Industrial	Construction & Demolition
Food	38.9%	21.5%	0.0%
Paper [(a)]	3.0%	4.3%	0.9%
Garden and Green	18.3%	4.5%	2.0%
Wood [(a)]	1.0%	6.5%	7.2%
Waste from HWP production [(a)]	0.0%	7.1%	0.0%
Textiles	2.2%	4.5%	0.0%
Sludge	0.0%	1.7%	0.0%
Nappies	4.4%	0.0%	0.0%
Rubber and Leather	0.7%	4.0%	0.0%
Inert (concrete, metal, plastics and glass, soil etc)	31.5%	45.8%	89.9%

Sources: Derived from GHD 2008 and Hyder Consulting 2008; (a) DE estimates based on data and assumptions in Table 7.5 and GHD 2008.

Table 7.9 Total waste and individual waste types disposed to landfill (kt): Australia

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	10,444	1,978	933	1,878	1,925	421	4,726
1990	16,505	3,000	2,227	1,321	1,787	726	7,445
2005	20,627	3,477	2,052	1,556	1,890	982	10,671
2008	21,875	4,011	1,249	1,732	1,885	1,151	11,847
2009	20,079	3,786	1,308	1,609	1,546	1,118	10,711
2010	19,996	3,866	898	1,679	1,594	1,122	10,837
2011	20,004	3,769	1,037	1,627	1,538	1,140	10,894
2012	18,628	3,891	765	1,566	1,331	1,163	9,912
2013	18,547	3,896	649	1,560	1,324	1,159	9,958

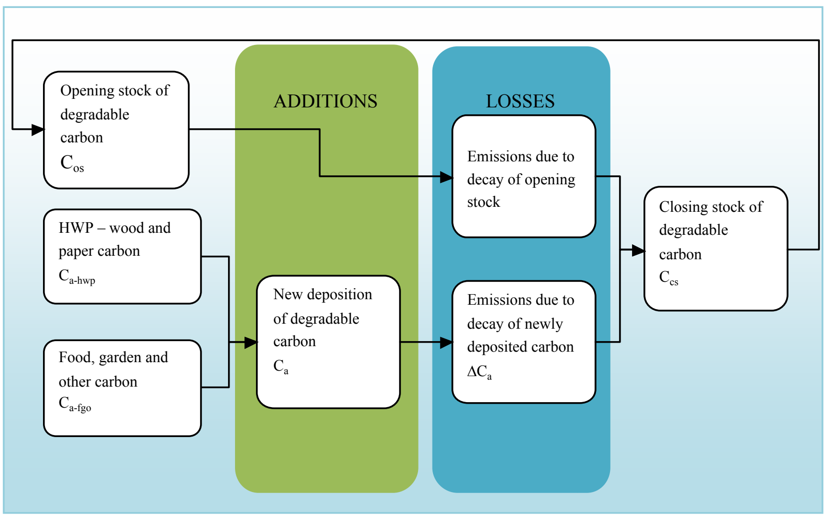
(a) State Government Agencies; (b) Department of Environment estimates.

7.3.4 Methodology

The Australian methodology for the estimation of emissions from solid waste disposal utilises the IPCC tier 2 FOD model presented in the Guidelines for National Greenhouse Gas Inventories (IPCC 2006).

The key parameters determining the amount of methane emissions are the fraction of degradable organic carbon in each individual waste type (DOC); the rate of decay assumed for each individual waste type (decay function 'k'); the fraction of degradable organic carbon that dissimilates through the life of the waste type (DOCf); the methane correction factor (MCF) and the amount of methane captured for combustion. The model is explained in detail in IPCC 2006. The 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 7.6.

Figure 7.6 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.

$C_{cs} = C_{os} - \Delta C_{os}$ (emissions lost from opening stock) $+ C_a - \Delta C_a$ (emissions lost from new deposition)

In Australia recent field work estimating methane generated at particular landfills (Bateman 2009, Dever *et al.* 2009 and Golder Associates 2009) has demonstrated that there is potentially a wide variation in methane generation rates across Australian landfills. In Australia, this is interpreted as principally reflecting:

- differences in waste composition at landfills, reflecting both the differing values of degradable organic carbon (DOC) of individual waste types and differing degradable organic carbon that is dissimitable (DOCf) values of individual waste types; and
- differences in the decay rate 'k' reflecting differences in waste composition, management regimes or local climatic conditions.

7.3.4.1 Degradable Organic Carbon

Values for the degradable organic carbon (DOC) content for each waste mix category used in the model are listed inTable 7.10. The source for these parameters is IPCC (2006).

Table 7.10 Key model parameters: DOC values by individual waste type

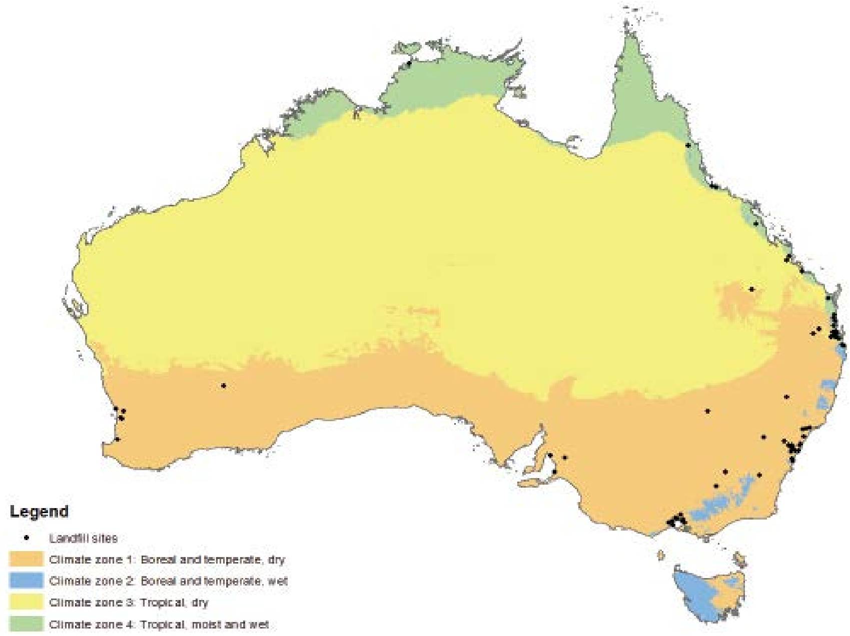
Waste Type (wet)	DOC
Food	0.15
Paper	0.40
Garden and Green	0.20
Wood and waste from HWP production	0.43
Textiles	0.24
Sludge	0.05
Nappies	0.24
Rubber and Leather	0.39
Other	-

Source: IPCC 2006.

7.3.4.2 Decay function values 'k'

The half-lives and associated 'k' values for each waste mix category applied in the FOD model are consistent with those provided in IPCC 2006.

Figure 7.7 Australian climate zones and major landfill locations.



Decay rate constants are applied to disposed waste in two ways. For landfills covered by the NGER system, the geographical location of the landfill is used to determine which of the 4 IPCC climatic zones is applicable. The distribution of the climate zones across Australia is illustrated in Figure 7.7. The map below has been produced on the basis of average monthly grids of rainfall, pan-evaporation and average temperature from Bureau of Meteorology records between 1970 and 2010.

For the proportion of disposed waste which is not covered by the NGER system, decay rate constants are assigned according to the 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 Bureau of Meteorology. The assumptions of climatic conditions for each State/Territory and 'k' values for each waste mix category are outlined in Table 7.11.

Table 7.11Key model parameters: 'k' values by individual waste type 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.

7.3.4.3 Fraction of degradable organic carbon dissimilated (DOCf)

DOC_f is an estimate of the fraction of carbon in waste that is ultimately degraded anaerobically and released from solid waste disposal site (SWDS) and reflects the fact the some carbon in waste does not degrade or degrades very slowly under anaerobic conditions (IPCC 2006,Vol 5 p3.13). Most countries (but not all) utilise the IPCC default factor 0.5 which is an average DOC_f value that is used for all putrescible waste types and which appears to be based on the results of one study in the Netherlands. On the use of country-specific DOC_f values the IPCC Good Practice Guidance states the following:

> *National values for DOC_f or values from similar countries can be used for DOC_f, but they should be based on well documented research.*

There is a growing body of research into the fraction of degradable carbon that is available for anaerobic decay from both Australia and overseas. There is evidence that for certain types of waste such as wood the IPCC default DOCf value of 0.5, which is an average value, may be an overestimate whilst for waste types such as food it may be an underestimate.

In the Australian context there has been an ongoing program of research into the decay of wood in landfill by researchers from the NSW Department of Primary Industries, the Cooperative Research Centre for Greenhouse

Accounting, the Research and Development Division of State Forests NSW and the Chemistry Centre of Western Australia.

This research program was initiated in 2001 when excavated wood samples taken from two sites at Sydney landfills were examined for the extent of decomposition (Gardner *et al.* 2004). The extent of loss of initial carbon from softwood and hardwood materials retrieved from the two landfills that had been closed for 19 and 29 years was found to be insignificant (4.1%). The tests showed slightly greater decay in the samples taken from the site closed for 19 years than the 29 year samples which was explained by the waste management practices at the two sites (one site had leachate recirculation whilst the other had an active methane extraction system in place).

Ximenes *et al.* (2008b) supplemented this work with further field-based research, extracting wood samples from a second Sydney landfill that had been closed for 46 years. Carbon loss from softwood and hardwood material retrieved from the third landfill from the site closed for 46 years was found to be 18% and 17% respectively.

As these investigations are field-based, the results reflect the prevailing conditions and waste management practices in the particular landfills under examination. Nevertheless, the results suggest that wood products are much more resistant to decay under anaerobic conditions than would be implied by the use of the average DOCf value of 0.5.

The Australian field-based results reflect decomposition over restricted time profiles. They reflect both the DOC_f applicable to the wastes types analysed, which represents the total decomposition of the waste under anaerobic conditions over very long term time horizons, but also the rate of decomposition, 'k', experienced for the period that the waste has been in place.

Estimates of DOC_f that are applicable to very long term time horizons (3-5 half lives) can be estimated from investigations into the carbon storage under anaerobic conditions of a range of waste types under laboratory conditions (Doorn and Barlaz 1995; Barlaz 1998, 2005 and 2008). This experimental work involves the testing of a range of waste types in reactors operated to obtain maximum methane yields. As the laboratory work optimises the conditions for anaerobic decay, the results can be considered as true estimates of the DOC_f value that would apply over very long time horizons. These estimates could also be considered to represent an upper limit of the decay processes found in landfills under anaerobic conditions over more restricted time horizons.

The results of the Barlaz work are presented in Table 7.12 which shows reported values for the initial carbon content and carbon remaining after decomposition and the derived DOC_f value.

Table 7.12 DOC_f values for individual waste types derived from laboratory experiments

Waste type	Initial total organic carbon (kg/dry kg)	Organic carbon remaining after decomposition (kg/dry kg)	DOC_f (A-B)/A
	A	B	
Newsprint	0.49	0.42	0.15
Office paper	0.4	0.05	0.88
Old corrugated containers	0.47	0.26	0.45
Coated paper	0.34	0.27	0.21
Branches	0.49	0.38	0.23
Grass	0.45	0.24	0.47
Leaves	0.42	0.3	0.28
Food	0.51	0.08	0.84

Source: Derived by Hyder Consulting 2009 in consultation with Morton Barlaz.

In research currently underway, Barlaz is continuing with the examination of further waste samples including softwood, hardwood, plywood and MDF as well as some Australian wood species. Preliminary results from these laboratory-based experiments broadly confirm the earlier result that the value for wood is significantly less than 0.5. The testing on the additional wood samples is not yet complete. However, the results are expected to be available in the near future. In addition to the examination of wood samples in the study currently underway, a range of Australian paper types have been examined. Preliminary results from this portion of the study are also broadly consistent with results obtained previously and again highlight the range of different DOC_f values observed for different paper types.

Overall, well documented research is available on DOC_f values for individual waste types both from laboratory conditions and from field tests conducted in Australia. The quality of the work conducted in Australia by Ximenes *et al.* 2008b has recently been recognised by the IPCC Emission Factor Database Editorial Board. This well documented research supports the use of DOC_f values for individual waste types for this inventory.

The *2006 IPCC Guidelines* offer further recommendations on the use of DOC_f values for individual waste mix types:

> *Higher-tier methodologies (tier 2 or 3) can also use separate DOCf values defined for specific waste types... The introduction of waste-type specific values for DOCf can introduce additional uncertainty into estimates where good waste composition data are not available. Therefore it is good practice to use waste type specific DOC_f values only when waste composition data are based on representative sampling and analysis.*

As outlined above, Australia's waste to landfill data is currently supplied by State and Territory agencies responsible for waste management. The data are collected under the various levy schemes in place in each jurisdiction and are disaggregated into MSW, C&I and C&D waste streams. For example, in NSW landfills are licensed under the *Protection of the Environment Operations Act* 1997 – as part of the licensing provisions, landfill operators are required to report on quantities of waste received at the landfill. Similar arrangements are in place in all jurisdictions. The waste mix percentages used to further disaggregate the waste streams are based upon a wide range of waste audits carried out across Australian landfills typically commissioned by local and State/Territory Governments.

To assess the quality of Australia's waste composition data and acceptability for use with individual waste type DOC_f values, a review was undertaken by an external expert (Guendehou 2010). Guendehou concluded that 'Australia should take advantage of the availability of good waste composition data to apply waste type specific DOC_f in order to improve the accuracy of the emissions estimate'.

Australia's waste type specific DOC_f values

Values of DOC_f for individual waste types that are appropriate for Australia have been selected based on well documented research on DOC_f values contained in Barlaz 1998, 2005 and 2008. These estimates provide an upper limit of an appropriate DOC_f value. The approach adopted, while conservative, is based on the recommendations of Guendehou (2010) after consultations with a range of experts in the industry GHD (2010), Hyder Consulting (2010) and Blue Environment (2010).

For wood products, Australia has selected a value of 0.23 to apply to all wood deposited in landfills in Australia based on the Barlaz estimate for 'branches'. This should be considered as an upper limit of the DOC_f values that are applicable to the anaerobic decay of Australian wood products as the research of Ximenes et al. 2008b and Gardner *et al.* 2004 indicates that a range of lower DOCf values may be possible depending on the type of timber and type of wood product. Ximenes *et al.* 2008b, for example, note that the use of the Barlaz result for 'branches' for timber and wood products could be refined as it is likely that true DOC_f values for certain wood products may be lower depending on the type of timber and wood product. This view was confirmed by Barlaz in the preparation of the 2008 inventory (Hyder Consulting 2009) and supported by GHD 2010. Future research may provide a basis for a review of this factor at some later time and, in fact, preliminary data from Barlaz (forthcoming) indicates that certain timber classes may be displaying much lower rates of degradation for a range of timber classes in ideal anaerobic conditions. However, until these results are available, the Barlaz 1998 result for branches represents the best possible estimate for the anaerobic decay of timber and wood products.

For food waste the DOC_f value of 0.84 reported in Table 7.12, based on the work of Barlaz 1998 has been used.

For paper, the Barlaz work translates into a range of DOC_f values, for four classes of paper types meaning that it is important to understand the types of paper waste entering the landfill waste system in order to assign the appropriate weights for each of the Barlaz results. Newsprint contains high levels of lignin, which inhibits decomposition in anaerobic conditions, while office paper contains almost no lignin and therefore experiences high levels of decomposition even under anaerobic conditions. In addition, the Barlaz paper classes are not exhaustive of all paper types. Allowance must be made for non-identified paper classes. In these cases, consideration must be given to the possible chemical composition of the paper and theoretical approaches to the estimation of methane potential.

Consequently, it was necessary to make use of available waste audit data to compile a weighted average DOC_f value for the "paper and cardboard" waste mix category. Based on paper waste composition data presented in GHD 2008 and Lamborn 2009, the proportions of paper types corresponding to the Barlaz DOC_f categories have been derived for Australian landfills (Table 7.14).

Given that the classes of paper analysed by Barlaz were not comprehensive, a DOC_f value is also required to be assumed for 'other' paper. One factor important to the analysis of decomposition under anaerobic conditions relates to the amount of cellulose and hemicellulose in the product (see for example, Lamborn 2009). In the case of the paper types analysed with DOC_f values, the reported cellulose and hemicellulose proportions in the product range from 51.7 for coated paper up to 91.3 for office paper (Barlaz 1998). For the classification of 'other' paper, the value of cellulose and hemicellulose reported by Lamborn 2009 is 72.0 – which is very much in the middle of the range reported for the waste paper types for which DOC_f values are available. Consequently, the assumption made is that the DOC_f for the 'other' paper is the weighted average of the paper types for which DOC_f values are available.

Table 7.13 Derivation of a weighted average DOC_f value for paper

Paper type	Composition (% of total paper in analysis) [a]	Cellulose and hemicellulose (%) [b]	DOC_f [c]
Newspaper	4%	54.6	15%
Office paper	11%	91.3	88%
Cardboard	58%	67.2	45%
Coated Paper	1%	51.7	21%
Other paper	25%	72.0	49%
Weighted average of above			**49%**

(a) Lamborn 2009, (b) Barlaz 1998, (c) Hyder consulting 2009, except for 'other paper'.

Micales and Skog (1996) published a range of methane potentials for a comprehensive list of paper types (based on data in Doorn and Barlaz 1995) which show that methane potentials range between 0.054 g CH4/g refuse for newspaper and 0.131 g CH4/g refuse for office paper. These results also suggest that the range of DOC_f values shown in Table 7.12 above derived from Barlaz data encompass the broad range of paper types that may be present in Australian landfills and the degradabilities observed in the experimental data.

For garden and park waste a DOC_f value of 0.47 based on the work of Barlaz 1998 has been used. This value assumes the upper estimate calculated by Barlaz for "leaves" and "grass". On this assumption, it represents a conservative upper limit on the likely true DOC_f value for this category.

For the remaining waste categories in the inventory the IPCC default value of 0.5 has been retained. This includes values for textiles, sludge, nappies, and rubber and leather which require additional research to be undertaken before waste type specific values are adopted.

The complete list of DOC_f values for each inventory waste mix type is presented in Table 7.14. As indicated in the QA/QC section, the weighted average DOC_f value for Australian landfills is estimated to be 62.1 for 2013.

Table 7.14 Key model parameters: DOC_f values by individual waste types

Waste type	DOC_f value
Food	0.84
Paper and paper board	0.49
Garden and park	0.47
Wood	0.23
Wood waste	0.23
Textiles	0.50
Sludge	0.50
Nappies	0.50
Rubber and Leather	0.50
Inert waste (including concrete, metal, plastic and glass)	0.00

7.3.4.4 Methane correction factor (MCF)

An important parameter for the emissions calculation is the methane correction factor (MCF) which is intended to represent the extent of anaerobic conditions in landfills. It is assumed that all *solid waste disposal on land* in Australia is disposed to well managed landfills, hence a methane correction factor of 1.0 has been applied to all years. Data from a Waste Management Association of Australia (WMAA 2007) survey on waste management practices undertaken in 2007 was reviewed for this inventory and considered to provide strong evidence that the landfills in Australia adopt management practices that are consistent with the IPCC characterisation of well-managed landfills. 71% of landfills, receiving an estimated 95% of waste, operate with some form of permanent cover. The balance of landfills are assumed to operate within the meaning of well-managed landfills, as defined by the IPCC. No comprehensive data are available to accurately characterise changes to management practices over time.

7.3.4.5 Delay time

The IPCC default delay time of six months (M =13) has been used to reflect the fact that methane generation does not begin immediately upon deposition of the waste. Under this assumption, and given that all waste is assumed to be delivered at the mid-point of the year, anaerobic decay is set to start, on average, on the first day of the year following deposition.

7.3.4.6 Fraction of decomposition that results in methane (F)

The IPCC default value of 0.5 is assumed for this inventory, reflecting the assumption that the decomposition of organic carbon under anaerobic conditions is equally split between the generation of methane and the generation of carbon dioxide.

7.3.4.7 Oxidation factor (OF)

The IPCC default value of 0.1 is assumed for this inventory, reflecting the proportion of methane generated by the decomposition of organic carbon under anaerobic conditions that is oxidised before the gas reaches the surface of the landfill.

7.3.4.8 Methane capture

Net emissions are derived after accounting for methane recovery undertaken at the landfill site. The quantity of methane recovered for flaring and power is based upon reported methane capture under the NGER system for 2009 onwards and industry survey for the years 1990-2008.

Methane capture reported by landfill gas capture companies is measured according to the gaseous fuels measurement provisions set out in the *NGER (Measurement) Determination*. Under these provisions, a range of options are available to reporters including indirect measurement on the basis of invoices or electricity dispatched or direct measurement at the point of consumption using gas measuring equipment operated in accordance with set standards. Under these reporting provisions, landfill gas companies must also specify whether the collected gas is combusted for power generation, flared or sent offsite for other uses.

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.

Emissions from the combustion of landfill gas for power generation are reported in the energy sector (1.A.1.a – public electricity and head production)

7.3.5 Emission Estimates

7.3.5.1 Methane

Additions to and losses from the pool of organic carbon in landfills including both degradable and non-degradable organic carbon from all waste types are presented in Table 7.15. Half of the carbon losses are assumed to result in the generation of methane (assuming that F, the share of carbon decay resulting in methane, is the IPCC default value of 0.5). The other half is assumed to be carbon dioxide and is effectively estimated when this carbon is deducted from the pool of carbon in the harvested wood product pool.

Table 7.15 Methane generation and emissions, Australia: 1990 to 2013

Year	Carbon additions to landfill (kt C)	Carbon loss (through emissions) (kt C)	Methane generated (Gg CH4) [a]	Methane capture (Gg CH4)	Net methane (Gg CH4)
1990	2,581	1,086	726	2	651
2000	2,607	1,096	747	129	543
2005	2,740	1,128	777	207	492
2008	2,481	1,115	791	205	507
2009	2,574	1,150	798	215	504
2010	2,386	1,159	799	204	515
2011	2,269	1,163	799	221	498
2012	2,281	1,159	798	272	445
2013	2,094	1,151	801	305	416

Source: DE estimates.
Note: (a) methane generated prior to oxidation.

7.3.5.2 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 *et al.* 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 and 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.

7.4 Source category 5.B biological treatment of solid waste

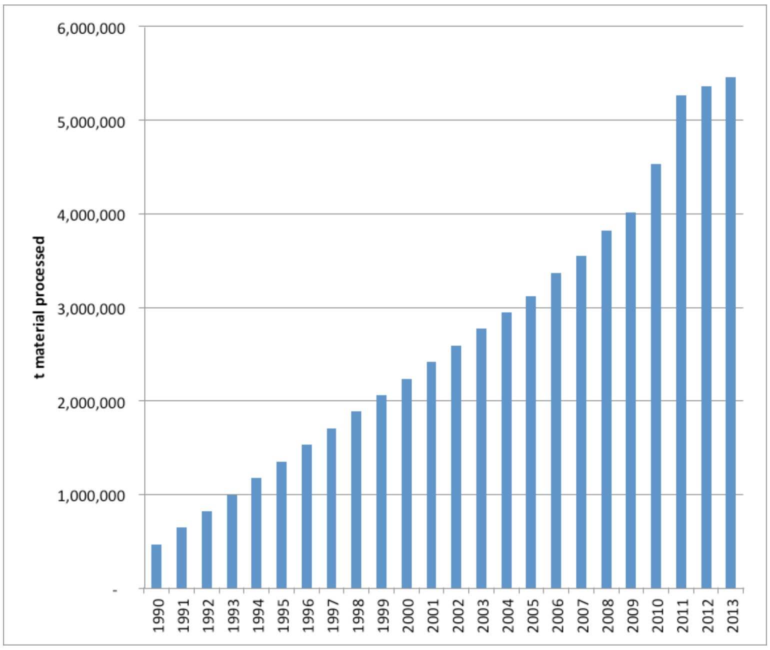
Emissions from the biological treatment of solid waste were 113 Gg CO_2-e in 2013.

Biological treatment of solid waste through processes such as windrow composting and enclosed anaerobic digestion is considered an emerging treatment pathway in Australia and one where a small amount of activity data has become available under the NGER system (2009 onwards) and through an annual industry survey. For this inventory, there is no anaerobic digestion being undertaken in Australia, however, it is expected that the use of these kinds of waste treatment processes will be taken up and reported on in coming years. This is based on more recent NGER facility level data now available.

Methodology

Australia has applied the tier 1 method from the *2006 IPCC Guidelines* to derive estimates of emissions based upon the total amount of material processed through composting and anaerobic digestion. Activity data are obtained from an annual industry survey undertaken by the Recycled Organics Unit at the University of New South Wales. Survey data cover the years 2004 to 2010 with extrapolation used to derive activity data for the years 1990 to 2003 (ROU various years). The time-series of quantities of waste material processed via composting is shown in Figure 7.8.

Figure 7.8 Quantities of material processed via composting 1990-2013



Choice of Emission Factors

Australia has adopted country-specific emission factors for CH_4 and N_2O emissions from composting based on research conducted by Amlinger (2008) covering the composting of bio-waste, loppings and home composting material. The emission factors are shown in Table 7.16.

Table 7.16 Composting emission factors (t CO2-e/t material processed) used in the Australian inventory

	CH4 emission factor (t CO2-e/t material processed)	N2O emission factor (t CO2-e/t material processed)
Composting	0.019	0.002

The country-specific emission factors have been drawn from the document *Update of emission factors for N_2O and CH_4 for composting, anaerobic digestion and waste incineration* (DHV 2010) which itself cites Amlinger 2008 as the source of its recommended emission factors. DHV 2010 presents a synthesis of all available research data covering emissions from the biological treatment of solid.

These emission factors are considered suitable for use in Australia's inventory due to the following:

1. Emission factors fall within the IPCC default ranges.

While the CH_4 and N_2O emission factors chosen are towards the lower end of the default range, it has been concluded by Alminger (2008) that values in excess of 0.065 t CO_2-e / t material processed probably indicate some kind of system mis-management such as insufficient aeration or mechanical turning. The mid-range IPCC default factors according to this conclusion would suggest a level of system mismanagement not thought to occur in Australia.

2. Waste types considered by Amlinger (2008) are representative of waste types commonly processed via biological treatment in Australia (namely bio-waste and greenwaste).

GHD 2010 cites typical materials treated by the various biological processes in Australia:

- Source separated garden organics;
- Source separated garden organic organics with biosolids;
- Source separated garden organics with food waste;
- Source separated garden organics with food waste and biosolids;
- Source separated food waste; and
- Mixed residual waste containing food waste and paper.

3. The technologies examined (windrow composting processes) are reflective of those commonly used in Australia. The Recycled Organics Unit identifies aerobic windrow composting as the dominant form of biological treatment of solid waste currently employed in Australia.

7.5 Source category 5.C incineration and open burning of solid waste

Emissions are estimated from the incineration of solvents and municipal and clinical waste. Incineration estimates include 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. Data on the incineration of solvents prior to 2004 is based on company data after which emissions from this source have been based on data estimated by the DE.

Carbon dioxide emissions from incineration of solvents are estimated by converting the volume of solvent incinerated (Litres) to the weight of solvent (using specific volume factor of 1229 L/t), deriving the energy content of the mass of solvent (using the energy content of 44 GJ/t), and using a carbon dioxide emission factor per petajoule of solvent (69.6 Gg/PJ).

Between 1990 and 1996, there were three incinerators receiving municipal solid waste. These were located in New South Wales and Queensland. All three 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 Queensland, New South Wales, South Australia and Western Australia. Data on the quantities of municipal solid waste incinerated are based upon published processing capacities of the three incineration plants prior to decommissioning. Data on the quantities of clinical waste incinerated have been obtained from a per-capita waste generation rate derived from data reported under the NGER (2009 onwards) system, by O'Brien (2006b) and an estimate of State population reported by the Australian Bureau of Statistics.

The quantity of CO_2 emitted as a result of the incineration of municipal and clinical waste is based upon the quantity of waste incinerated, the carbon content of the waste and the proportion of that carbon which is of fossil origin and the efficiency of the combustion process (oxidation factor). The country-specific fossil carbon content of municipal waste of 7% is based upon empirical data presented in NGGIC (1995) for incineration activities occurring in 1990. Of this 7% of fossil carbon in municipal waste, it is estimated that 80% of this carbon is combustible (NGGIC 1995). Emissions of N2O from the incineration of municipal solid waste are also estimated based on a country-specific emission factor of 0.00015 Gg of N_2O/Gg of waste taken from NGGIC (1995). The carbon content factors used in the emissions estimation are shown in Table 7.17. The 2006 IPCC guidelines do not provide default CH_4 and N_2O emission factors for the incineration of clinical waste and solvents. Accordingly, emissions of CH_4 and N_2O from this source are not estimated in the inventory.

Table 7.17 Parameters used in estimation of waste incineration emissions

	Municipal Solid Waste [(a)]	Clinical Waste [(b)]
Proportion of waste that contains fossil carbon	0.07	
Proportion of waste that is carbon		0.6
Proportion of fossil carbon containing products that is carbon	0.80	
Fossil carbon content as a proportion of total carbon		0.4
Oxidation factor	1	0.95

Sources: (a) NGGIC 1995, (b) IPCC 2000.

7.6 Source category 5.D wastewater treatment and discharge

7.6.1 Source Category Description

The anaerobic decomposition of organic matter in wastewater results in emissions of methane while chemical processes of nitrification and denitrification in wastewater treatment plants and discharge waters give rise to emissions of nitrous oxide.

Large quantities of CH_4 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 CH_4. 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 typically expressed in terms of Chemical Oxygen Demand (COD). COD is a measure of the oxygen consumed during total chemical oxidation (both biodegradable and non-biodegradable) of all material in the wastewater (IPCC 2006).

Nitrous oxide, N_2O, is also generated from municipal wastewater treatment plants. Nitrogen, which is present in the form of urea in urine and also as ammonia in domestic wastewater, can be converted to another compound—nitrate (NO_3). Nitrate is less harmful to receiving waters since it does not take oxygen from the water. The conversion of nitrogen to nitrate is usually done by secondary and tertiary wastewater treatment plants using special bacteria in a process called nitrification. Following the nitrification step some facilities will also use a second biological process, known as denitrification. Denitrification further converts the nitrogen in the nitrates to nitrogen gas, which is then released into the atmosphere. Nitrification and denitrification processes also take place naturally in rivers and estuaries. N_2O is a by-product of both nitrification and denitrification.

Municipal wastewater treatment plants in Australia treat a major portion of the domestic sewage and commercial wastewater, and a significant part of industrial wastewater. Approximately 5% of the Australian population is not connected to the domestic sewer and instead utilise on-site treatment of wastewater such as septic tank systems (WSAA 2005). Some industrial wastewater is treated on-site and discharged either to an aquatic environment or to the domestic sewer system which then feeds into a municipal wastewater treatment plant. A schematic diagram of the pathways for the treatment of wastewater in Australia is shown in Figure 7.9.

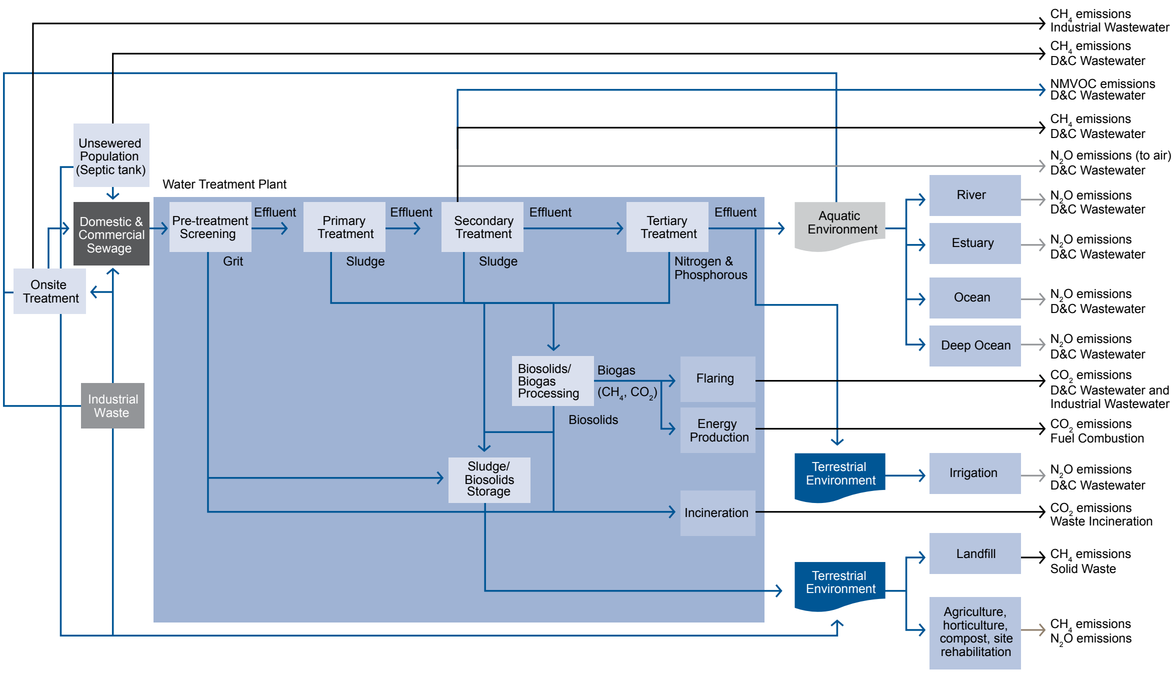
Consistent with IPCC *good practice*, methane emissions from effluent discharge to receiving waters is not reported in the inventory. Similarly, N_2O emissions from any form of industrial wastewater discharge and from discharge of municipal wastewater to ocean and deep ocean waters or used in irrigation are considered negligible and are not reported in the inventory.

Sludge removed from wastewater treatment plants is either disposed to landfill or can be further treated to produce biosolids and then used in a land application such as agriculture, horticulture, composting or site rehabilitation. Emissions of methane from disposal of sludge in a landfill are included in the solid waste sector. Emissions of nitrous oxide from land application are not included in the agriculture sector but are included within the wastewater sector itself.

Methane generated at wastewater treatment facilities may be captured and combusted for energy purposes or flared. The amount of CH_4 captured or flared is subtracted from the total CH_4 generated. Quantities of sludge biogas combusted for the production of energy and the associated non-CO_2 emissions are reported in the *stationary energy* sector.

Carbon dioxide emissions are not reported in the *wastewater treatment and discharge* sector except where they are derived from non-biomass sources of carbon.

Figure 7.9 Pathways for Wastewater



Wastewater treatment in Australia

A survey of the Australian wastewater industry was conducted by Department of Climate Change in 2009 (DCC 2009) to gather information on the operational characteristics of the wastewater sector including the location of discharge points, treatment levels, effluent volumes and type of aquatic environment to which the effluent flowed. The utilities which participated in the survey were selected on the basis of two criteria: that they serviced more than 50,000 customers and that these customers were living in coastal areas. The 11 utilities in Australia which met these criteria were asked to take part in the survey and 10 of these provided a response. In total, the respondents represented wastewater utilities which operate more than 100 facilities and treat wastewater for over 60% of the Australian population, all of which were living in coastal cities or communities.

More than three quarters of Australia's total population live in coastal areas. According to data from the Australian Bureau of Statistics (ABS 2009e), in 2009 the total Australian population was approximately 22 million people and around 16 million of these were living in capital cities and major centres on the coast of Australia. The residual population not covered by the DCC survey was approximately eight million people and it is estimated that at least three million of these people were also living on the coast of Australia.

The survey found that wastewater treatment facilities in Australia predominantly process wastewater to a secondary or tertiary treatment level before discharging the wastewater into an aquatic environment. However, some large facilities process the wastewater to a primary level only. As the treatment level increases from primary to secondary to tertiary, the number of unit operations used to treat the wastewater and the amount of organic matter and nitrogen removed before discharge to an aquatic environment increases.

Proportions of Australia's population connected to each treatment level are presented in Table 7.18 together with data for the residual population not covered by the survey which has been extrapolated from the survey data where possible. Nitrogen entering and leaving each treatment level is also shown in Table 7.18. The data clearly show that more complex treatment systems remove a greater proportion of nitrogen and thus generate more N_2O.

Table 7.18 Wastewater treatment plants by level of treatment

Wastewater Treatment Level	Population serviced		Annual quantity of nitrogen entering the system (tonnes of N)		Annual quantity of nitrogen in effluent discharged (tonnes of N) [c]	
Primary	2,761,280	13%	15,931	14%	16,169 [d]	66%
Secondary	6,960,027	32%	27,333	25%	6,170	25%
Tertiary	3,231,570	15%	15,849	14%	2,001	8%
Residual - Coastal Area	3,131,923 [a]	14%	18,040 [b]	16%	N/A	N/A
Residual - Inland Area	5,880,487 [a]	27%	33,872 [b]	31%	N/A	N/A
Total	**21,965,287**		**111,024**		**24,341**	

(a) Estimated using data from Australian Bureau of Statistics 2008a.
(b) Estimated using the IPCC default method and protein intake of 0.036 tonnes per year and IPCC default, 0.16 tonnes of nitrogen per tonne of protein.
(c)Total nitrogen discharged does not include the nitrogen discharged for the residual.
(d) Nitrogen discharged from primary treatment is greater than nitrogen received due to the lower removal rate for primary systems and the transfer of wastewater between plants.

The survey also examined the discharge practices of Australian wastewater facilities. The effluent discharged by wastewater treatment plants enters one of four classes of aquatic environment which are defined as follows:

- River means all waters other than estuarine, ocean or deep ocean waters;
- Estuarine waters means all waters (other than ocean or deep ocean waters):
    - (a) that are ordinarily subject to tidal influence, and
    - (b) that have a mean tidal range greater than 800 mm (being the average difference between the mean high-water mark and the mean low-water mark, expressed in millimetres, over the course of a year);
- Ocean means all waters except for those waters enclosed by a straight line drawn between the low-water marks of consecutive headlands and deep ocean waters; and
- Deep ocean means all waters, except for river and estuarine waters, that are more than 50 metres below the ocean surface.

Survey results shown in Table 7.19 indicate that the majority of effluent is discharged to either ocean or deep ocean outfalls. Only a small proportion of effluent from coastal treatment plants is discharged to a river environment (9%). However, when the non-coastal population is taken into consideration, this proportion becomes 29%, with the additional assumption that all wastewater generated from the non-coastal population is also discharged to river. The residual population also includes the population that is unsewered; estimated at approximately 5% of the Australian population. As the type of discharge environment is critical to emissions of N_2O from discharge, this information is also included in Table 7.19 and shows a large proportion of nitrogen discharged goes to deep ocean outfalls, typically more than two kilometres from the coastline at a depth of 50 metres or more.

Table 7.19 Effluent discharged from wastewater treatment plants by type of aquatic environment for 2008 and 2009

Type of aquatic environment	Population serviced		Annual volume of effluent discharged (kilolitres)		Annual quantity of nitrogen entering the plant (t)		Annual quantity of nitrogen in effluent discharged (t)	
River	2,564,463	12%	117,734,320	9%	11,545	10%	1,334	5%
Estuary	2,920,629	13%	187,480,682	14%	16,862	15%	1,775	6%
Ocean	4,405,912	20%	385,746,932	29%	23,055	20%	6,376	22%
Deep Ocean	3,015,430	14%	360,797,519	27%	17,601	15%	16,562	57%
Residual - Coastal Area	3,178,366 [a]	14%	N/A	N/A	18,307 [b]	16%	N/A	N/A
Residual - Inland Area	5,880,487 [a]	27%	269,972,736	20%	28,384 [b]	25%	3,162 [c]	11%
Total	**21,965,287**		**1,321,732,189** [d]		**115,756**		**29,210** [d]	

(a) Estimated using data from Australian Bureau of Statistics 2008a.
(b) Estimated using the IPCC default method and protein intake of 0.036 tonnes per year and IPCC default, 0.16 tonnes of nitrogen per tonne of protein
(c) Data value estimated from extrapolation of survey data for river discharge
(d) Total effluent and nitrogen discharged does not include the nitrogen discharged for the residual coastal population.

Sludge treatment and disposal practices were also examined in the survey. Results show that approximately 87% of the nitrogen in sludge transferred out of treatment plants was reported as being used in a land application and 13% was reported as being sent to landfills. The sludge generated by the residual population not covered by the survey has been estimated by extrapolating the data from the survey using a per-capita sludge generation value. Emissions from sludge sent to landfills are included in the solid waste sector while emissions from biosolids (treated sludge) used in a land application are included in wastewater treatment.

Table 7.20 Survey data for sludge reuse and disposal in 2008 and 2009

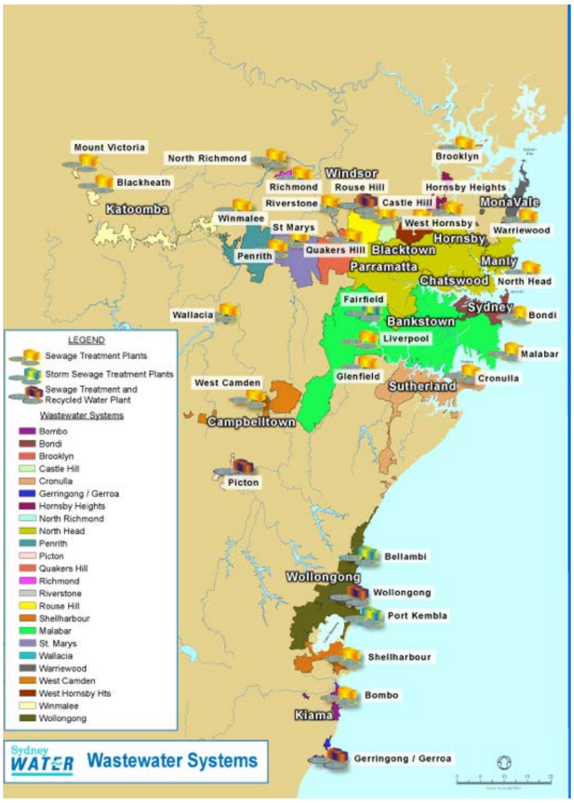
	Nitrogen (t)	% Contribution
Sludge to Landfill	1,435	13%
Sludge Reused in Land Application	5,494	49%
Residual Population - Sludge	4,336 (a)	38%
Total	**11,264**	

(a) Data value estimated from extrapolation of survey data for sludge

Sectoral snapshot: Sydney Water's effluent discharge Sydney Water Corporation is Australia's largest wastewater utility, with around 30 facilities servicing approximately 20% of Australia's population mainly living in the cities of Sydney and Wollongong. In addition to providing annual reports on each facility to the New South Wales state government, Sydney Water also publish information about their operations on their website at www.sydneywater.

com.au. A map of Sydney Water's operations is shown in Figure 7.10 and information made available on their website has been summarised in Table 7.21 below. The data in Table 7.21 shows that 17 of Sydney Water's facilities discharge into a river, however, most of the effluent discharged by volume, approximately 87%, enters ocean and deep ocean waters.

Figure 7.10 Sydney Water Wastewater Systems



Source: Sydney water

Table 7.21 Sydney Water Corporation Wastewater Treatment Plants 2008

	Discharge Type	Discharge Point	Level of Treatment	Total volume of treated wastewater discharged to the waterway (million litres)	Estimated population Serviced	Total discharge load to waterway (kg)	
						BOD	Total nitrogen
Inland sewage treatment plants							
St Marys	River	South Creek (a tributary of South Creek)	Tertiary treatment	14,829	139,700	57,925	63,824
Quakers Hill	River	South Creek (Breakfast Creek, a tributary of Eastern Creek)	Tertiary treatment	13,816	144,400	36,693	64,606
Riverstone	River	South Creek (Eastern Creek, a tributary of South Creek)	Tertiary treatment	743	8400	1,532	5,796
Brooklyn	River	Hawkesbury River at Kangaroo Point	Tertiary treatment	14	500	36	127
West Hornsby	River	Waitara Creek, a tributary of Berowra Creek	Tertiary treatment	5,210	53,500	9,876	21,645
West Camden	River	Matahill Creek, a tributary of the Nepean River	Tertiary treatment	3,913	49,700	13,156	49,545
North Richmond	River	Redbank Creek, a tributary of the Hawkesbury River	Tertiary treatment	341	3,760	886	2,005
Richmond	River	Discharging mainly to irrigation schemes for a local university campus and golf course. Excess flows are discharged to an inland waterway (Rickabys Creek).	Tertiary treatment	391	7,800	675	1,671
Winmalee	River	Unnamed tributary of the Nepean River	Tertiary treatment	6,792	56,300	22,005	66,220
Hornsby Heights	River	Calna Creek, a tributary of Berowra Creek	Tertiary treatment	2,496	28,300	6,058	7,826
Rouse Hill	River	Second Ponds Creek, a tributary of Cattai Creek (partial discharge only)	Tertiary treatment plant and recycled water plant	4,355	63,100	6,168	31,662
Castle Hill	River	Cattai Creek	Tertiary treatment	3,134	24,900	13,157	46,805
Penrith	River	Boundary Creek, a tributary of the Nepean River	Tertiary treatment	9,541	96,800	18,776	39,799
Wallacia	River	Warragamba River	Tertiary treatment	242	2,670	721	1,351

	Discharge Type	Discharge Point	Level of Treatment	Total volume of treated wastewater discharged to the waterway (million litres)	Estimated population Serviced	Total discharge load to waterway (kg)	
						BOD	Total nitrogen
Blackheath	River	Hat Hill Creek, a tributary of the Grose River	Tertiary treatment	424		1,676	10,983
Mount Victoria	River	Fairy Dell Creek, a tributary of the Cox's River	Tertiary treatment	72		843	885
Gerringong Gerroa	Recycled or to wetland	Treated wastewater is mainly discharged to an irrigation scheme for a local dairy farm.	Tertiary treatment		11,000	326	201
Coastal sewage treatment plants							
Wollongong (incl. Bellambi and Port Kembla STPs)	Ocean	Reuse at Bluescope steelworks with remainder discharging to the ocean via an extended outfall one kilometre from the shoreline	Tertiary treatment	21,238	199,000	142,551	377,149
Shellharbour	Ocean	Ocean via a nearshore outfall (at Barrack Point).	Secondary treatment	6,681	60,000	29,557	121,904
Bombo	Ocean	Ocean via a shoreline outfall at the headland north of Bombo Beach	Secondary treatment	1,372	13,300	7,212	11,683
North Head	Deep Ocean	Ocean Outfall - The outfall discharges 3.7 km from the shoreline at 65 m maximum water depth	Primary treatment	138,623	1,240,000	34,096,767	6,816,185
Malabar (incl. Liverpool, Glenfield and Fairfield STPs)	Deep Ocean	Ocean Outfall - outfall discharges 3.6 km from the shoreline at 82 m maximum water depth	Primary treatment	185,415	1,690,000	38,204,663	7,669,426
Bondi	Deep Ocean	Ocean outfall 2.2 km from the shoreline at 63 m maximum water depth	Primary treatment	45,256	480,000	9,441,442	2,218,050
Cronulla	Ocean	Ocean via a shoreline outfall at Potter Point	Tertiary treatment	26,930	200,000	84,719	551,882
Warriewood	Ocean	Ocean via a shoreline outfall at Turimetta Head	Secondary treatment	6,878	59,000	71,445	216,595
TOTAL (for all plants)				**498,782**	**4,647,335**	**82,268,865**	**18,397,999**

Waste

7.6.2 Domestic Wastewater (5.D.1) Methodology

7.6.2.1 Methane Emissions from Wastewater Treatment at Municipal Wastewater Treatment Plants (MWTPs)

Methane emissions from the treatment of wastewater at municipal wastewater treatment plants are estimated according to the default method set out in The IPCC *Good Practice Guidance* which relates emissions to the total quantity of organic waste treated at the MWTP. The emission factors applied to this quantity of organic waste are derived from a consideration of the type of treatment process used at the MWTP and the degree to which the organic waste is treated anaerobically.

Activity data: Organic waste in wastewater

Quantities of organic waste in wastewater treated at individual MWTPs have been obtained under the NGER system (2009 onwards) and used for the first time in this inventory. Around 60% of facilities reporting under the NGER system (numbering 75 in total and servicing around 60% of Australia's population) measured the quantity of COD entering their facility directly. The weighted average per-capita COD entering these facilities is 0.06426 tonnes of COD per person per year.

For the remainder of the category's facilities, a country-specific value of 0.0585 tonnes of COD per person per year (NGGIC 1995) was used for the amount of organic waste in wastewater received at their sites.

Utilities reporting under the NGER system are also required to report the quantities of COD leaving their facility in effluent and treated in the form of sludge. Sludge refers to the solids generated in the wastewater treatment process. All wastewater treatment plants produce sludge requiring disposal. Sludge generated in Australia is often treated in sludge lagoons, sludge drying beds or anaerobic digesters. Treatment 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 applied to the sludge. Biosolids are the product of sludge treatment suitable for use in land applications. Emissions from application of biosolids to land are included in the agriculture sector. Sludge and biosolids may also be sent to landfill. Emissions arising from the decomposition of sludge disposed to landfill are included in the solid waste sector.

As with the COD entering the facilities, NGER facility-specific data on COD sludge leaving the facility has been used where this variable has been measured directly. Where this data was unavailable, a country-specific fraction of COD removed and treated as sludge of 0.54 has been applied (NGGIC 1995).

Methodology

Emissions generated from the treatment of COD in wastewater are estimated according to the following equation:

$$CH_{4(t)} = (COD_{in} - COD_{sl} - COD_{out}) * EF_t$$

Where

$CH_{4(t)}$ is the estimated CH_4 emissions from the treatment of sewage at wastewater plants

COD_{in} is the amount of COD input entering into wastewater treatment plants

COD_{sl} is the amount of COD treated separately as sludge

COD_{out} is the amount of COD effluent discharged from wastewater treatment plants into aquatic environments

EF_t is the emission factor for wastewater treated by wastewater plants.

Emissions generated from the treatment of sludge are estimated according to the following equation:

$$CH_{4(t)} = (COD_{sl} - COD_{trl} - COD_{tro}) * EF_{sl}$$

Where

$CH_{4(t)}$ is the estimated CH4 emissions from the treatment of sewage at wastewater plants

COD_{sl} is the amount of COD treated separately as sludge

COD_{trl} is the amount of COD as sludge removed and sent to landfill

COD_{tro} is the amount of COD as sludge removed and to a site other than landfill

EF_{sl} is the emission factor for sludge treated by wastewater plants.

Under the NGER system reporting provisions, wastewater facilities must characterise the type of treatment process used in terms of the fraction of COD (as both sludge and wastewater) treated anaerobically. This parameter is defined as the methane conversion factor (MCF). The 2006 IPCC default MCF values and the definition of the corresponding treatment processes associated with these defaults in Australia are shown in Table 7.22. Facilities reporting under the NGER system select the most appropriate MCF value for their operational circumstances.

Table 7.22 MCF values listed by wastewater treatment process

Classes of wastewater treatment in 2006 IPCC Guidelines	MCF Values	Applicable Wastewater Treatment Processes
Managed Aerobic Treatment	0.0	• Preliminary treatment (i.e. screens and grit removal) • Primary sedimentation tanks (PST) • Activated sludge processes, inc. anaerobic fermentation zones and anoxic zones for biological nutrient removal (BNR) • Secondary sedimentation tanks or clarifiers • Intermittently decanted extended aeration (IDEA), intermittently decanted aerated lagoons (IDAL) and sequencing batch reactors (SBR) • Oxidation ditches and carrousels • Membrane bioreactors (MBR) • Mechanically aerated lagoons • Trickling filters • Dissolved air flotation • Aerobic digesters • Tertiary filtration • Disinfection processes (e.g. chlorination inc. contact tanks, ultraviolet, ozonation) • Mechanical dewatering (e.g. centrifuges, belt filter presses)
Unmanaged Aerobic Treatment	0.3	• Gravity thickeners • Imhoff tanks
Anaerobic Digester / Reactor	0.8	• Anaerobic digesters • High-rate anaerobic reactors (e.g. UASB)
Anaerobic Shallow Lagoon (< 2 m deep)	0.2	• Facultative lagoons • Maturation / polishing lagoons • Sludge drying pans
Anaerobic Deep Lagoon (> 2 m deep)	0.8	• Sludge lagoons • Covered anaerobic lagoons

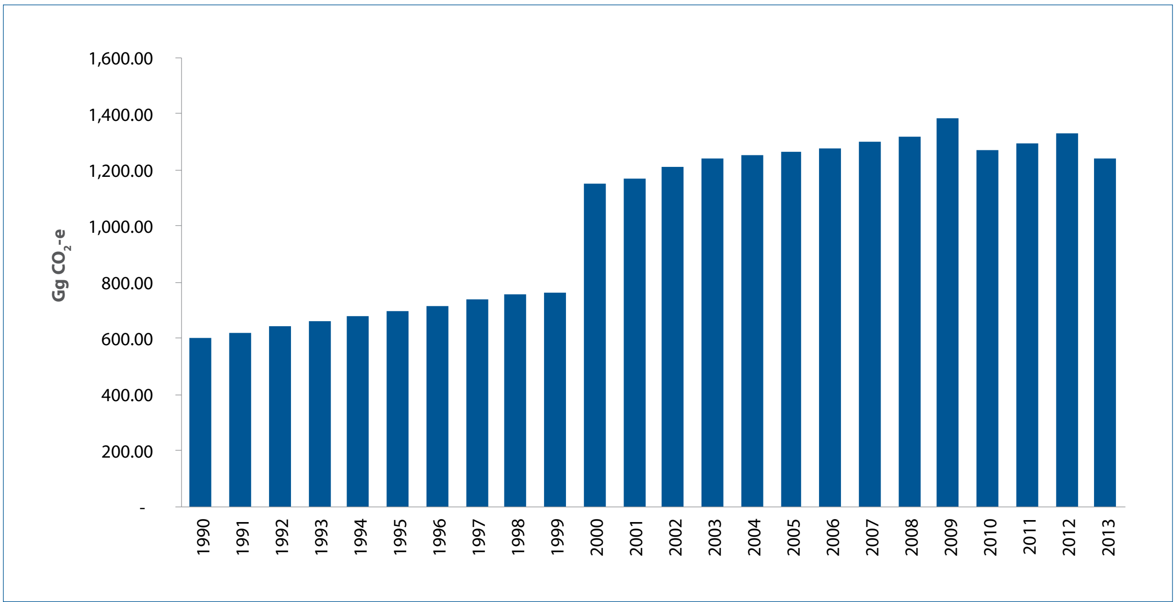
Source: WSAA 2011

Emission factors for each facility for wastewater and sludge are derived using equation 6.2 in the IPCC *Good Practice Guidance*. The IPCC default maximum methane producing capacity (B_o) of 0.25 kg CH_4/kg COD is used for all facilities.

Methane Capture

Methane recovered for combustion for energy or flared is deducted from the estimated methane generated and is based on directly measured quantities of methane captured for combustion and flaring reported under the NGER system (2009 onwards)for the years 2009 onwards. For 1990-2008, recovery is based upon a consideration of historical changes in methane capture capacity at individual wastewater treatment plants. A capture time-series for each wastewater utility has been established based on capture rates for 1990 reported in NGGIC 1995 and on subsequent reported commissioning of cogeneration plants, odour control system upgrades, and general plant capacity upgrades. Figure 7.11 shows the time-series for methane capture from domestic and commercial wastewater treatment. The significant increase in capture from the year 2000 corresponds to an improvement in capture capacity due to the commissioning of cogeneration facilities at a number of key wastewater treatment facilities serving particularly large populations. The small decline in capture in 2010 reflects a combination of changes to treatment processes (i.e. a shift to aerobic treatment) and reported declines in flaring and combustion of sludge biogas for energy production.

Figure 7.11 Methane capture from domestic and commercial wastewater treatment 1990 – 2013



No data is available on the precise split of methane recovery between wastewater and sludge treatment. For the purposes of reporting in table 5.B.s1 of the CRF table, methane recovery is allocated between wastewater and sludge such that emissions generated from the treatment of sludge are captured and the balance of reported capture is then allocated to wastewater treatment.

Choice of emission factor

There is a proportion of the wastewater treatment sector where no facility-specific data is available under NGER. The choice of parameters applicable to the residual portion of the sector was made in accordance with the decision tree described in Section 1.4.1.

As treatment processes employed at individual facilities are highly technology specific, it was not considered reasonable to extrapolate the factors obtained from NGER data to the facilities in the residual portion of the sector. Consequently, the per-capita COD and region-specific MCF values from NGGIC 1995 were used for 2009 for the residual of the category where no facility-specific data under NGER was available.

Time-series consistency

The use of NGER data has required careful consideration of time-series consistency issues. Facility-level activity data and emission factors are available from 2009 onwards. In order to preserve time-series consistency, facility-level activity data obtained under NGER has been back-cast as a fixed proportion of total population serviced in each state. Constant facility level MCF values and the proportion of methane generated that was captured in 2009 have been used with the back-cast activity data. This approach to maintaining time series consistency was based on the consideration that the larger-scale facilities covered by NGER utilise well established infrastructure and treatment processes that have not undergone significant changes since 1990.

The residual portion of the sector, for which no NGER facility-specific data is available, has been handled as described above for the entire time-series.

7.6.2.2 Methane Emissions from On-Site Domestic and Commercial Wastewater Treatment

The IPCC *good practice* default method for estimating methane emissions is used to estimate 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 (ABS 2009e) and WSAA data (WSAA 2005). It is assumed that each person in unsewered areas in Australia produces 0.0585 tonnes of COD per person per year (NGGIC 1995). The amount of COD that settles out as solids and undergoes anaerobic decomposition (MCF) is assumed to be 15%, which is the IPCC default fraction for total urban wastewater (IPCC Vol. 3 1997). The IPCC good practice default emission factor of 0.25 kg CH_4/kg COD is used.

Sludge is also generated by on-site domestic and commercial wastewater treatment. Septic tank systems must be emptied occasionally of the sludge that accumulates inside the system. This sludge is typically transferred to a municipal wastewater treatment facility for further treatment.

7.6.2.3 Nitrous Oxide Emissions from Domestic and Commercial Wastewater Treatment

The methodology used to estimate N_2O emissions from domestic and commercial wastewater treatment utilises a detailed IPCC good practice methodology and comprises estimates for emissions from sewage treatment at a wastewater plant; emissions from discharge of effluent into aquatic environments; and emissions from disposal of treated sludge to land.

$$\text{Total } N_2O\text{-}N = N_2O_{(t)}\text{-}N + N_2O_{(d)}\text{-}N + N_2O_{(l)}\text{-}N$$

Where

N_2O-N is the estimated N_2O emissions from domestic and commercial wastewater treatment

$N_2O_{(t)}$-N is the estimated N_2O emissions from sewage treatment at a wastewater plant

$N_2O_{(d)}$-N is the estimated N_2O emissions from discharge of effluent

$N_2O_{(l)}$-N is the estimated N_2O emissions from application of treated sludge to land

N_2O emissions from sewage treatment at wastewater treatment plants

The emissions of N_2O from sewage treatment at wastewater treatment plants are estimated using the following equation:

$$N_2O_{(t)}\text{-}N = (N_{in} - N_{out} - N_{trl} - N_{tro}) * EF_6$$

Where

$N_2O_{(t)}$-N is the estimated emissions from the treatment of sewage at wastewater plants

N_{in} is the amount of nitrogen input entering into wastewater treatment plants

N_{out} is the amount of nitrogen effluent discharged from wastewater treatment plants into aquatic environments

N_{trl} is the amount of nitrogen removed from wastewater treatment plants as sludge and disposed to landfill

N_{tro} is the amount of nitrogen removed from wastewater treatment plants as sludge and disposed at a site other than landfill (reused in land applications) and

EF_6 is the emission factor for sewage treated by wastewater plants

The total nitrogen input entering wastewater treatment plants for Australia in 2009 is obtained from facility specific measurements under NGER and, in addition, DCC 2009 yielded nitrogen treatment and discharge data for a group of utilities not captured under NGER. In total, facility level data obtained under NGER and DCC 2009 covered 108 facilities.

Estimates of the remainder of the nitrogen entering the national system is based on the residual population not covered by the facilities reporting under NGER or DCC 2009 and the average nitrogen input received by the wastewater plants per person serviced by the plants derived from the NGER system (2009 onwards)and DCC 2009 facility data. Together with the IPCC good practice assumption for the fraction of nitrogen in protein, 0.16 kg N/kg protein, the facility level data translates into a per capita protein consumption level of 32.8kg per person per year in 2013.

Estimates of nitrogen leaving the system as effluent or as sludge disposed to landfill or to a land application, N_{out}, N_{trl} and N_{tro} have also been obtained by facility under the NGER system and DCC (2009).

The emission factor for the estimation of N2O emissions from wastewater treatment, EF_6, is the IPCC good practice default, 0.01 kg N_2O-N/kg N.

N_2O emissions from discharge of effluent

The effluent discharged into an aquatic environment may enter directly into a river, estuary, ocean surface waters or deep ocean environment depending on the location of the wastewater outfall of each treatment plant. As extensive facility-level information has been collected from verifiable sources on the quantities of nitrogen discharged by location of outfall, Australia is able to use a more detailed country-specific method rather than the IPCC tier 1 method while using IPCC (1997) default factors available for each aquatic receiving environment.

The emissions of N_2O from the discharge of effluent are estimated using the following equation:

$$N_2O_{(d)}\text{-}N = N_{outr} * (EF_{5\text{-}r} + EF_{5\text{-}e}) + N_{oute} * (EF_{5\text{-}e})$$

Where

$N_2O_{(d)}$-N is the emissions from discharge of effluent

N_{outr} is the amount of nitrogen discharged into rivers which then flows into an estuary

N_{oute} is the amount of nitrogen discharged into estuaries

$EF_{5\text{-}r}$ is the emission factor for rivers

$EF_{5\text{-}e}$ is the emission factor for estuaries

The amount of nitrogen discharged by aquatic environment for 2013 is obtained by facility under the NGER system and DCC 2009.

The IPCC good practice default initial emission factors are 0.0075 kg N_2O-N/kg N for wastewater discharged into rivers ($EF_{5\text{-}r}$) and 0.0025 kg N_2O-N/kg N for wastewater discharged into estuaries ($EF_{5\text{-}e}$) (IPCC good practice 4.73). For wastewater discharged into rivers, the final emission factor is cumulative, ($EF_{5\text{-}r}$ + $EF_{5\text{-}e}$), as it is assumed that the wastewater passes from the river system, through the estuaries and then into the sea. For wastewater discharged directly into an estuary, only ($EF_{5\text{-}e}$) is applied.

While the IPCC *Guidelines* state that nitrous oxide emissions resulting from sewage nitrogen are estimated from 'input of sewage nitrogen to rivers and estuaries' (IPCC 1997 page 4.109) it also states that no methodology is provided for 'N_2O from nitrogen exported to the continental shelf region' (IPCC 1997 page 4.108). Consequently, it is considered that there is no IPCC default method available for the estimation of emissions from effluent discharged directly to ocean waters. Nor is there any empirical literature available on emissions from disposal to ocean waters in Australia - such a study would be prohibitively expensive at this time. The results of the limited number of studies conducted that relate to ocean bodies outside of Australia are not considered appropriate to Australian marine conditions. They are, nonetheless, reviewed in the QA-QC section of this Chapter.

Ocean waters are defined to include only those bodies of water that are beyond the straight line drawn between the low-water marks of consecutive headlands so that waters within headlands, such as bays and basins, are included as part of the estuarine waters. Consequently, the delineation of ocean waters is considered conservative.

Table 7.23 IPCC emission factors for disposal of effluent by type of aquatic environment

Type of Aquatic Environment	Emission factor for initial disposal
River (EF5-r).	0.0075 kg N2O-N/kg N
Estuary (EF5-e).	0.0025 kg N2O-N/kg N

Source: IPCC (1997) page 4.110.

N2O emissions from the application of treated sludge to land

The emissions of N_2O from the application of treated sludge to land is estimated using the following equation:

$$N_2O_{(l)}\text{-}N = N_{tro} * EF_7$$

Where

$N_2O_{(l)}$-N is the emissions from treated sludge applied to the land

N_{tro} is the amount of nitrogen removed as treated sludge and applied to the land

EF_7 is the emission factor for treated sludge applied to land

The amount of nitrogen applied to land is obtained by facility under the NGER system (2009 onwards)and DCCEE (2009b). The emission factor for the application of treated sewage to land is 0.009 kg N2O-N/kg N applied and is consistent with the N_2O emission factors for manure applied to crops and pastures (Bouwman *et al.* 2002). Emissions from the application of sludge to agricultural land are reported under agricultural soils (4.D) consistent with good practice guidance.

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.

7.6.3 Industrial Wastewater (5.D.2) Methodology

Technologies for dealing with industrial wastewater in Australia are varied. Some industrial wastewater 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.

The methodology to determine the amount of CH_4 generated from industrial wastewater is based on IPCC 2000 and focuses on the 9 industrial sectors which are considered to generate the most significant quantities of wastewater in Australia:

- Dairy production;
- Pulp and paper production;
- Meat and poultry processing;
- Organic chemicals production;
- Sugar production;
- Beer production;
- Wine production;
- Fruit processing; and
- Vegetable processing.

Organic waste in wastewater

Quantities of organic waste in wastewater treated at industrial facilities have been obtained under the NGER system for 2009 onwards. Where available, the quantity of COD treated at each facility has been taken from direct measurements reported under the NGER system. Where facility-specific data under the NGER system are unavailable, estimates are based on country-specific wastewater and COD generation rates shown in Table 7.24.

NGER data are used where industry coverage is considered sufficient to provide a representative picture of wastewater treatment practices in a given industry. In the 2015 inventory submission, NGER data covering the pulp and paper, beer and sugar, dairy, meat and poultry, wine, fruit and vegetables industries are used.

Table 7.24 Country-specific COD generation rates for industrial wastewater, 2013

Commodity	Wastewater generation rate (m^3 wastewater/ t commodity produced)	COD generation rate (kg COD/m^3 wastewater generated)
Dairy	5.7	0.9
Pulp and Paper	26.7 [(b)]	0.4
Meat and Poultry	13.7	6.1
Organic Chemicals	67.0 [(a)]	3.0
Sugar	0.4	3.8
Beer [(c)]	C	C
Wine	23.0 [(a)]	1.5
Fruit	20.0	0.2
Vegetables	20.0	0.2

Source: O'Brien 2006a and NGER 2013 unless otherwise stated. (a) NGGIC 1995, (b) Australian Plantation Products and Paper Industry Council 2006, (c) facility-level parameters obtained for beer production under the NGER system are confidential.

Choice of methane correction factor

Emission factors for each facility for wastewater and sludge are derived using equation 6.2 in the IPCC *Good Practice Guidance*. The IPCC default maximum methane producing capacity (B_o) of 0.25 kg CH_4/kg COD is used for all facilities.

Under the NGER system reporting provisions, industrial wastewater facilities must characterise the type of treatment process used in terms of the fraction of COD (as both sludge and wastewater) treated anaerobically. This parameter is defined as the methane conversion factor (MCF). As with COD, data on facility-specific MCF values at industrial wastewater facilities are available for the airy, paper, meat and poultry, sugar, beer, wine, fruit and vegetable processing industries. Country-specific values outlined in Table 7.24 have been used by NGER reporters who have not taken site-specific measurements based on data in O'Brien (2006a) or NGGIC (1995).

Table 7.25 Methane conversion factors for industrial wastewater emissions, 2013

Commodity	MCF wastewater	MCF Sludge
Dairy	0.4	0.3
Pulp and Paper	0.0	0.7
Meat and Poultry	0.4	0.2
Organic Chemicals	0.1 (a)	0.2
Sugar	0.3	0.2
Beer (b)	C	C
Wine	0.3	0.3
Fruit	1	0.2
Vegetables	1	0.2

Source: NGER 2013 unless otherwise stated. (a) NGGIC 1995, (b) facility-level parameters obtained for beer production under the NGER system are confidential.

7.6.3.1 Methane Emissions from Disposal of Sludge Generated by Industrial Wastewater Treatment

A proportion of the COD generated in the industrial wastewater is ultimately treated as sludge. Quantities of COD treated as sludge have been obtained for the dairy, paper, meat and poultry, sugar, beer, wine, fruit and vegetable processing industries from the NGER system. For the organic chemicals, a constant fraction of COD of 0.15 is assumed to be treated separately as sludge (NGGIC 1995).

Methane Capture

Estimates of the quantities of methane captured have been obtained from the NGER system for dairy, paper, meat and poultry, sugar, beer, wine, fruit and vegetable processing facilities for 2009 onwards and derived from facility-level data in O'Brien (2006a) and NGGIC (1995) for the years 1990-2008. For organic chemicals for which NGER data has not been used, the sources are O'Brien (2006a) and NGGIC (1995).

As with domestic and commercial wastewater treatment, no data is available on the precise split of methane recovery between wastewater and sludge treatment. For the purposes of reporting in Table 5.B.s1 of the CRF table, methane recovery is allocated between wastewater and sludge on the basis of emissions generated from sludge treatment as a proportion of total capture with the balance being allocated to wastewater.

Table 7.26 Methane recovered as a percentage of industrial wastewater treatment 2013

Commodity	Fraction of methane recovered/flared (%)
Dairy (c)	27%
Pulp and Paper (c)	58%
Meat and Poultry (c)	7%
Organic Chemicals (a,b)	2%
Sugar (c)	0%
Beer (c)	54%
Wine (c)	2%
Fruit (c)	0.3%
Vegetables (c)	1%

Source: (a) O'Brien 2006a, (b) NGGIC 1995 (c) NGER 2013.

Waste

Time-series consistency

Time-series consistency has been maintained through the interpolation of MCF values and proportions of methane captured for pulp and paper , sugar, dairy, meat and poultry, wine and fruit and vegetables for 1990-2008. For the beer industry, facility-specific MCF values and quantities of methane captured were available for the years 2003 to 2005. For the years 1990-2002 in the beer time series, the 2003 values for MCF and proportion of methane generated that was captured have been used. For the years 2006 – 2008, the 2009 NGER MCF and proportion of methane captured have been applied. This introduces a step change in the methane capture estimates for beer in 2006 where the amount of methane captured doubles, reflecting a doubling in treatment plant capacity in the beer industry during 2006.

For the organic chemicals where NGER data have not been used, time-series consistency is ensured through the use of a consistent methodology and associated parameters.

7.6.3.2 Nitrous oxide emissions from industrial wastewater

Nitrogen generated and discharged to the sewer system is ultimately treated at centralised municipal wastewater treatment plants. As N_2O emissions estimates at these plants are estimated based on the measurement of nitrogen entering the plant, this value is also inclusive of any nitrogen originating from industrial sources. Therefore emissions of N_2O from *industrial wastewater* are included in the estimate of N_2O emissions from *domestic wastewater*.

7.7 Uncertainties and Time Series Consistency

7.7.1 Waste sector

The uncertainty analysis in Annex 2 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.

7.7.2 Wastewater treatment and discharge

Facility level data on nitrogen entering the domestic and commercial wastewater system is used for the years 2008 onwards, as reported in DCC 2009 and under the NGER system (2009 onwards). Time-series consistency has been maintained for the estimates of Australia's protein per capita intake through the following assumptions. The protein per capita consumption value for the years 1990 to 1993 of 99.4 g/day (36.28 kg/year) is sourced from the Australian Institute of Health and Welfare (AIHW) (de Looper and Bhatia 1998). The values for 1994 to 1998 are based upon data presented in AIHW 2002. Linear interpolation was used to derive values for 1999 to 2007, which is the period for which no data are available. The following table shows the time series for values used for protein per capita consumption.

Table 7.27 Estimates of implied protein per capita: Australia: 1990-2013

Year	Protein per capita g/capita/day
1990	99.4
2000	100.0
2005	97.6
2008	96.1
2009	98.3
2010	87.3
2011	85.2
2012	90.6
2013	89.8

Sources: de Looper and Bhatia 1998 (1990-1993), AIHW 2002 (1994 – 1998), DCC 2009 (2008), NGER 2009 onwards.
Note: interpolation used for years 1999 to 2007 inclusive.

7.8 Source Specific QA/QC

7.8.1 Solid waste disposal

Emissions from solid waste disposal reflect a large amount of activity data and assumptions in relation to parameters in the IPCC first order decay model. Consequently, an intensive and systematic quality control system is required to ensure that emission estimates meet the required quality characteristics of accuracy, completeness, comparability, time series consistency and transparency.

The quality control system has established measures to test the key data inputs and emissions estimates against each of these criteria.

The solid waste sector category is covered by the general QC measures undertaken for inventory identified in Section 1.6. In particular, emissions are estimated subject to the application of carbon balance constraints that ensures completeness; that carbon is tracked from harvest to disposal and that consistency between the harvested wood product and landfill pools is maintained. Estimates of carbon stored in wood products and in landfills are provided in Annex 6.

Quality assurance in relation to key parameters and the overall method for the sector was provided through review by an international external expert not involved in the inventory process (Guendehou 2009). Independent external review provides assurance that the approach adopted by Australia is consistent with the approaches adopted by other parties.

Additionally, as part of a systematic quality control process the emission estimates obtained for the Australian inventory are compared with those reported by other parties. Methane generation at landfills in Australia was assessed against the reported estimates of methane generated at landfills across all Annex I parties. It was concluded that the implied emission factor for Australian landfills was not significantly different to the mean implied emission factor for all Annex I parties.

Key parameters such as waste type fractions have been the subject of consultations with industry and industry experts. In particular, external experts have been utilised or review of available waste audit data, MCF, DOC_f and oxidation rates.

Analysis of available waste audit data utilised in this inventory was undertaken independently by two external expert consultancies (Hyder consulting 2008, GHD 2008).

The methane correction factor (MCF), which is intended to represent the extent of anaerobic conditions in landfills, was reviewed for this inventory by GHD 2010. The assessment of GHD confirmed that an MCF factor of 1.0 is appropriate for Australian landfills.

Country specific values for DOC_f for individual waste types were selected after consultation with independent consultants (GHD 2010, Hyder consulting 2010, Blue Environment 2010) and reviewed by an international expert reviewer not involved in the preparation of the inventory (Guendehou 2010). Guendehou concluded that the approach adopted lead to a significant improvement in the emission estimates.

Oxidation rates were reviewed (GHD 2010). Following the review, it was decided to retain the IPCC default assumption of 10% until further research can be undertaken.

When NGER data were used for methane capture for the first time in the inventory in 2010, it was important to ensure time-series consistency was maintained. In order to ensure this was the case, the DCCEE engaged the external consultant who was previously used to collect methane capture information from landfill gas capture companies to undertake a QC analysis of the NGER capture data. Data were assessed for completeness and consistency with previously reported values. Capture estimates were compared with data available from the renewable energy certificate register as well as the NSW Greenhouse Gas Reduction Scheme register. The analysis confirmed that methane capture for energy generation was complete and consistent with previously reported data. For methane flaring, the analysis highlighted a completeness issue with respect to flaring occurring at local council landfills (in general, councils are not required to report under the NGER (2009 onwards) system). Therefore, this portion of flaring activity data had to be estimated for 2009 based on previously reported data.

Through this QC project, the DE was able to ensure continuity of expertise and knowledge used in the compilation of previous inventory submissions.

CRF table checks

The CRF tables are populated automatically using a piece of software developed in Australia called the CRF wizard. The CRF wizard is the interface between our Australian Greenhouse Emissions Information System (AGEIS) and the CRF reporter tool. The wizard undertakes the process of merging AGEIS data into CRF reporter XML output files.

In order to check CRF data are merged correctly by the wizard, there are general checks that are undertaken:

Emissions

1. Check overall aggregate emissions exactly match those output by our AGEIS software – if there is a mismatch then go to 2.
2. Check sectoral totals match AGEIS output – if there is a mismatch then go to 3
3. Check sub-sectoral emissions by gas match AGEIS output by gas
4. These steps are taken iteratively until Aggregate CO2-e exactly match the AGEIS output.

Activity Data

Activity data issues are identified using 3 main approaches:

1. Check implied emission factor time-series fluctuations. Where implied emission factors change beyond the expected levels, then AD are assessed and corrected manually where necessary.
2. Check time-series AD using CRF reporter chart functionality
3. Sectoral experts perform manual checks of AD

CRF additional information

CRF additional information is more difficult to check than emissions or AD. Additional information is not generated by AGEIS in many cases. Most additional information is calculated within the calculation spread-sheets that are used as a QC check for AGEIS output.

CRF additional information QC these checks rely on manual crosschecking between the CRF reporter information and the spread-sheets used to derive additional information.

7.8.2 Wastewater treatment and discharge

The quality of the data utilised in this report has been assessed against facility data available through the State Government EPA licensing system. The Australian wastewater industry is heavily regulated by State Governments, which administer relevant state legislation such as the *Environmental Protection Act* 1994 in Queensland and the *Protection of the Environment Operations Act* 1997 in New South Wales. Under this legislation the State Governments issue environment protection licences to each premises treating wastewater. The licences require compliance with strict conditions including limits on odours, noise and organic matter and nutrients (nitrogen and phosphorus) discharged to water catchments. Annual reports must be submitted by wastewater facility operators to their state government to demonstrate their compliance and some of this information is publicly available through public registers, the National Pollutant Inventory and, in some cases, the operator's own website.

The protein per capita intake applied in this inventory was compared with an estimate calculated using the nitrogen entering treatment plants reported by Sydney Water in DCC 2009 and the population for Sydney Water's service area in 2007 according to the Australian Bureau of Statistics (Sydney Water services the cities of Sydney and Wollongong excluding Gosford and Wyong). A comparison of the calculated values for protein per capita is presented in Table 7.28 below.

Table 7.28 Estimates of implied protein per capita for Sydney Water Corporation: 2008, 2009

	Population	Protein per capita g/capita/day 2009
Sydney Water Estimated Population Serviced (DCC 2009)	4,262,840	98.3
ABS Population for Sydney and Wollongong (excluding Gosford and Wyong) in 2007	4,307,057	97.3
Inventory values used for residual population connected to the sewer	6,734,007	98.3

The estimated population serviced as reported by Sydney Water in DCC (2009) is less than the 2007 population reported by the Australian Bureau of Statistics (ABS 2007). Sydney Water's estimate of population serviced excludes four of the smaller facilities and the unsewered population and is derived from forecast dwellings in the NSW Government's Metropolitan Development Program (MDP) for 2007/08. The protein per capita values calculated using the Sydney Water estimated population therefore provide a more appropriate estimate of the protein per capita value than those derived from the ABS population figures. Per capita protein consumption based on Sydney Water population serviced and DCC 2009 has been estimated as 98.3 g/day for 2009.

The protein per capita consumption for the 2012 inventory, derived from NGER facility data, has decreased to 90.6 g/day. Facility data received under the NGER system for the first three years of reporting indicates a degree of volatility associated with this factor. Those facilities reporting the underlying data, however, do undertake frequent sampling and analysis and must also adhere to legislated requirements to ensure the data is representative and free from bias. Nitrous oxide emissions are concentrated in rivers and estuaries where the processes for N_2O production can take place in both the water column and the sediments. N_2O emissions also arise from ocean waters in the continental shelf region; however, while these emissions may occur from human activity, they also occur naturally and are very difficult to isolate empirically.

A good understanding of how N_2O emissions occur in the continental shelf region and the influences of human activity on them is still being formed. Nitrous oxide formation is very dependent on regional conditions and chemistry and location of outfalls. Some studies have been undertaken which attempt to measure or characterise the N_2O in the continental shelf regions of Europe (Bange 2006, Barnes and Owens 1998), Canada (Punshon and Moore 2004) and North China (Zhang *et al.* 2008). A literature survey of four such studies determined an average emission rate for continental shelf/oceanic coastal waters of 0.0018 kg N_2O-N/kg N discharged. The regions studied, however, are influenced by very different marine conditions to those in Australian waters and also do not consider the effects of treated wastewater discharges (Foley and Lant, 2007). The regional marine conditions are a major influence on the production of N_2O (Zhang *et al.* 2008). An appropriate method and emission factor for estimating N_2O emissions from wastewater discharged to coastal and continental shelf waters would require further research.

A reconciliation of the quantity of sludge transferred from wastewater treatment to landfills and the sludge entering the landfills has been undertaken. To estimate the sludge transferred from industrial wastewater treatment it is assumed that 40% of the sludge removed from the wastewater is sent to landfill. The conversion of COD to wet sludge is calculated by assuming the volatile solids proportion of dry solids is in the range of 60 – 90% and the dry content matter of wet sludge is 15%. For domestic and commercial wastewater, the tonnes of nitrogen sent to landfill are converted to wet sludge using a nitrogen content range of 40,000 to 80,000 mgN per kg dry solids and a dry content matter of wet sludge of 15%.

Using these assumptions an estimate of the minimum and maximum possible quantities of wet sludge sent to landfill has been calculated for 1990 to 2012. The range of estimates for each year was found to be very large. In 2012, the minimum quantity of wet sludge sent to landfill from wastewater treatment was 613 kt while the maximum quantity was estimated to be 1,229 kt. These values are significantly higher than the estimate of wet sludge disposed to landfills estimated under the solid waste sector (less than 100 kt). This comparison highlights the challenges in converting quantities of nitrogen and COD to a quantity of wet sludge disposed to landfill. The assumptions and parameters such as nitrogen content of dry solids require further investigation to determine their suitability and exact magnitude.

The wastewater sector source categories are also covered by the general QA/QC of the greenhouse gas inventory in Section 1.6.

7.9 Recalculations Since the 2012 Inventory

7.9.1 Solid waste disposal

Recalculations have been performed for solid waste as a result of the incorporation of additional NGER facility data into the estimates for this submission. These NGER data include quantities and composition of waste disposed in landfill, methane capture and decay rate constants based on the geospatial coordinates of each landfill. Where new facilities begin to report under the NGER (2009-onwards) system, their entire historical waste disposal profile since landfill opening needs to be taken into account in the estimates. As a result, recalculations have occurred in all inventory years as set out in Table 7.29.

In addition to the inclusion of new reporting entities, corrections were undertaken to the procedure used to ensure integration with the output of the harvested wood products model. This followed a review of the business rules used to decide whether an NGER facility's reported waste mix should be adjusted. It has been decided that where a reporting landfill under the NGER System opts to use default waste compositions, these will be adjusted to ensure that the sum of paper, wood and wood waste disposed to landfill is consistent with the values reported in the Harvested Wood Products model.

Recalculations have also occurred as a result of the application of new GWPs in accordance with revised UNFCCC reporting requirements.

Table 7.29 5.A Solid Waste: recalculation of methane emissions (Gg CO_2-e)

	2014 Submission Gg CO_2-e	2015 Submission Gg CO_2-e	Change Gg CO_2-e	Change %
5.A Solid Waste Disposal				
1990	13,188	16,269	3,080	23.36%
2000	11,041	13,569	2,528	22.90%
2005	9,865	12,289	2,424	24.57%
2008	10,220	12,674	2,454	24.02%
2009	10,195	12,598	2,403	23.57%
2010	10,466	12,883	2,417	23.09%
2011	10,143	12,455	2,312	22.79%
2012	8,981	11,135	2,154	23.98%

7.9.2 Wastewater treatment and discharge

Recalculations have occurred as a result of the application of new GWPs in accordance with revised UNFCCC reporting requirements.

Table 7.30 5.D Domestic wastewater: recalculation of emissions (Gg CO_2-e)

	2014 Submission Gg CO_2-e	2015 Submission Gg CO_2-e	Change Gg CO_2-e	Change %
5.D.1 Domestic Wastewater				
1990	1,765	2,074	309	17.48%
2000	1,533	1,747	214	13.98%
2005	1,590	1,811	221	13.90%
2008	1,692	1,954	262	15.47%
2009	1,684	1,951	267	15.87%
2010	1,726	2,085	359	20.78%
2011	1,628	1,949	321	19.72%
2012	1,608	1,642	33	2.06%

Table 7.31.5.D Industrial wastewater: recalculation of emissions (Gg CO_2-e)

	2014 Submission Gg CO_2-e	2015 Submission Gg CO_2-e	Change Gg CO_2-e	Change %
5.D.2 Industrial Wastewater				
1990	1,997	2,356	359	17.99%
2000	1,230	1,446	216	17.55%
2005	1,196	1,405	209	17.43%
2008	1,205	1,417	212	17.60%
2009	1,197	1,413	216	18.08%
2010	1,099	1,317	218	19.88%
2011	1,055	1,259	203	19.27%
2012	1,009	1,194	185	18.35%

7.9.3 Incineration and open burning of waste

Recalculations have occurred as a result of the application of new GWPs in accordance with revised UNFCCC reporting requirements.

Table 7.32.5.C Incineration: recalculation of emissions (Gg CO_2-e)

	2014 Submission Gg CO_2-e	2015 Submission Gg CO_2-e	Change Gg CO_2-e	Change %
5.C Incineration and Open Burning of Waste				
1990	85.0	84.6	- 0.5	-0.54%
2000	27.7	27.7	-	0.00%
2005	28.4	28.4	-	0.00%
2008	29.5	29.5	-	0.00%
2009	29.9	29.9	-	0.00%
2010	29.7	29.7	-	0.00%
2011	29.6	29.6	-	0.00%
2012	29.8	29.8	-	0.00%

7.9.4 Biological treatment of solid waste

Recalculations have occurred as a result of the application of new GWPs in accordance with revised UNFCCC reporting requirements.

Table 7.33.5.B Biological Treatment of Solid Waste: recalculation of emissions (Gg CO_2-e)

	2014 Submission Gg CO_2-e	2015 Submission Gg CO_2-e	Change Gg CO_2-e	Change %
5.B Biological Treatment of Solid Waste				
1990	8	10	1	16.45%
2000	40	46	7	16.45%
2005	55	65	9	16.45%
2008	68	79	11	16.45%
2009	71	83	12	16.45%
2010	81	94	13	16.45%
2011	94	109	15	16.45%
2012	95	111	16	16.45%

7.10 Source Specific Planned Improvements

7.10.1 Solid waste disposal

Australia initiated a move to the use of tier 3 methods for the estimation of emissions from solid waste disposal in the 2013 submission. The availability of facility-level data collected under the NGER system (2009 onwards) has enabled a facility-specific and spatially explicit approach to be adopted for the largest landfills which has supplemented the previous State-based approach which continues to be used for the non-NGER proportion of the landfill sector.

Facility-level data used in this submission are limited to waste disposal quantities and composition and methane capture for all landfill facilities triggering NGER system reporting thresholds. Decay rate constants have been assigned to each landfill based on their individual geospatial coordinates and BOM climate data.

Under the NGER system, operators of landfills are encouraged to undertake audits of waste data received and to collect data on methane generation rates to enable the operator to determine a facility-specific 'k' value so that 'k' will reflect both localised climate and management conditions. However, to date, no landfills have undertaken these measurements. Australia will continue to review the availability of data and where available these will be used to ensure that the decay functions applied at individual landfills reflect both local climatic conditions and facility management practices. The latter is particularly important as practices can vary considerably – for example, two in every five landfills practice leachate control which would significantly increase the value of 'k' at a landfill facility.

Initial testing of the methods at landfills has demonstrated the value of ensuring that local climate and management practices are explicitly taken into account. The methods to be used to determine 'k' are provided in the *National Greenhouse and Energy Reporting (Measurement) Determination 2008*.

For the residual disposal not covered by the NGER system reporting, Australia will explore the possibility of estimating emissions at a more spatially disaggregated level to enable climatic variation to be accounted for in the residual estimates. The implementation of this planned improvement will depend of the availability of disposal data at a more disaggregated level than is currently available.

Research is continuing into the DOC_f and decay values applicable to Australian waste types in Australia under both laboratory conditions and in situ across various regions of Australia. When finalised, the new empirical results will be reviewed for their appropriateness to Australian conditions and to the Australian national inventory.

As part of the in-country review of Australia's 2008 national inventory, the Expert Review Team encouraged

Australia to develop country-specific DOC values. This will be explored over coming years to determine the best empirical approach to support the development of such values.

Similarly the ERT encouraged Australia to further investigate methane correction factors for the period prior to 1990. Australia plans to undertake this verification process subject to the availability of suitable historical data on waste management practice.

7.10.2 Wastewater treatment and discharge

Australia will keep industrial wastewater model parameters and methods under review based on facility level data reported under the NGER system.

7.10.3 Incineration and open burning of waste

The DE will review NGER system reports with a view to the potential inclusion of additional facility data for future inventory submissions.

7.10.4 Biological treatment of solid waste

Methods and emission factors will be kept under review.

8 Other (CRF Sector 6)

Australia does not report any emissions under CRF sector 6, 'Other'.

9 Indirect CO_2 and Nitrous Oxide emissions

For the purpose of paragraph 29 of decision 24/CP.19, Australia has elected not to report indirect CO_2 and nitrous oxide emissions. Information on indirect CO_2 and nitrous oxide emissions in the *Energy* and *Agriculture* sectors can be found in Chapters 3 and 5 respectively.

10 Recalculations and improvements

Emissions processes are pervasive and complex and, consequently, emissions estimation techniques and data sources for the Australian inventory continue to be refined, updated and improved.

Internationally, guidelines for the preparation of national inventories have been updated which has necessitated significant changes for this inventory.

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 changes in international practice. Some of the principal elements of the improvement programme are set out in Section 10.4.

10.1 Explanations and justifications for recalculations

A key reason for recalculations in the 2013 inventory has been that, from 2015, inventories must be prepared in accordance with revised UNFCCC Reporting Guidelines on Annual Inventories (FCCC/CP/2011/9/Add.2) and the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories. Implementing the new guidelines has required changes to the coverage of emission sources and changes to some methods and emissions factors (EFs). It has also required a change to the global warming potentials (GWPs) used to convert emissions into carbon dioxide equivalents.

In addition to recalculations due to updates in EFs and GWPs within the 1990–2012 time series there have been a number of sectors where recalculations have been undertaken. Details of these recalculations are given in the sectoral chapters and are summarised in Table 10.1. Principal reasons include revisions of activity data, the inclusion of additional sources of data or from refinements in the estimation methodology including in response to recommendations of previous UNFCCC expert reviews. 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.

Table 10.1 Reasons for the recalculations for the 2013 inventory (compared with the 2012 inventory)

Sector		Category	Reason for Recalculation
1.A	Energy		The primary driver for recalculations is revisions by DIS (BREE) to the Australian Energy Statistics (AES). The revisions to the AES are due to the incorporation of improved activity data available under the NGER, subsequent improvements in time series consistency and the alignment of the reporting of conversion activities, including electricity generation with reporting requirements under the IEA. Recalculations have also been made as a result of the adoption of the 2006 IPCC guidelines, with the application of 100% oxidation affecting default emission factors for CO_2 estimates, updated non CO_2 emission factors and AR4 global warming potential affecting CH_4 and N_2O estimates.
	Stationary Combustion	1.A.1	Electricity Generation: Revisions that reallocate fuel from minor recalculations also arise from revisions by DIS (BREE) to the AES. Electricity Generation: For all fuels other than coal, EFs have been updated to reflect the application of 100 per cent oxidation affecting default emission factors for CO_2 estimates. CH_4 and N_2O EFs have also been updated to reflect updated default factors by equipment type available in the *2006 IPCC Guidelines*.
	Transport	1.A.3.	Recalculations of emissions from the transport sector are a result of the adoption of the 2006 IPCC guidelines, with the application of 100% oxidation affecting default emission factors for CO_2 estimates, and AR4 global warming potential affecting CH_4 and N_2O estimates. There are no recalculations of activity data or updates to methods.
1.B	Fugitive Emissions	1.B.1	NGER data for open cut coal mines have been incorporated into the emission estimates resulting in recalculations throughout the time series.
		1.B.2	Improved natural gas well drilling data incorporated into exploration emissions has resulted in whole time series recalculations. Data overlapping analysis for natural gas distribution has resulted in emissions recalculations for the whole time series.
2	Industrial Processes	2.A	There are no recalculations for the estimate of emissions from mineral products in 2012. Note that estimates for soda ash production have allocated to 2.B.7 soda ash production in accordance with IPCC 2006 (and included in 2.B to protect confidentiality). There are otherwise no updates to methods, or recalculations of activity data.
		2.B	Recalculations of emissions from chemical production are a result of the adoption of the 2006 IPCC guidelines, with the application of 100% oxidation affecting default emission factors for CO_2 estimates, and AR4 global warming potential affecting CH_4 and N_2O estimates. There are no recalculations of activity data or updates to methods.
		2.C	Recalculations of emissions from metal production are a result of the adoption of the 2006 IPCC guidelines, with the application of 100% oxidation affecting default emission factors for CO_2 estimates, and AR4 global warming potential affecting CH_4 and N_2O estimates. There are no recalculations of activity data or updates to methods.
		2.D	Recalculations of emissions from *non-energy products from fuels and solvent use* are a result of the adoption of the 2006 IPCC guidelines, with the application of 100% oxidation affecting default emission factors for CO_2 estimates, and AR4 global warming potential affecting CH_4 and N_2O estimates. There are no recalculations of activity data or updates to methods.

Sector		Category	Reason for Recalculation
		2.F	Recalculations of emissions from other production are a result of the adoption of the 2006 IPCC guidelines, with the application of 100% oxidation affecting default emission factors for CO_2 estimates, and AR4 global warming potential affecting CH_4 and N_2O estimates. There are no recalculations of activity data or updates to methods.
3	Agriculture	3.A,B, D	Animal input and activity data has been revised as described in chapter 5.
		3.A	New enteric fermentation relationship for dairy cattle and beef cattle on pasture. New EFs for alpaca, deer and ostriches and emus.
		3.B	Revised IPCC and CF EFs and updated management system allocations. Inclusion of new indirect N_2O emission sources. Mass flow approach applied to feedlot cattle, pigs and poultry.
		3.C	2006 IPCC EF adopted
		3.D	Revised IPCC and CS EFs. Revised crop residue characteristics and stubble management data. Removal of emissions from N fixing crops. Inclusion of new emission sources: N mineralisation associated with loss of soil C, and N from below ground crop residue and pasture renewal.
		3E	New methods and revised fire scar analysis.
		3F	Revised crop residue characteristics and stubble management data.
		3G	Emission from lime application moved from LULUCF to the agriculture sector.
		3H	Inclusion of CO_2 emissions from urea application for the first time.
5	LULUCF	5.A.1	Changes to estimation and reporting of emissions from wildfire. Updated activity data for harvested forests. Implementation of new spatial monitoring systems
		5.A.2	The annual update of remote sensing data of forest cover change has resulted in a recalculation of the *grassland converted to forest land* sub-category.
		5.B.1	This time series of soil carbon estimates has been recalculated due to the implementation of spatially and temporally explicit agricultural species and management practices database, recalibration of soil decomposition rates, new baseline map of organic carbon in Australian soil, new clay surface from the Australian three-dimensional soil grid and isolation of the impacts of changes in human activities.
		5.B.2	Updates to treatment of area of forest land converted to grassland. The method to initialise soil carbon stocks for land observed as clear of forest in 1972 was updated to be consistent with the method used in 5.B.1.
		5.C.1	This time series of soil carbon estimates has been recalculated due to the implementation of spatially and temporally explicit agricultural species and management practices database, recalibration of soil decomposition rates, new baseline map of organic carbon in Australian soil, new clay surface from the Australian three-dimensional soil grid and isolation of the impacts of changes in human activities.
		5.C.2	Updates to treatment of area of forest land converted to grassland. The method to initialise soil carbon stocks for land observed as clear of forest in 1972 was updated to be consistent with the method used in 5.C.1.
6	Waste	6.A	Recalculations have been performed for all years for solid waste as a result of the incorporation of additional NGER data into the estimates for the first time in this submission. Corrections were undertaken to the procedure used to ensure integration with the output of the harvested wood products model.

10.2 Implications for emission levels

The impact of the recalculations on emission levels for the sectors excluding LULUCF was an increase in the estimate of total emissions; these increases were 13.3 Mt or 3.2 per cent in 1990 and 6.1 Mt or 1.1 per cent in 2012 compared with estimates presented in the *National Inventory Report 2012* (see Table 10.3). The primary reason for the large recalculations between the 2012 submission and 2013 submissions is updates to the GWPs and EFs in accordance with the 2006 IPCC *Guidelines for National Greenhouse Gas Inventories*. Conversely, the recalculations including the LULUCF sector resulted in a decrease in the estimate of total emissions, these decreases were 13.9 Mt or 2.5 per cent in 1990 and a decrease of 14.1 Mt or 2.5 per cent in 2012.

Table 10.2 Estimated recalculations for this submission (compared with previous submission): 1990, 2005-2012

Sector	1990 Mt	2005 Mt	2006 Mt	2007 Mt	2008 Mt	2009 Mt	2010 Mt	2011 Mt	2012 Mt
1.A Fuel Combustion	1.9	3.1	3.4	4.2	3.6	7.3	4.0	5.1	6.7
1.A.1, 2, 4, 5 Stationary Energy	0.8	1.3	1.5	2.2	1.6	5.3	1.9	3.0	4.6
1.A.3 Transport	1.2	1.8	1.9	1.9	2.0	2.0	2.1	2.1	2.2
1.B Fugitives	4.2	1.1	1.0	1.4	1.0	0.3	0.2	-0.5	-1.3
2 Industrial Processes	1.4	1.4	1.3	1.4	1.5	1.5	1.6	1.9	1.9
4 Agriculture	2.1	-0.1	-2.8	-3.8	-6.7	-3.3	-2.6	-1.8	-3.6
6 Waste	3.7	2.9	2.9	2.9	2.9	2.9	3.0	2.9	2.4
Total recalculation (excluding LULUCF)	**13.3**	**8.3**	**5.8**	**6.0**	**2.3**	**8.6**	**6.2**	**7.5**	**6.1**
5 Land use, land use change and forestry	-27.2	44.0	67.1	-36.2	51.7	25.4	-0.5	59.4	-20.2
Total recalculation (including LULUCF)	**-13.9**	**52.4**	**72.9**	**-30.2**	**54.0**	**34.0**	**5.7**	**66.9**	**-14.1**

Source: Department of the Environment

10.3 Implications for emission trends, including time series consistency

The full time series of estimated recalculations is set out in Table 10.3. The net effect of the recalculations on aggregate emission trends for the sectors excluding LULUCF is an increase of emission estimates between 0.3 and 3.2 per cent. Key reasons for the recalculations are the updated GWPs and EFs that have been applied throughout the time series. The recalculations for estimates including LULUCF have also been applied consistently throughout the time series although the net effect on emissions is more variable in terms of the magnitude and direction of the changes given the nature of the data.

Table 10.3 Estimated recalculations for this submission (compared with the previous submission); 1990-2012

	Excluding LULUCF				Including LULUCF			
	Previous estimate	Current Estimate	Difference		Previous estimate	Current Estimate	Difference	
	Mt CO2-e	Mt CO2-e	Mt	%	Mt CO2-e	Mt CO2-e	Mt	%
1990	415.0	428.3	13.3	3.2%	545.5	531.6	-13.9	-2.5%
1991	416.5	428.1	11.6	2.8%	575.3	513.6	-61.7	-10.7%
1992	420.8	433.1	12.4	2.9%	508.5	493.4	-15.1	-3.0%
1993	422.8	434.1	11.3	2.7%	442.1	482.2	40.1	9.1%
1994	423.2	434.9	11.7	2.8%	474.3	504.9	30.6	6.4%
1995	436.9	444.5	7.6	1.7%	455.2	484.3	29.1	6.4%
1996	443.2	451.5	8.3	1.9%	475.4	487.6	12.3	2.6%
1997	455.7	463.8	8.1	1.8%	468.4	504.3	35.9	7.7%
1998	470.6	479.0	8.4	1.8%	507.4	501.8	-5.6	-1.1%
1999	479.6	485.7	6.0	1.3%	472.6	520.2	47.6	10.1%
2000	489.8	497.0	7.2	1.5%	513.0	554.8	41.8	8.1%
2001	502.3	505.2	2.9	0.6%	552.2	566.6	14.4	2.6%
2002	503.6	508.9	5.3	1.0%	593.6	578.5	-15.1	-2.5%
2003	506.2	508.0	1.7	0.3%	724.4	554.4	-170.0	-23.5%
2004	519.0	524.2	5.2	1.0%	516.5	571.3	54.9	10.6%
2005	523.5	531.8	8.3	1.6%	548.4	600.8	52.4	9.6%
2006	529.9	535.6	5.8	1.1%	532.1	605.0	72.9	13.7%
2007	537.9	544.0	6.0	1.1%	621.6	591.4	-30.2	-4.9%
2008	544.6	546.9	2.3	0.4%	537.5	591.5	54.0	10.0%
2009	541.2	549.8	8.6	1.6%	558.0	592.0	34.0	6.1%
2010	540.2	546.4	6.2	1.1%	568.8	574.5	5.7	1.0%
2011	541.5	549.1	7.5	1.4%	480.9	547.8	66.9	13.9%
2012	543.6	549.8	6.1	1.1%	558.8	544.7	-14.1	-2.5%

Source: Previous estimate – Department of the Environment 2014.

10.4 Recalculations, including in response to the review process, and planned improvements to the inventory

10.4.1 External factors also play a role in driving inventory improvements. The key external catalysts for inventory improvement include:

Priorities for the inventory development process have been set out in the *National Inventory Systems Inventory Improvement Plan* and have been informed by analysis of key sources and key trends. The overall aim of inventory improvement is to improve the accuracy and reduce uncertainties associated with the national inventory estimates.

The Department has implemented systematic review processes into the national inventory system to drive continuous improvements in inventory quality. *The Quality Assurance-Quality Control Plan* is an integral part of this process.

In terms of emission estimation methodologies, these annual processes are principally implemented by the following.

Review of selection of methods

Decisions are made each year as to whether IPCC tier 1, 2 or 3 methods should be applied for a category, implementing QC Measure 3.A.1 (i) as set out in the *National Inventory Systems Quality Assurance-Quality Control Plan*. Method selection is reviewed in light of enhanced national data collection at facility or project level data available from private sources; public empirical literature; and in relation to updates in international guidelines and international practice.

Review of model parameters and emission factors – model validation and calibration

This review implements QC Measures 3.A.1 (ii)-(iv) set out in the *National Inventory Systems Quality Assurance-Quality Control Plan*. The measures provide for review of model parameters in light of new data collected from private measurements or from public empirical research and provide either evidence to validate existing parameters or a basis for improving the parameters or method specification based on newly available information.

10.4.1 External factors also play a role in driving inventory improvements. The key external catalysts for inventory improvement include:

- *Changing international practice*
  The Department actively monitors the implementation of inventory guidelines by other parties to the UNFCCC / Kyoto Protocol to ensure comparability of national inventories. More specifically, the Department also monitors the implementation of other major domestic reporting systems. The European Union, for example, has established facility-level methods for the estimation of emissions for its emission trading system while the United States Environment Protection Agency has established similar methods for its mandatory reporting system. These major systems may set new benchmarks of international practice that the Department monitors and evaluates for their potential implications for Australia.
- *Enhancements to Australian National Greenhouse Accounts Framework*
  Australia's national inventory system incorporates an integrated national greenhouse accounts framework. This builds common approaches and estimation methods from national to State to company, facility and project levels across the national greenhouse accounts. Investment will also be undertaken in a set of regional greenhouse accounts, including in support of the national income accounts framework, and a carbon stock account, including for Australia's forest lands which will provide complementary information for the national inventory.
- *Responses to Quality Control Outcomes and Quality Assurance reviews*
  Responses to quality assurance reviews are an integral part of the inventory improvement process – in particular, the UNFCCC ERT reviews, the review by the Australian National Audit Office and public consultations on NGER methods. As part of the national inventory development process all issues identified by the UNFCCC ERT review teams are assessed for their implications for the national inventory. A full set of UNFCCC ERT recommendations, and Australia's responses to these recommendations, are included in Annex 6. Areas for inventory improvement are identified each year in the *Evaluation of Outcomes* document.

10.5 Investment in national inventory systems

Ultimately, the quality of emission estimates depends on the quality of measurement, data management and quality control systems.

Investment in the National Measurement System

The national inventory system relies on a large number of measurements undertaken by private organisations. For this inventory, data collected for the *energy*, *industrial process* and *waste* sectors is largely obtained through the National Greenhouse and Energy Reporting (NGER) System. Estimation methods used for NGER are governed by the *National Greenhouse and Energy Reporting (Measurement) Determination 2008* and are designed to be consistent with the national inventory estimation methods.

Improvements in accuracy of measurement will flow into improvements in the quality of the national inventory.

In support of the Emission Reduction Fund, new standards are being developed to support improved measurements across the land sector. The Department has supported the development of sampling and testing protocols for the direct measurement of Soil Organic Carbon at paddock scale. New measurement protocols are also being developed for the measurement of vegetation both as environmental plantings (conversion to forests) and for rangelands vegetation. The new standards are designed to support confidence in data collected under private measurement systems and should be considered in conjunction with the Emission Reduction Fund's compliance and enforcement regime.

Investment in Research and Development

The national inventory system utilises public funding for research into greenhouse gas measurement in Australia. In recent years there has been a focus on the land based sectors given the land sectors contribute significant key categories, the extent of the sectors, the relatively high cost of private measurement and the relatively high variability of spatial and temporal emission processes.

National Inventory quality control systems

The Department will continue to invest in the quality control framework that provides a systematic approach to the assessment of new information on emissions as it emerges over time.

As indicated in 10.4.1, in relation to NGER, a systematic assessment of all new facility-specific information received will be undertaken to test the quality of existing tier 2 country-specific parameters. New information will be assessed against predetermined criteria for applicability. As a test of the quality of the existing parameters, the new information will either verify values currently used in the inventory or be used to update the parameters.

The Department will also continue to invest in the integration of new quality control tools within the AGEIS system. These tools include completion of the systematic carbon balance assessments; automated comparability tests with the inventories of other parties and development of tier 2 proxy methods where tier 3 methods have been implemented (e.g. coal mining). Similarly, the Department will invest in enhanced quality control and output reporting systems for the *LULUCF* sector.

Australia has a small network of atmospheric monitoring stations that provide data on atmospheric greenhouse gas concentrations which, when combined with air dispersion models, provide a complementary verification system to the estimates presented in this national inventory. In this submission, estimates are presented for PFCs, HFCs and SF_6. Work on other gases, particularly methane and nitrous oxide, is ongoing.

Investment in IT systems

Investment in IT software systems including the Australian Greenhouse Emissions Information System (AGEIS) and FullCAM for *LULUCF* is a critical part of the improvement plan. Investment will be focussed on the integration of the AGEIS and FullCAM systems, increasing the flexibility of the FullCAM with regard to the possibility of producing specific parameters and intermediate outputs to support enhanced quality control systems as well as regional accounts; and the development of project level tools to support the Emission Reduction Fund.

10.6 Improvements to activity data

The Department is investing in an ongoing program to review and to update the quality of activity data used in the national inventory. A major focus includes data obtained under NGER and data for the land sector.

10.6.1 National Greenhouse and Energy Reporting (NGER) System

The National Greenhouse and Energy Reporting System data is being used to progressively to update the data sources used in the *energy*, *industrial process* and *waste* sectors. From a systems point of view, the principal benefits of the NGER for the national inventory include:

(a) establishment of a systematic, mandatory data collection system at facility level for all facilities that exceed a certain threshold;

(b) streamlined data collection processes – existing multiple collection processes undertaken by various agencies of the Australian Government have been streamlined into a single collection process;

(c) facility level data are available to the Department for the purposes of preparing the inventory by February each year – this allows a significant enhancement of the timeliness of previous collection processes;

(d) improved data quality from reporters reflecting compliance and public disclosure provisions of the NGER Act; and

(e) improved sectoral estimates for those sectors where existing data collection processes may have experienced limited coverage in the past – consequently, some small reallocation of emissions between sectors has been observed in this year's inventory.

For each IPCC sector, the principal benefits of NGER will differ depending on the current data collection processes. A summary of the expected relative benefits of NGER for various IPCC sectors is provided in Table 10.4.

Table 10.4 Principal benefits of the NGER data for the inventory, by IPCC sector

Category		Systematic data collection	Streamlined data collection	Improved timeliness	Improved data quality	Improved sectoral estimates
1.	**Energy**					
1.A	**Fuel Combustion**					
1.A.1a	Electricity		Yes	Yes	Yes	
1.A.1b	Petroleum refining		Yes	Yes	Yes	Yes
1.A.1c	Coke production		Yes	Yes	Yes	Yes
1.A.2	Manufacturing		Yes	Yes	Yes	Yes
1.A.3	Transport					
1.A.4	Other sectors		Yes	Yes	Yes	Yes
1.A.5	Other		Yes	Yes	Yes	Yes
1.B	**Fugitive emissions**					
1.B.1	Coal Mining	Yes		Yes	Yes	
1.B.2	Oil & Gas	Yes		Yes	Yes	

Category		Systematic data collection	Streamlined data collection	Improved timeliness	Improved data quality	Improved sectoral estimates
2	**Industrial Processes**					
2.A	Mineral products		Yes	Yes	Yes	Yes
2.B	Chemical products		Yes	Yes	Yes	
2.C	Metal products		Yes	Yes	Yes	
2.D	Other		Yes	Yes	Yes	
2.E	HFC production					
2.F	HFC consumption					
3	**Solvents**					
4	**Agriculture**					
5	**LULUCF**					
6	**Waste**					
6.A	Solid waste		Yes	Yes	Yes	
6.B	Wastewater	Yes		Yes	Yes	
6.C	Waste incineration	Yes		Yes	Yes	
6.D	Biological treatment of solid waste	Yes		Yes	Yes	

10.6.2 Other sectors – improvements in inventory activity data

Outside the sectors covered by NGER and the Emission Reduction Fund, the Department has been seeking to update the following activity data sources to improve their reliability, completeness, time series consistency or accuracy. Much of the improvements will occur for spatial data layers for the land sectors, as efforts are made to better provide for the progressive implementation of the *2006 IPCC Guidelines*.

Improved mapping of forest areas and forest management activities

Investment in the use of remote sensing techniques to support estimates of forest management activities is ongoing, utilising available spatial information for calibration. Time-series mapping of the transfer of harvested native forests to conservation reserves and improved accuracy of mapping of harvested native forest areas, public and private and including mapping of areas that are not available for harvesting due to, inter alia, codes of practice. The Department is collaborating with CSIRO to continue to enhance the use of Landsat data cube, developed by Geoscience Australia, which contains calibrated surface reflectance products from Landsat 5, 7 and 8 satellites to derive additional information on forest management.

Mapping of sparse woody vegetation cover for the Grasslands remaining grasslands category

Enhancement of the mapping of time series sparse woody vegetation across Australia through remote sensing is being undertaken by CSIRO to improve the consistency of this data and, in combination with research into fire dynamics, will be used to improve estimates of emissions from grasslands remaining grasslands and savanna burning.

10.7 Updates to method and method selection

10.7.1 Using National Greenhouse and Energy Reporting System and other private sources of data for model validation and calibration

NGER establishes a framework to encourage the private measurement of key emissions data. Sources covered by NGER include *energy (fuel combustion), energy (fugitive emissions), industrial processes* and *waste*.

Data made available under NGER from private measurements of facility-specific emission factors and other parameters is used to systematically review or validate existing tier 2 model parameters in relevant sectors. If a tier 2 model parameter is not validated by new NGER data, then the inventory parameter may be recalibrated or the equation may be re-specified in accordance with the provisions of the Inventory Improvement plan.

Each year, as new data or information is collected under NGER, the method selected to estimate emissions for a source will be reviewed. At this stage there is a presumption that the inventory will transition to tier 3 methods over time as more data based on private measurements of emission parameters becomes available, assuming that data preconditions for a more disaggregated tier 3 structure to be implemented have been met.

Table 10.5 Summary of planned uses of NGER data for Australia's national inventory, by IPCC sector

Category		Facility – level activity data	Tier 2/3	Verification test for tier 2 parameters	Completeness/ sectoral improvement	Improved uncertainty estimates
1	**Energy**					
1.A.1a	Electricity (coal)	**Implemented**	**Implemented**	**Yes**	**No**	**Yes**
1.A.1a	Electricity (gas)	**Implemented**	**Implemented**	**Yes**	**No**	**Yes**
1.A.1a	Electricity (liquid)	**Implemented**	**Potentially**	**Potentially**	**No**	**Potentially**
1.A.1b	Petroleum refining	Implemented	Potentially	Potentially	Yes	**Potentially**
1.A.1c	Coke production	Potentially	Potentially	Potentially	No	**Potentially**
1.A.2	Manufacturing	Potentially	Potentially	Potentially	No	**Potentially**
1.A.3	Transport	Potentially	No	No	No	No
1.A.4	Other sectors	No	No	Potentially	No	No
1.A.5	Other	No	No	Potentially	No	No
1.B.1	Coal Mining	Implemented	Implemented	Potentially	Yes	**Potentially**
1.B.2	Oil & Gas	Partially Implemented	Potentially	Potentially	No	**Potentially**

Category		Facility – level activity data	Tier 2/3	Verification test for tier 2 parameters	Completeness/ sectoral improvement	Improved uncertainty estimates
2	**Industrial Processes**					
2.A.1	Cement	Implemented	Potentially	Potentially	Yes	**Potentially**
2.A.2	Lime	Implemented	Implemented	Potentially	Yes	Yes
2.A.3	Limestone and Dolomite use	Implemented	Potentially	Potentially	No	Yes
2.A.4	Soda ash production and use	Implemented	Implemented	NA	Yes	**Potentially**
2.B.1	Ammonia	Implemented	Potentially	Potentially	Yes	**Potentially**
2.B.2	Nitric acid	Implemented	Implemented	NA	Yes	**Potentially**
2.B.5	Synthetic rutile and titanium dioxide	Implemented	Potentially	Potentially	Yes	**Potentially**
2.C.1	Iron and steel	Implemented	Potentially	Potentially	Yes	**Potentially**
2.C.2	Ferro-alloy metals	Implemented	Potentially	Potentially	Yes	**Potentially**
2.C.3	Aluminium	Implemented	Potentially	Potentially	Yes	**Potentially**
2.C.4	Other metals	Implemented	Potentially	Potentially	No	**Potentially**
2.E	HFC production	No	No	No	No	No
2.F	HFC consumption	No	No	No	No	No
2.F	SF6 consumption	Implemented	Implemented	Potentially	Yes	No
3	**Solvents**	**No**	**No**	No	No	No
4	**Agriculture**	No	No	No	No	No
5	**LULUCF**	No	No	No	No	No
6	**Waste**	Waste				
6.A	**Solid waste**	Implemented	Implemented	No	No	**Potentially**
6.B.1	Domestic and Commercial Wastewater	Implemented	Implemented	No	No	**Potentially**
6.B.2	Industrial Wastewater	Partially implemented	Potentially	No	No	**Potentially**
6.C	Waste incineration	Partially implemented	Potentially	Yes	No	**Potentially**
6.D	Biological treatment of solid waste	No	No	No	No	No

Note:
(1)For activity data, 'implemented' means that data have been included in the national inventory calculations, however unless the completeness column is also 'yes' the data do not change the total national activity data which is taken from alternative sources. This step is necessary to be able to implement facility-specific emission factors at a later time.

(2) For emission factors, 'potentially' means that new NGER data is assessed each year in accordance with prescribed pre-conditions to test whether the method selection should be raised from tier 2 to tier 3 or the mixed tier 2/3.

(3) For the verification column, 'potentially' means that new NGER data is assessed each year in accordance with prescribed preconditions to test whether the parameters for the tier 2 component of the method are verified by the new data or whether the parameters should be revised or calibrated with the new data.

Similar approaches to the review of newly available data will be adopted for other potential sources of information, such as the Carbon Farming Initiative (CFI)/Emission Reduction Fund (ERF).

Table 10.6 Summary of planned uses of CFI/ERF data for Australia's national inventory, by IPCC sector

Category		Facility/ Project – level activity data	Tier 2/3	Verification test for tier 2 parameters	Completeness/ sectoral improvement	Improved uncertainty estimates
3.A.	Enteric Fermentation dairy/beef	Potentially (feeds)	Potentially	No	Partially	Yes
3.B	Manure Management	Potentially	Potentially	Potentially	Yes	Yes
3.E	Savanna Burning[(a)]	No	No	No	No	No
4.A	Grasslands conversion to forests	Yes	Yes	Yes	No	Yes

(a) The inventory and CFI/ERF methodologies are generally consistent. Key difference is in resolution of remote sensing imagery used to identify fire areas

10.7.2 Using data from public research for method development and model validation and calibration

New information generated by publicly funded research programs or other sources also provide opportunities to test the validity of existing parameters, to consider changes to model structures, or to develop new methods.

Major areas of inventory where research data are being used for these purposes include the following:

Enteric fermentation

Research on enteric fermentation emissions from livestock, co-ordinated through the Reducing Emissions from Livestock Research Program, has now produced an important dataset on methane emissions from Australian cattle and sheep. The data for beef and dairy cattle has been analysed and a new method developed and implemented in the 2015 submission. A process to view the sheep data has been initiated to determine if changes are required to the current methods.

Nitrous oxide emissions from agricultural soils

Research on nitrous oxide emissions from agricultural soils through the Nitrous Oxide Research Program (NORP) and National Agricultural Nitrous Oxide Research Program (NANORP) has built on a large volume of data collected since 2003 using continuous chambers across a range of crops and crop practices. This data has been analysed and revised EF have been implemented in the 2015 submission.

Emissions from animal waste

The National Agricultural Manure Management Program (NAMMP) has been funded by the Australian Government to provide data on emissions from manure management systems and animal waste applied to soils. As data from the NAMMP are published the results will be used to check the quality of the EFs selected in the inventory. Where new studies give values that are significantly different from the current EFs these factors are identified for review.

Waste

The DOC_f, decay and oxidation values applicable to Australian waste types in Australia under both laboratory conditions and *in situ* across various regions of Australia will continue to be monitored by the department for possible elaboration and future update given the emerging character of this field of research.

10.7.3 Elaboration of national inventory methods

In general, Australia is planning to implement tier 3 models and approaches wherever appropriate in order to enhance accuracy of emission estimates, particularly of the land sector.

Within the land sectors, development activity will build on existing inventory models contained in FullCAM and will need to take into account:

- existing and future guidance under the UNFCCC inventory reporting guidelines;
- emerging empirical data from publicly-funded research programs into the effects on emissions and removals of changes in land management actions;
- the integration of project level data generated, for example, through the Emission Reduction Fund;
- the importance of modelling long term responses to land management actions while abstracting from short term, temporal effects that are ephemeral in nature to ensure policy relevance;
- costs of data management and associated complexities; and
- the need for transparency and other related factors identified in the IPCC Workshop, '*Use of Models and Facility-Level Data in Greenhouse Gas Inventories, Report of the IPCC Expert Meeting on Use of Models and Measurements in GHG Inventories, 9-11 August 2010, Sydney, Australia*'
    - ffi(i.e. reporting requirements include basis and type of model, application and adaptation of the model, main equations/processes, key assumptions, domain of application, how the model parameters were estimated, description of key inputs and outputs, details of calibration and model evaluation, uncertainty and sensitivity analysis, QA/QC procedures adopted and references to peer-reviewed literature).

Model development will be progressed across all land sectors. In particular, it is intended that the FullCAM will be extended to provide an improved modelling framework for the consideration of new data as it becomes available:

- methods for forest lands remaining forests will be elaborated over time to provide for a tier 3 spatially explicit method with additional estimation of forest carbon stocks as well as fluxes;
- methods for spatial modelling of sparse woody vegetation across Australia's grasslands;
- fire mapping will be incorporated to support improved estimates of emissions and carbon stocks across both forests and grasslands;
- soil modelling will be developed to integrate carbon and nitrogen cycles; and
- grassland modelling will be developed to ensure the reconciliation of vegetation and livestock models.

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