



Australian Government
Department of Climate Change

AUSTRALIA'S NATIONAL

GREENHOUSE ACCOUNTS



National Inventory Report 2005 (Revised) — Volume 2

The Australian Government Submission to the UN Framework Convention on Climate Change February 2008

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7. LAND USE, LAND USE CHANGE AND FORESTRY

7.1 OVERVIEW

The net emissions from the *land use, land use change and forestry* sector were 24.9 Mt CO₂-e in 2005 (Table 7.1).

Table 7.1 Land use, land use change and forestry net CO₂-e emissions, 2005

Greenhouse gas source and sink categories	CO ₂ -e emissions (Gg)			Total
	CO ₂	CH ₄	N ₂ O	
5 Land use, land use change and forestry^(a)				24 884
A. Forest lands ^(b)	-47 286	1 078	294	-45 913
B. Croplands ^{(c) (d)}	1 814	699	191	2 704
C. Grassland ^{(c) (d)}	69 106	1 801	492	71 399
D. Wetlands	NE	NE	NE	NE
E. Settlements	NE	NE	NE	NE
F. Other Lands	NE	NE	NE	NE
G. Other ^(e)	-3 306		NE	-3 306

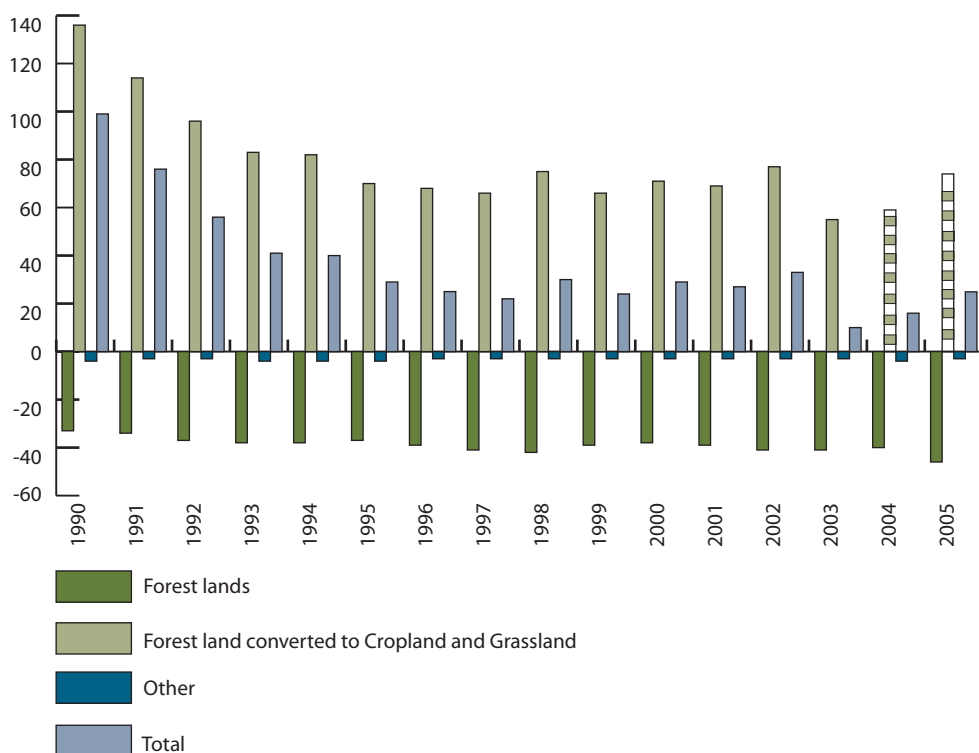
(a) A negative sign denotes a sink. (b) Includes emissions from prescribed burning and wildfires. (c) Includes emissions from biomass burning.

(d) The results for 2005 will be revised when areas of forest conversion are confirmed following the next update of estimates using the National Carbon Accounting System. (e) Includes Harvested Wood Products and Agricultural Lime Application.

Forest lands (5A) comprises emissions and removals from harvested native forests and plantations, emissions from fuelwood consumption and non-CO₂ gas emissions from prescribed burning and wildfire in forests. These subsectors are estimated to have constituted a net sink of 45.9 Mt CO₂-e in 2005.

The preliminary estimate for *Forest land converted to Cropland and Grassland* in 2005 is 74.1 Mt. The estimates for 2004 and 2005 should be considered as being interim only, as they will be revised when areas of forest conversion are confirmed in the the next update of the inventory using the National Carbon Accounting System.

Harvested wood products are not reported in the Forest lands category and carbon stocks are transferred to the 5G Other – Harvested Wood Product. As the reporting tables do not account for transfers of carbon stocks, this leads to an apparent, but not real, emission from forest lands and a 4.6 Mt 'sink' in harvest wood products.

Figure 7.1 Total net CO₂-e emissions from Land use, land use change and forestry, 1990–2005

Note: The results for forest conversion for 2004 and 2005 will be revised following the next update of the inventory.

Trends

Overall the total *land use, land use change and forestry* emissions declined from 99.1 Mt CO₂-e in 1990 to 24.9 Mt CO₂-e in 2005.

The preliminary estimate of total emissions from *forest land converted to cropland and grasslands*, was 45.7% (62.4 Mt) lower than in 1990. Since 1990 the annual rates of *forest conversion* have decreased substantially reflecting both the effects of changing market and climatic conditions and of regulatory impacts with consequent reductions in estimated emissions from burning and decay of above-ground biomass and below-ground carbon. There is also a diminishing effect of extensive past *land use change* on decay of above-ground biomass and below-ground carbon.

Within *forest lands* (5A), net removals from *forest land remaining forest land* declined by 26.2% (8.1 Mt) to -23.0 Mt CO₂-e from 1990 to 2005, while the removals from *lands converted to forest land* increased from -2.0 Mt to -21.8 Mt CO₂-e. The combined effect of these changes is an increase in the *forest lands* net sink of 38.6 % (12.8 Mt) between 1990 and 2005.

Emissions from *agricultural lime application* have increased from 0.2 Mt in 1990 to 1.4 Mt in 2005.

Table 7.2 Annual area of forest conversion (ha)

	Forest land converted to	
	Croplands	Grassland
1990	117,324	444,465
1991	89,165	338,630
1992	69,750	320,038
1993	65,337	323,026
1994	76,623	292,146
1995	60,788	253,876
1996	65,767	251,179
1997	65,359	246,712
1998	62,887	266,167
1999	62,152	273,237
2000	62,596	289,299
2001	65,941	286,648
2002	63,605	232,352
2003	62,714	216,452
2004	76,499	286,218
2005	55,955	277,611

7.2 OVERVIEW OF SOURCE CATEGORY DESCRIPTION AND METHODOLOGY – LAND USE, LAND USE CHANGE AND FORESTRY

Land use and management activities influence a variety of ecosystem processes that affect greenhouse gas fluxes. The focus of this sector is the estimation of emissions and removals of carbon dioxide (CO₂) from these activities. CO₂ fluxes between the atmosphere and managed land systems are primarily controlled by uptake from plant photosynthesis and releases from respiration, decomposition and oxidation of organic material. Nitrous oxide (N₂O) 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 (CH₄), carbon monoxide (CO), other oxides of nitrogen (NO_x) and non-methane volatile organic compounds (NMVOC).

7.2.1 LAND USE IN AUSTRALIA

Australia has a land mass of 769 million hectares containing unique land, water, vegetation and biodiversity resources. The distribution and land areas of the continent under different land uses are shown in Figure 7.2 and Table 7.3 shows the representation of land according to the IPCC categories.

The most significant agricultural activities include wool, beef, wheat, cotton and sugar. Australia is also a significant exporter of dairy produce, fruit, rice and flowers.

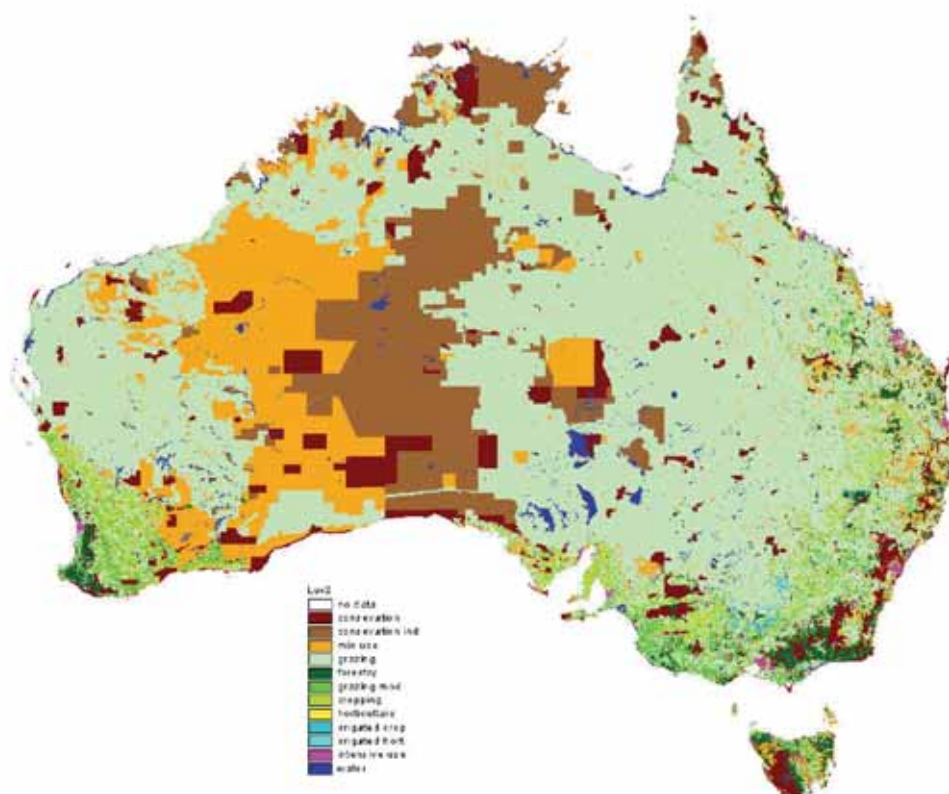
Table 7.3 Land representation matrix (2005)

Land Category	1990 (Mha)	2005 (Mha)	Net Change (Mha)
Forest lands total	112.0	108.9	-3.2
Forest remaining Forest	111.3	106.2	-5.2
<i>Harvested Native Forests</i>	14.9	14.9	0.0
<i>Plantations</i>	0.8	0.8	0.0
<i>Other Native Forest (a)</i>	95.6	90.5	-5.2
Grassland converted to Forest Land	0.1	1.2	1.1
Forest balancing term (b)	0.6	1.5	0.9
Grasslands total	441.2	444.3	3.1
Grassland remaining Grassland	440.8	439.7	-1.1
Forest Land converted to Grassland	0.4	4.6	4.2
Cropland total	24.8	25.8	1.0
Cropland remaining Cropland	24.7	24.7	0.0
Forest Land converted to Cropland	0.1	1.1	1.0
Wetlands total	13.5	13.5	0.0
Settlements total	1.6	1.6	0.0
Other Lands	176.4	176.4	0.0
TOTAL LAND AREA (c)	769.0	769.0	0.0

(a) Australia is not in a position to identify managed and unmanaged forests within the forest estate. In the interim until Australia confirms the definition of "managed forests" all non-harvested forests are reported as Forests remaining Forests – Other Native Forest with emissions and removals assumed to be in equilibrium. These forest areas will be revised once the determination of "managed forests" has been made.

(b) The forest balance term is a net term - that is there are transitions in both directions from forest regrowth and forest dieback which are in large part driven by climate variability. The total land area is balanced by subtracting the forest balancing term.

(c) Total area does not include external territories.

Figure 7.2 Land Use in Australia

7.2.2 CLIMATE

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

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

7.2.3 SOILS

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

Figure 7.3 Forest Extent in Australia

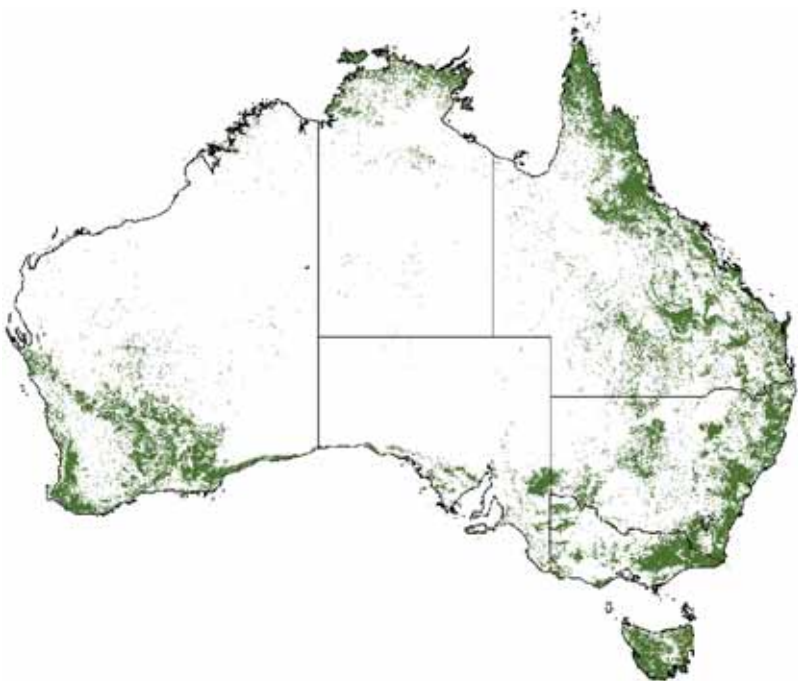


Figure 7.4 Average Annual Rainfall

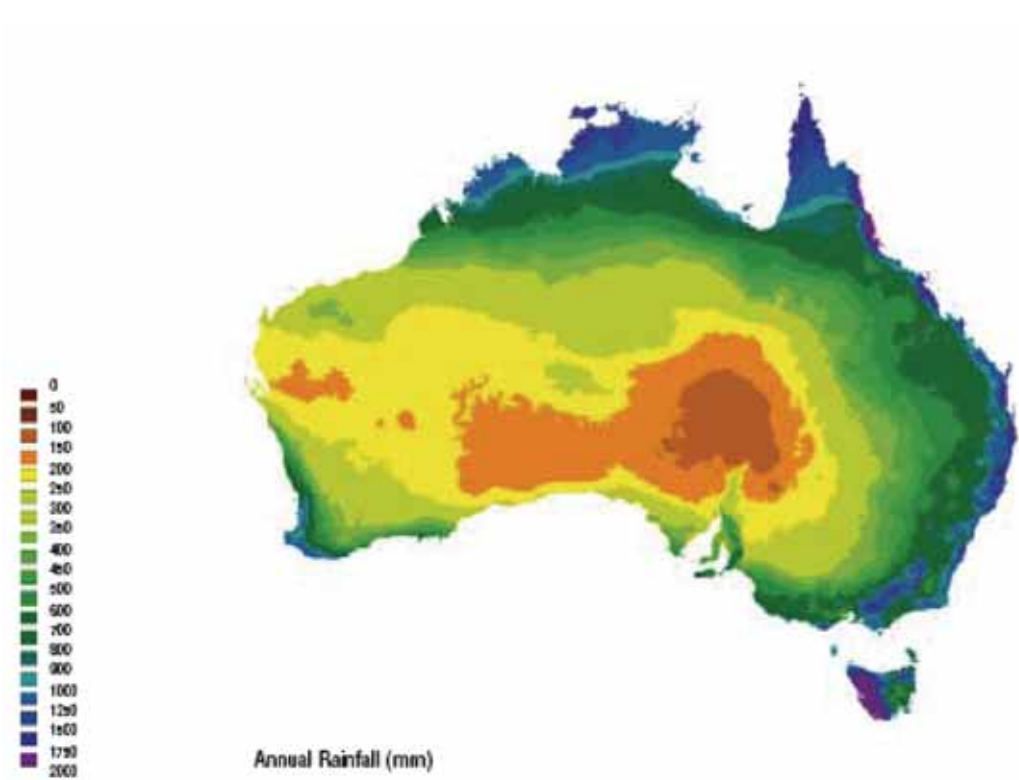


Figure 7.5 Average Annual Temperature

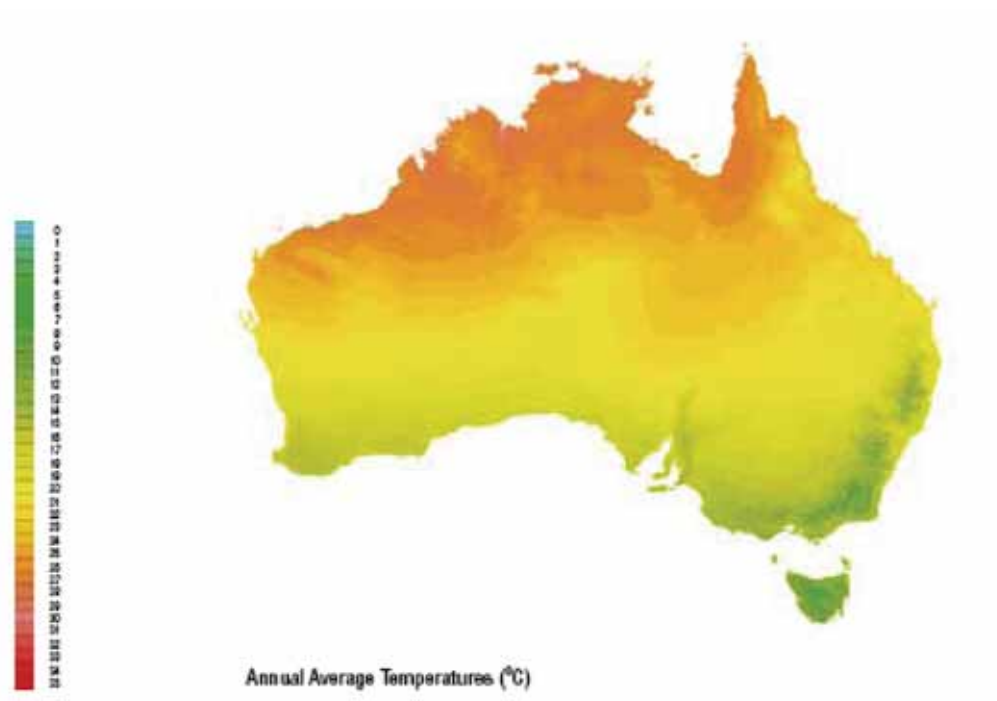
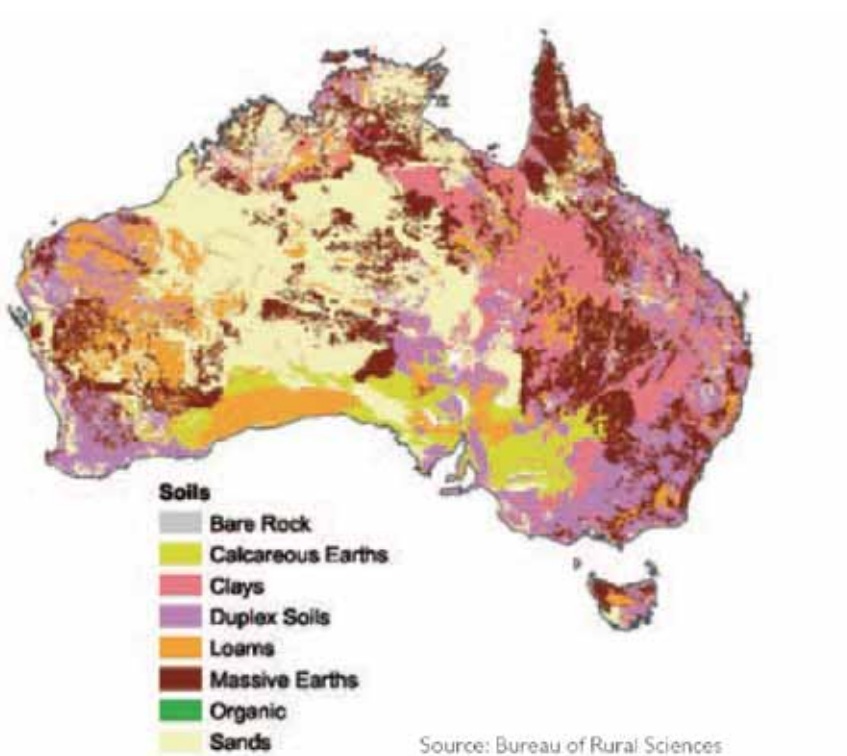


Figure 7.6 Soils Map of Australia



7.2.4 GENERAL APPROACH

The Australian LULUCF methodology contains predominantly country specific methodologies and Tier 3 models (Table 7.4). The principal method of representing land is through a time-series national remote sensing program. This consistent representation of land is a fully spatial and time-series application of Approach 3 as described in the IPCC Good Practice Guidance (IPCC 2003), but in some instances, interim data is drawn from Australia's National Forest Inventory. Where this is done, reconciliations on a land unit by land unit basis are done to ensure that there are no gaps or overlaps leading to under or double counting of land.

The methods used in the reporting of this inventory are described in detail in Appendices 7.A to 7.D.

Appendix 7.A – Harvested Native Forests for *Forest land remaining Forest land*;

Appendix 7.B – Forest Plantations for *Forest land remaining Forest land* and *Grassland converted to Forest land*;

Appendix 7.C – *Forest land converted to Grassland and Cropland*;

Appendix 7.D – *Harvested Wood Products*.

The NCAS development is staged over a ten year period, 1998 to 2008, with progressive implementation of a complete national (all lands, land use activities, pools and gases) reporting capability for agriculture, forestry and land use activities. To date the full NCAS capabilities (fully spatially explicit process-based ecosystems modelling) has only been completed for the conversion of forests to other land uses (e.g., cropping and grazing). For Australia, this represents the majority of emissions associated with *Land Use, Land Use Change and Forestry* activities. The methods applied to the estimation of emissions from the conversion of forest land to other land uses is described in Appendix 7.C. Appendix 7.E gives an outline of the current and planned NCAS capabilities for inventory improvement.

The methods used to estimate emissions from other activities (not associated with forest conversion) that use interim approaches are described in Appendices 7.A, 7.B and 7.D.

Table 7.4 Summary of methodologies and emission factors – Land use, land use change and forestry sector

Greenhouse Gas Source And Sink	CO ₂		CH ₄		N ₂ O		NO _x , CO and NMVOC	
	Method applied	EF	Method applied	EF	Method applied	EF	Method applied	EF
5. Land Use, Land Use Change and Forestry								
A. Forest Lands								
1. Forest Land Remaining Forest Land								
Harvested Native Forests	CS, T2	CS						
Other Native Forests	T1	CS						
Plantations	T3	M						
Fuelwood consumed	T1	CS						
5(V) Biomass Burning - 5.A.1.			CS	CS	CS	CS	CS	CS
2. Land Converted to Forest Land	T3	M						
B. Cropland								
1. Cropland remaining Cropland	T1	CS						
2. Land Converted to Cropland	T3	M						
5(V) Biomass Burning - 5.B.2	T3	M	CS	CS	CS	CS	CS	CS

Greenhouse Gas Source And Sink	CO ₂		CH ₄		N ₂ O		NO _x , CO and NMVOC	
	Method applied	EF	Method applied	EF	Method applied	EF	Method applied	EF
5. Land Use, Land Use Change and Forestry								
5(III) Disturbance associated with land conversion					IE	IE		
C. Grassland								
1. Grassland remaining Grassland	T1	CS						
2. Land Converted to Grassland	T3	M						
5 (V) Biomass Burning - 5.C.2	T3	M	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						
F. Other								
Harvested Wood Products	T3	M						
5(I) N fertilisation					IE	IE		
5(II) Drainage of Soils					NE	NE		
5(III) Disturbance associated with land conversion						IE	IE	
5(IV) Agricultural lime application	CST1	D						

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

7.2.5 AUSTRALIA'S NATIONAL CARBON ACCOUNTING SYSTEM

Australia has embarked on a 10 year development program for a National Carbon Accounting System (NCAS) to provide a complete accounting capability by 2008 (AGO 2005). With a current annual investment of approximately AUD \$4 million per year, the NCAS will be progressively developed to provide a complete (all carbon pools, gases, lands and land use activities) greenhouse gas accounting capability for agriculture, forestry and land use. The eventual capacity will be a full spatial enumeration with emissions and removals calculated using a process-based, mass balance, carbon and nitrogen cycling, ecosystem model.

The full spatial enumeration is achieved through an extensive remote sensing program that uses medium resolution (50m and 25m) Landsat satellite data in a time-series since 1972 (Furby 2002; Caccetta et. al., 2003). There are currently fifteen national coverages in the time-series. The medium resolution data is used to determine change in forest and sparse woody vegetation, and to determine plantation area, age and type. Land use is being mapped using a coarse 1km resolution (NOAA) satellite, with a higher temporal resolution time-series (16 day) and constrained to agricultural survey statistics.

Monthly climate maps at 1km resolution since 1968 have been derived to provide the annual variability due to climatic process drivers (Kesteven et. al., 2004). Coupled with management practices, the vegetation cover change and climate variability are together the principal causes of emissions, and source of annual variability in emissions.

The progressive development of the NCAS is set around priorities according to the scale of emissions from either the land use activity or carbon pool. For Australia, by far the largest component of emissions is the conversion of forests to cropland and grassland. In the 2005 Revised national inventory, only the forest to cropland and forest to grassland conversions are reported using the full Tier 3, Approach 3 capability of the NCAS.

The other principal reporting elements, forests remaining forests and land converted to forest are reported using interim methods that, as yet, have not been fully spatially developed within the NCAS framework. This is also the case for harvested wood products.

As the NCAS operates under a tightly integrated singular framework, and generates the bulk of its required input data, specifications are applied that ensure that the collection of data and analysis meet both technical and policy specifications. This has led to the development of detailed methods and protocols to ensure that all data meets quality and consistency standards. These specifications and protocols have been published and are publicly available through the internet, library deposits and circulation on compact disk as part of the free-of-charge distribution of the National Carbon Accounting Toolbox (NCAT).

7.2.6 CROSS-CUTTING ISSUES

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

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

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

The following describes the way in which the cross-cutting issues are addressed in the NCAS around:

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

Each of these is discussed in relation to the various processes used in inventory preparation.

7.2.6.1 Quality Assurance and Quality Control

Harvested Native Forests

The growth rates used in the harvested native forests model are drawn from Australia's National Forest Inventory and are 'benchmarked' against independent estimates. The area estimates are also benchmarked against independent data, but these estimates are highly variable. Data on stem to whole tree conversions, carbon contents and wood densities are all cross-checked against independent estimates. Data on harvest volumes are drawn from national statistics on forest products production consumption. Decomposition estimates, such as for harvested wood products and forest slash are within ranges developed/used in independent studies.

Plantations

Data on the area of plantations is drawn from the published data of Australia's National Forest Inventory. Growth rate estimates of the various plantation types are also extracted from the National Forest Inventory published report on national wood flow estimates. Appendix 7.B of this report describes the approach taken. Model parameters have been drawn from various studies, both specifically for, and prior to the development of the NCAS. The values used represent the estimates judged as most probable.

The model, model parameterisation and results were submitted for external independent quality assurance. The quality assurance report is at Attachment 7.B2 of Appendix 7.B. The models used are also the 'benchmark' systems for the NCAT, and are publicly available and widely used by the forest industry in estimating carbon budgets.

Forest Converted to Other Land Uses

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

Harvested Wood Products

The data for the harvested wood products model described in Appendix 7.D has been drawn from a variety of sources. As described in the Appendix, wherever possible data has been cross-checked against independent sources. The model has also been subjected to independent quality assurance and the report of this is at Attachment 7.D2.

7.2.6.2 Verification

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

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

Land Cover Change and Plantation Classification

Extensive independent verification programs of the land cover change and plantation mapping via remote sensing techniques have been continuously applied throughout the time-series updates. The methods applied to verification of the land cover change results are published in the NCAS Technical Reports (Lowell et. al., 2003 and Jones et. al., 2004) and in peer review literature (Lowell et. al., 2005). This program initially relied on verification against historic air photographs, and more recently, by using very high resolution satellite data (1m). The verification of the plantations mapping (MBAC Consulting *in prep.*) was based on on-site field inspection. This alternative approach was used because it was able to provide a definite date of planting (from signage or company records) and could accurately provide parameters such as species, stocking rate, condition etc. that could not be derived with certainty from remote techniques. This program was based on several hundred sites throughout Australia, selected to be representative of geographic regions, plantation types and plantation ages.

Forest Growth

The direct measurement of forest biomass is rare, and as destructive sampling is required, no time-series growth data based on whole mass measurement is available. However, through the use of allometric equations from measurable forest stand parameters of basal area, height etc. it is possible to model total stand biomass. As these measures are widely used in forest inventory, there is a wealth of industry data available as both single point in time and time-series (permanent plot) measurements against which growth and biomass estimates have been verified. In addition, research site data comparisons and select whole-stand mass measurements have been applied. The benefits of comparisons with research data has been that additional to commonly available stand biomass estimates are data on site conditions and management. Because of the cost and logistical difficulty in actually measuring total stand biomass, the approach taken was to destructively sample and weigh forest plots of a single species across a productivity gradient (Ximenes et. al., 2005). This approach could then test both the biomass predictions and replication of the gradient in forest productivity and carrying capacity by model estimates.

Soil Carbon

Much like the verification activities for forest biomass, a tiered approach was applied to the verification of modelled soil carbon change estimates. Most geographically widespread and representative data were taken from paired site samples, before and after land use change. The change in total soil organic carbon was compared to modelled estimates. Soil fractionations were also completed to test the model performance in predicting turnover in various soil carbon pools. Wherever possible, models were also compared to research site data (Skjemstad and Spouncer 2002). This had the benefit of multiple pool, time-series measurements for comparison, along with the recorded impacts of detailed site condition and management.

7.2.6.3 Sensitivity and Uncertainty Testing

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

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

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

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

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

7.2.6.4 Transparency and Peer Review

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

- > published specifications, protocols and methods;
- > published verification results;
- > public release of models, tools and data; and,
- > publication in peer reviewed literature.

These aspects of transparency are discussed further in the methods Appendices (7.A-7.E).

7.2.7 Forest definition and monitoring of forest conversion

7.2.7.1 Forest Definition

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

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

The Marrakech Accords provide ranges for forest attributes from within which countries are to derive national

definitions. The ranges were for height of 2 to 5 metres, crown canopy cover 10 to 30%, a minimum area of 0.05 to 1.0 hectare. Consistent with the definition used for Australia's National Forest Inventory that has been used for reporting to the FAO and Montreal Process, a height of 2 metres and crown canopy cover of 20% were adopted for the forest definition.

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

7.2.7.2 Understanding patterns of change

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

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

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

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

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

7.2.7.3 Data availability

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

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

- > select an analytic method;
- > develop scene acquisition specifications for the geometric registration, radiometric calibration, and analysis and processing of the images to forest monitoring products;

- > trial the methods using pilot studies of which the results were used to form detailed operational specifications (Furby and Woodgate, 2002);
- > develop methods for continuous improvement and verification of the data; and
- > establish the R&D programs that led to enhancement of the processes, such as described by Caccetta et al (2003) and Wu, Furby and Wallace (2004).

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

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

7.2.7.4 Time-series consistency

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

The conditional probability network uses a series of spatial and temporal rules for determining forest presence/absence and change (forest and non-forest conversions). The temporal rules bias against unlikely events such as multiple one year conversions between forest and non forest – for example conversion from non-forest to forest back to non-forest is an unlikely event over a short, say three year, period. In the example given, 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 (eg isolated pixels). The spatial and temporal rules work together providing spatial and temporal consistency, minimising temporally varying “mixed pixel” effects (due to spatially varying sampling from independent satellite overpass year to year) and subsequent error in pixel and change labelling.

7.2.7.5 Mapping resolution and resampling

Modelling grid resolution

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

The pixel resolution of 50m and 25m are also guided by the need to integrate this spatial data with other spatial data sets. To achieve consistency in this integration a minimum 25m resolution, or select multiples of 25m (eg 50m, 1000m, 200m, 250m, 1km) are applied so that pixel to pixel registration is achieved.

Land cover grid resolution

In order to deal with the change in pixel size of the various Landsat sensors over time and the need for spatially and temporally consistent integration with other spatial data used in the model, the 'natural' pixel size of the Landsat MSS (57m x 79m) was re-sampled to a 50 x 50m pixel. The Landsat TM (~30 x 30m native resolution) and ETM+ data available after 1988 were produced as 25 x 25m pixels (see details in Appendix 7.C).

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

Data are taken to a consistent 25m resolution for the full time-series analysis by resampling the 50m pixels into four 25m pixels. The spatial-temporal model is important at this time, as it reduces the effect of "mixed" isolated and edge MSS pixels in the same way as described in section 7.2.7.4.

The period of the transition to the true 25m data takes place prior to the period where it would have any significant effect on the first reported year of emissions. The 50m data resolution is effectively only used to run-in the model to establish forest age (if a regrowth from non-forest land or in response to a forest removal since 1972). The ability to determine, from 1990 onwards, the effects of land use change to 0.2ha minimum areas is robust, given that this area is greater than the pixel resolution and the approach used removes mixed and other pixels which are temporally and spatially inconsistent. It is important to note that the change area within the commitment period (1990 onwards) is consistent at the 0.2ha resolution.

The use of a 25m pixel resample for Landsat TM and ETM data is common practice. The use of a 50m resample to provide consistency over the multiple resolutions of MSS sensors also provides for uniformity in the time-series. QA and validation processes confirm that accurate results are achieved with this resampled data.

7.2.7.6 Carbon stocks in 1990

As the first reporting period is 1990 and data is available since as early as 1972, the 1972 to 1989 period is used to run-in the model. This is informed by the mapping of forest extent in 1972, and the histories of forest disturbance since that time. This disturbance history is used to determine the age of forests, and therefore their carbon stocks. The carbon stocks for 1972 are determined from their 'native' condition in a largely undisturbed state (Richards and Bracks 2004; and Webbnat Land Resource Services 2002).

The raster-based spatial model then uses the disturbance histories, climate and management data etc to determine the carbon stocks in the run-in level for 1990.

The effect of this approach is that areas of forest in 1972 are tracked through time, and if they remain forests until 1990 they will hold the carbon stocks of a largely undisturbed forest. For any forest regrowth after disturbance, and any new forest areas, their age, and therefore carbon stocks can be calculated.

7.2.7.7 Land Classification

Australia's reporting meets the IPCC (2003) land representation criteria of being consistent over time, and that land is represented in only one category. Movement of land between categories is reported where a land use change occurs, such as a conversion of forest to cropland and grassland, or grassland to a forest.

In cases where there is a temporary change, such as a forest harvest, that land is not temporarily transferred

in and out of that land category as per good practice guidance. Equally, a temporary regrowth of woody biomass, as occurs in many grassland systems in Australia, is continuously reported under the grassland category. As such consistency in treatment of temporary changes in land classification is maintained.

Using an Approach 3 land representation system, Australia monitors, over a consistent time-series, land use categories and change between them. As recognised in IPCC (2003), it may take many years to reach a new equilibrium condition after a land use conversion for all reported carbon pools. As Australia applies Tier 3 ecosystems modelling to most land use conversion categories, no limit is imposed on the time taken to reach equilibrium as is applied when using Tier 1 or 2 methods. Therefore Australia does not adopt the use of a default such as the 20 year period upon which land is moved automatically from a land use conversion to a land use remaining category.

7.3 SOURCE CATEGORY 5A FOREST LANDS

7.3.1 METHODOLOGY

7.3.1.1 Forest Land Remaining Forest Land

There are three broad components to *Forest land remaining Forest land* – Harvested Native Forests, Other Native Forests and Plantations. These are treated as independent strata and emissions estimates are modelled independently.

The methods for estimating emissions from controlled burning and wildfires in *Forest land remaining Forest land* are described in section 7.10.

Forests are defined as having vegetation (trees) with a height of at least 2m and a minimum crown canopy cover of 20%. These parameters are the same as used in Australia's National Forest Inventory. A minimum area of 0.2ha is additionally used for identifying areas of forest for greenhouse gas reporting purposes. The National Forest Inventory does not apply a specified minimum area.

Harvested Native Forests

Harvested native forests are taken to be those comprised of endemic species arising from natural regrowth, although various silvicultural techniques may be applied to initiate and promote particular growth characteristics. The areas considered are those subject to harvest and regrowth from prior harvest. Areas of deforestation that change to a non-forest land use or to plantation (native and exotic) are excluded from this account and are reported elsewhere.

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

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

Harvested wood products are not reported in this category and carbon stocks are transferred to the harvest wood products reporting (G Other). In the structure of the reporting tables that do not account for transfers of carbon stocks, this leads to an apparent, but not real, emission from harvested native forests and a 'sink' in harvested wood products.

Other Native Forests

Other native forests include those forests that (a) are comprised of endemic species, (b) are not harvested

native forests (c) are not areas of deforestation, and (d) are not plantations (native or exotic).

Net CO₂ emissions and removals from other native forests are reported as '0'. These forests are assumed to be in equilibrium as there are no significant anthropogenic removals of carbon stocks. While local and short-term variability in emissions and removals due to natural causes (ie forest die back and regrowth associated with climate variability) and fires can be substantial the natural 'background' of greenhouse gas emissions and removals by sinks average out over time.

As no removals by regrowth are estimated for these forests only non-CO₂ emissions associated with controlled burning and wildfires are estimated (see section 7.10).

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

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

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

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

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

Harvested wood products are not reported in this category and carbon stocks are transferred to the harvest wood products reporting (G Other). In the structure of the reporting tables that do not account for transfers of carbon stocks, this leads to an apparent, but not real, emission from plantation forests and a 'sink' in harvested wood products. This leads to these plantations appearing as a source of emissions when coupled with the reporting of plantations in *Grassland converted to Forest land* also removes the expansion of the plantation area (young forests) that act as a sink.

Fuelwood Consumed

For transparency the CO₂ emissions associated the consumption of fuelwood are reported separately. The

amount of fuelwood collected from forest lands is based on the estimates of fuelwood consumption (t dry matter) reported by ABARE. Dry matter is converted to carbon content (0.5) and multiplied by 44/12 to give CO₂ emissions.

7.3.1.2 Land Converted to Forest Land

In Australia, lands converted to forest land are almost always formerly grassland, and even if they have been previously cropped at some time, they will have had a period as grassland prior to conversion of forest land. All emissions are therefore reported as *Grassland converted to Forest land*. High land values and high soil nutrient status both limit the access to, and suitability of, former croplands for plantation establishment.

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

The modelling method used to estimate emissions is described in Appendix 7.B and is the same as the method used for plantations under *Forest land remaining Forest land*. Again, the soil carbon pool has not been estimated. Polglase et. al. (2004), Paul et. al. (2002b) and Paul et. al. (2003b) have shown that with the establishment of plantations on pasture land an initial loss of soil carbon will be recovered over time. Given the mix of ages of the plantations reported under this category, it is expected that initial losses of soil carbon in young forests would be counterbalanced by the accumulation in older forests. As with *Forest land remaining Forest land*, a calibrated and verified soil carbon model will be used to estimate soil carbon emissions in future when the full NCAS spatially explicit modelling (Tier 3, Approach 3) is applied.

When a fully spatially explicit approach is taken in parallel to that used for *Forest land converted to Grassland*, it will be possible to remove any potential overlap in land areas between these two categories. This could occur where plantations are established after 1990 on land that was cleared after 1970.

7.3.2 UNCERTAINTIES AND TIME SERIES CONSISTENCY

Uncertainties for Forest lands were estimated to be $\pm 30\%$ for CO₂. Further details are provided in Annex 7. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to methodology.

7.3.3 SOURCE SPECIFIC QA/QC

Specific QA/QC and verification activities undertaken for this source category are described in detail in section 7.2.6.1.

7.3.4 RECALCULATIONS SINCE THE 2004 REVISED INVENTORY

The following recalculations were performed for the 2005 inventory:

- a) updating of harvested volume data
- b) correction to several components of the models identified following internal QC and UNFCCC review activities.
- c) CO₂ emissions from fuelwood burning in the wood, pulp and paper industries has been excluded from the total fuelwood burnt as these industries will typically use offcuts from roundwood, which is already accounted for in the native forest harvesting section of the inventory.

The above changes result in a reduction in CO₂ removals from *Forest land remaining Forest land* of 9.6 Mt in 1990 and 7.8 Mt in 2004.

7.3.5 SOURCE SPECIFIC PLANNED IMPROVEMENTS

The method used is yet to reflect the fully spatially explicit (Approach 3), Tier 3 process-based modelling methods of Australia's NCAS. The methods being developed as described in Appendix 7.E will provide a comprehensive estimation capability for future reporting when the national implementation has been fully calibrated, verified, quality assured and peer reviewed. This is consistent with the approach to inclusion of NCAS results in the national inventory only after all appropriate cross-cutting processes have been completed.

In addition with the calibration of a forest soil carbon model within the NCAS soil carbon pools will also be estimated and reported for these forests when the fully spatial area data is available.

7.4 SOURCE CATEGORY 5B CROPLAND

7.4.1 METHODOLOGY

7.4.1.1 Cropland Remaining Cropland

Forest land converted to Cropland is taken to be all of the current croplands that were deforested since 1972 (commencement of the NCAS national remote sensing of land cover change as described in Appendix C). *Cropland remaining Cropland* is therefore a land use that has persisted for a period of over 30 years. The results of field trials and paired site sampling analyses carried out for Australia's NCAS (Skjemstad and Spouncer 2002) show that soil carbon is in equilibrium at this stage. Also, the biomass of annual crops is generally consistent year to year, particularly with variability across regions tending to an average over the entire country. The carbon stock change and CO₂ emissions for *Cropland remaining Cropland* are therefore reported as '0'.

Non-CO₂ greenhouse gas emissions from *Cropland remaining Cropland* are reported under the Agriculture sector of the inventory.

7.4.1.2 Land Converted To Cropland

In many Australian agricultural land systems there is an ongoing practice of rotations between crops and grasslands. These are considered as ongoing use as cropland because this part of the rotational system has the greatest influence on carbon stocks and greenhouse gas emissions. Because of this, whenever land is cropped it is considered cropland and reported under a Cropland category (although the emissions are estimated taking account that land use may have transferred to and fro between a grassland and crop use).

Forest Land Converted to Croplands

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

The reporting of *Forest land converted to Cropland* includes all on-site carbon pools. The areas are identified by the NCAS remote sensing program as described in Appendix C. As all national land areas are covered by this program in time-series since 1972, all *Forest land converted to Cropland* has been identified

Emissions and removals are estimated using the Tier 3, Approach 3 NCAS mass balance, process-based

ecosystem model *FullCAM*, as described in Appendix C. The calibration and verification of this model, along with the associated quality assurance and quality control program are described in Appendix C.

7.4.2 UNCERTAINTIES AND TIME SERIES CONSISTENCY

Uncertainties for Cropland conversion were estimated to $\pm 10\%$ for CO₂. Further details are provided in Annex 7. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to methodology.

7.4.3 SOURCE SPECIFIC QA/QC

Specific QA/QC and verification activities undertaken for this source category are described in detail in section 7.2.6.1.

7.4.4 RECALCULATIONS SINCE THE 2004 REVISED INVENTORY

Emissions for the most recent years in the *forest conversion* categories are recalculated each year following confirmation of the status of areas where the occurrence of forest removal was previously uncertain.

For the 2005 inventory additional recalculations have been made following the incorporation of a number of methodology improvements. These improvements have enabled more comprehensive national spatial coverage through filling of previous spatial data gaps; new detections of small areas of clearing in regions where land management activity data was previously lacking; and improved forest type identification, which has allowed for enhancement of confirmation of clearing events.

These improvements have also resulted in the reallocation of converted lands between grassland and cropland categories.

The above changes result in an increase in emissions from *forest lands converted to croplands* of 10.7 Mt in 1990 and 8.3 Mt in 2004.

7.4.5 SOURCE SPECIFIC PLANNED IMPROVEMENTS

In taking a land systems based approach with its Tier 3 fully spatially explicit methods Australia is in the process of implementing fully integrated emissions estimates. To achieve this Australia will develop capabilities for the comprehensive reporting of all forms of emissions for all activities on the land from which they occur. Australia will therefore be in a future position to report all emissions, CO₂ and non-CO₂, for each of the land categories.

7.5 SOURCE CATEGORY 5C GRASSLAND

7.5.1 METHODOLOGY

7.5.1.1 Grassland Remaining Grassland

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

Zero emissions are reported from *Grassland remaining Grassland* on the basis that annual cycles for plants and litter do not vary year to year. Also, these lands are considered to have been under a Grassland use for 30 years (they would otherwise be identified as a Cropland or *Forest land converted to Grassland*). After this period of

time it is presumed that carbon stocks will have reached an equilibrium (Skjemstad and Spouncer (2002). Non-CO₂ emissions are reported in the Agriculture sector.

7.5.1.2 Land Converted To Grassland

Forest Land Converted to Grassland

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

The reporting of *Forest land converted to Grassland* includes all carbon pools. The areas are identified by the NCAS remote sensing program as described in Appendix C. As all national land areas are covered by this program in time-series since 1972, all *Forest land converted to Grassland* has been identified. All lands converted from forest to continuous grassland use are included. Cyclic forest regrowth and reclearing of woody regrowth in grasslands is continuously reported under *Forest land converted to Grassland*. Where a cropping activity takes place on these lands they are removed from this account and are reported under *Forest land converted to Cropland*.

Emissions and removals from this category are estimated using the Tier 3, Approach 3 NCAS mass balance, process-based ecosystem model *FullCAM*, as described in Appendix C. The calibration and verification of this model, along with the associated quality assurance and quality control programs are also described in Appendix C.

7.5.2 UNCERTAINTIES AND TIME SERIES CONSISTENCY

Uncertainties for Grassland conversion were estimated to be $\pm 10\%$ for CO₂. Further details are provided in Annex 7. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to methodology.

7.5.3 SOURCE SPECIFIC QA/QC

Specific QA/QC and verification activities undertaken for this source category are described in detail in section 7.2.6.1.

7.5.4 RECALCULATIONS SINCE THE 2004 REVISED INVENTORY

Emissions for the most recent years in the *forest conversion* categories are recalculated each year following confirmation of the status of areas where the occurrence of forest removal was previously uncertain.

For the 2005 Revised inventory additional recalculations have been made following the incorporation of a number of methodology improvements. These improvements have enabled more comprehensive national spatial coverage through filling of previous spatial data gaps; new detections of small areas of clearing in regions where land management activity data was previously lacking; and improved forest type identification, which has allowed for enhancement of confirmation of clearing events.

These improvements have also resulted in the reallocation of converted lands between grassland and cropland categories.

The above changes result in a decrease in emissions from *Forest land converted to Grasslands* of 3.3 Mt in 1990 and 2.3 Mt in 2004.

7.5.5 SOURCE SPECIFIC PLANNED IMPROVEMENTS

In taking a land systems based approach with its Tier 3 fully spatially explicit methods Australia is in the process of implementing fully integrated emissions estimates. To achieve this Australia will develop capabilities for the comprehensive reporting of all forms of emissions for all activities on the land from which they occur. Australia will therefore be in a future position to report all emissions, CO₂ and non-CO₂, for each of the land categories.

7.6 SOURCE CATEGORY 5D WETLAND

7.6.1 METHODOLOGY

7.6.1.1 Wetland Remaining Wetland

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

7.6.1.2 Land Converted To Wetland

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

7.7 SOURCE CATEGORY 5E SETTLEMENTS

7.7.1 METHODOLOGY

7.7.1.1 Settlements Remaining Settlements

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

7.7.1.2 Land Converted To Settlements

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

7.8 SOURCE CATEGORY 5F OTHER LANDS

7.8.1 METHODOLOGY

7.8.1.1 Other Lands Remaining Other Lands

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

7.8.1.2 Land Converted To Other Land

It is assumed that no Lands are converted to Other Lands

7.9 SOURCE CATEGORY 5G OTHER

7.9.1 METHODOLOGY

7.9.1.1 Harvested Wood Products

Australia reports the carbon stock changes and associated emissions and removals of CO₂ from the harvested

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

7.9.1.2 N₂O Emissions From N Fertilisation 5(I)

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

7.9.1.3 N₂O Emissions From Drainage of Soils 5(II)

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

7.9.1.4 N₂O Emissions from Disturbance Associated with Land-Conversion to Cropland 5(III)

Emissions of N₂O from conversions to Cropland and other emissions including due to the application of nitrogen fertiliser are reported under the Agriculture sector.

7.9.1.5 CO₂ Emissions from Agricultural Lime Application 5(IV)

Limestone and dolomite are used in Australia to ameliorate soil acidity and improve plant growth. Adding carbonates to soils in the form of lime (eg. calcic limestone (CaCO₃) or dolomite (CaMg(CO₃)₂)) leads to CO₂ emissions as the carbonate limes dissolve and release biocarbonate which evolves into CO₂ and water

For agricultural lime application, the annual emissions of CO₂ are calculated as:

$$E_{ijk} = ((M_{ijk} \times \text{FracLime}_{ijk} \times P_{k=1} \times EF_{k=1}) + (M_{ijk} \times (1 - \text{FracLime}_{ijk}) \times P_{k=2} \times EF_{k=2})) \times C_g / 1000 \quad (5IV_1)$$

Where: E_{ijk} = annual emission of CO₂ from lime application (Gg)

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

FracLime_{ijk} = fraction limestone

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

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

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

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

C_g = 44/12 factor to convert elemental mass of CO₂ to molecular mass

7.9.2 UNCERTAINTIES AND TIME SERIES CONSISTENCY

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

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

7.9.3 SOURCE SPECIFIC QA/QC

Specific QA/QC and verification activities undertaken for this source category are described in detail in section 7.2.6.1.

7.9.4 RECALCULATIONS SINCE THE 2004 REVISED INVENTORY

The source category 5(IV) CO₂ Emissions from Agricultural Lime Application is included in the inventory for the first time. This source adds 0.2 Mt to the 1990 emissions and 1.2 Mt to the estimate for 2004.

7.9.5 SOURCE SPECIFIC PLANNED IMPROVEMENTS

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

7.10 SOURCE CATEGORY 5(V) BIOMASS BURNING

7.10.1 METHODOLOGY

7.10.1.1 Forest Lands (5A.1) - Prescribed Burning and Wildfires

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

The release of CO₂ in fire is not synchronous with the rate of uptake by regrowing forest and may take many years to sequester the quantity of carbon released in a wildfire of prescribed burn. As the Australian method does not report removals by regrowth after these fires Australia also does not report CO₂ emissions associated with the fires, in accordance with IPCC (2003, page 3.49) guidelines.

Treatment of C stock changes and fire

As the growth rates, age class and forest areas of the harvested native forest are fixed, the increment to living biomass is independent of any fire activity. Hence the method does not account for regrowth after fires. Where fully spatial data is used Australia derives fire masks for each satellite data overpass, and these are used during spatial modeling to remove any regrowth from these areas from accounting.

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

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

$$M_{jkl} = A_{jkl} * FL_{jkl} * Z_{jk} * 10^{-3} \text{ (Gg)} \quad (5V_1)$$

Where: A_{jkl} = area of category burnt annually (ha),

M_{jkl} = mass of fuel burnt annually (Gg),

FL_{jkl} = fuel loading (dry weight) (Mg ha⁻¹) (Table 7.5 and 7.6),

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

Z_{jk} = burning efficiency (Table 7.7).

then for CH_4 , CO and NMVOCs calculate total annual emissions:

$$E_{ijkl} = M_{jkl} * CC_{jk} * EF_{ijk} * C_i \text{ (Gg)} \quad (5V_2)$$

Where: E_{ijkl} = annual emission of gas i from biomass burning (Gg),

M_{jkl} = mass of fuel burnt annually (Gg yr⁻¹).

CC_{jk} = carbon mass fraction in vegetation (Table 7.8),

EF_{ijk} = emission factor for gas i from vegetation (Table 7.9),

C_i = factor to convert from elemental mass of gas species i to molecular mass (Table 7.10),

and total annual emissions for NO_x and N_2O are:

$$E_{ijkl} = M_{jkl} * CC_{jk} * NC_{jk} * EF_{ijk} * C_i \text{ (Gg)} \quad (5V_3)$$

Where: E_{ijkl} = annual emission of gas i from biomass burning (Gg),

M_{jkl} = mass of fuel burnt annually (Gg),

CC_{jk} = carbon mass fraction in vegetation (Table 7.8)

NC_{jk} = nitrogen to carbon ratio in biomass (Table 7.8)

EF_{ijk} = emission factor for gas i from vegetation (Table 7.9)

C_i = factor to convert from elemental mass of gas species i to molecular mass (Table 7.10)

Table 7.5 Fuel loads for Prescribed Burning of Forest in Australia

State	ACT ^(a)	NSW ^(a)	NT ^(a)	Qld ^(a)	SA ^(b)	Tas ^(b)	Vic ^(a)	WA ^(a)
	FL _{ijkl} (Mg/ha)							
Load	17.6	18.2	4.1	9.7	9.6	20.0	17.9	12.0

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

Table 7.6 Fuel loads for Wildfires in Australia

State	ACT ^(a)	NSW ^(a)	NT ^(a)	Qld ^(a)	SA ^(b)	Tas ^(b)	Vic ^(a)	WA ^(a)
	FL _{ijkl} (Mg/ha)							
Load	35.6	36.4	7.2	19.4	19.2	40.0	35.8	33.4

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

Table 7.7 Burning efficiencies for Prescribed Burning and Wildfires in Australia

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

Tolhurst (1994)

Table 7.8 Forest vegetation composition

System	Carbon mass fraction in dry residue CC_{ijk}	Nitrogen to carbon mass fraction NC_{ijk} ^(a)
Forest	0.50	0.011

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

Table 7.9 Mean emission factors for carbon and nitrogen trace gases from forest biomass burning

	Gas species i	Emission factor EF _{ijk} (Gg element in species/Gg element in fuel burnt)
1.	CH ₄	0.0054
2.	N ₂ O	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 7.10 Elemental to molecular mass conversion factor(C_i)

CH ₄	N ₂ O	NO _x	CO	NMVOC
1.33	1.57	3.29	2.33	1.17

7.10.1.2 Forest Lands Converted to Croplands and Grasslands (5B.2 AND 5C.2)

Carbon dioxide emissions from on-site burning associated with land conversion is estimated by the National Carbon Accounting System (Appendix C). The mass of fuel carbon burnt annually (FC_{jkl}) is taken directly from the National Carbon Accounting System and is used to estimate the non-CO₂ gases associated with burning.

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

The algorithms for total annual emissions of CH₄, CO and NMVOCs are:

$$E_{ijkl} = FC_{jkl} * EF_{ijk} * C_i \text{ (Gg)} \quad (5V_4)$$

and for total annual emissions for NO_x and N₂O are:

$$E_{ijkl} = FC_{jkl} * NC_{jk} * EF_{ijk} * C_i \text{ (Gg)} \quad (5V_5)$$

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

EF_{ijk} = emission coefficient for gas i from vegetation (Table 7.9),

NC_{jk} = nitrogen to carbon ratio in biomass (Table 7.8)

C_i = factor to convert from elemental mass of gas species i to molecular mass (Table 7.10).

7.10.2 UNCERTAINTIES AND TIME SERIES CONSISTENCY

Uncertainties for biomass burning CH₄ and N₂O were estimated to be in the order of -45 to +93% for Forest Lands and ±20% for forest conversion categories. Further details are provided in Annex 7. Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to methodology.

7.10.3 SOURCE SPECIFIC QA/QC

Specific QA/QC and verification activities undertaken for this source category are described in detail in section 7.2.6.1. Data quality used in the inventory is kept under review by the AGO. This source category is also covered by the general QA/QC procedures detailed in Section 1.6.

7.10.4 RECALCULATIONS SINCE THE 2004 REVISED INVENTORY

The following recalculations were performed for the 2005 inventory:

- a) emissions for the most recent year in the Forest lands biomass burning category are recalculated each year due to the recalculation of the three-year average of emissions once the third year of data becomes available.
- b) The amount of carbon burnt in forest conversion was revised following changes made to methods and data as described in sections 7.3.4 and 7.4.4.
- c) The carbon mass fraction has been changed to 0.5 to be consistent with the value used in the estimation of emissions/removals in 5A1.

The above changes result in an increase in *Forest lands* biomass burning emissions of 0.2 Mt in 1990 and 0.4 Mt in 2004. *Forest conversion* burning emissions decreased by 0.8 Mt in 1990 and increased by 0.2 Mt in 2004.

7.10.5 SOURCE SPECIFIC PLANNED IMPROVEMENTS

All data and methodologies are kept under review and development.

APPENDIX 7.A: HARVESTED NATIVE FORESTS

Background

The model used for the reporting of carbon stock changes and CO₂ emissions from harvested native forests currently only considers the above and belowground biomass and harvest slash. The areas and activities considered in the model are those associated with forest harvesting of Australia's native forests. Changes in dead organic matter, other than that generated as harvest slash, and soil carbon are not considered. The areas of harvest and regrowth, and growth rate data are drawn from Australia's National Forest Inventory.

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

It is anticipated that the fully spatial reporting capability will be introduced in the 2008 inventory for *Forest land remaining Forest land*. For now, the following methods describe the harvested native forests reporting, while Appendix 7.B describes the methods used for reporting plantations. Together the harvested native forests, other native forests and plantations represent the entirety of reporting of Australia's managed *Forest land remaining Forest land* and *Land converted to Forest land*.

An overview of the methods that will be applied to future reporting for native forests can be found in Appendix 7.E.

Growth Modelling

Growth rates (in tC yr⁻¹) are modelled by broad forest types and age classes (Table 7.A1). The total area of each forest type is divided into a series of age classes, each with different growth rates (Table 7.A2). A weighted average growth rate based on the area of forest in each age class is calculated to give an average per hectare growth rate for each forest type [1]. Total annual growth for each forest type is then calculated by multiplying the weighted average by the total forest type area [2], with all forest types summed to provide a total harvested native forest growth value [3]. Growth is then converted to CO₂ removals using a standard conversion rate based on the relative mass of C and CO₂ [4].

The total area of each forest type is that outside of nature conservation reserves. Only areas within the commercially managed estate (i.e., those outside conservation reserves) are included in the emissions reporting. The forest areas within each forest type are assumed to not change with time and there is no movement between conservation and production areas. The model is constant for both area and growth rates for each forest type and forest age class. Hence the calculated CO₂ removals associated with forest growth remain constant through time.

Weighted average growth rate for forest type = $S (\text{Area in age class} * \text{age class growth}) / \text{Total forest type area}$ [1]

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

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

CO₂ removed by forest growth = total growth (tC yr⁻¹) * Fraction of carbon dioxide that is carbon (12/44) [4]

Table 7.A1: Growth Rates by Forest Type and Age Classes (tC ha⁻¹ yr⁻¹)

Forest Type	All Forests in All Tenures (excluding nature conservation reserves) Whose Age Class is Known						
	State Forests Whose Age Class is Unknown	Establishment 1-10 yrs	Juvenile 11-30 yrs	Immature 31-100 yrs	Mature 100-200 yrs	Senescent > 200 yrs	Average Annual Increase, Weighted by Area
		t C ha ⁻¹ yr ⁻¹					
Rainforests	0.56				0.86		0.576
Tall Dense Eucalypt Forests	3.24	6.44	4.41	2.23	0.74		2.403
Medium Dense Eucalypt Forests	1.62	4.24	2.80	0.99	0.18		0.948
Low Dense Eucalypt Forests							
Tall Sparse Eucalypt Forests	0.24						0.176
Medium Sparse Eucalypt Forests							
Low Sparse Eucalypt Forests							
Eucalypt Mallee							
Callitris Forests	0.25						0.254
Acacia Forests							
Other Forests	0.23						0.235

Table 7.A2: Areas by forest type and age classes (tC ha⁻¹ yr⁻¹)

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

Sources of Data, QA, QC and Verification

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

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

Emission due to harvest slash

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

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

Emissions from the decay of forest slash from harvested native forests is presumed as linear, with carbon moving to the atmosphere within a pre-defined number of years (Table 7.A4).

Table 7.A3: Annual Roundwood Removals from Harvested Native Forests

Year	Roundwood Removal 1,000 m ³
1990	10,535
1991	10,037
1992	9,512
1993	9,801
1994	9,793
1995	10,857
1996	9,920
1997	9,442
1998	9,793
1999	9,229
2000	10,942
2001	10,571
2002	9,445
2003	10,018
2004	10,394
2005	9,727

Emissions from the decay of forest slash from harvested native forests is presumed as linear, with carbon moving to the atmosphere within a pre-defined number of years (Table 7.A4).

Model Parameterisation

Key parameters and the 'constraints' used in the model are shown in Table 7.A4. The parameters fall into grouping of similar types:

- > carbon fraction of biomass;
- > carbon to CO₂ conversion;
- > partitioning of tree biomass to various components;
- > carbon density of wood; and,
- > decay times of various products.

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

Table 7.A4: Parameters and Default Values Used in the Model

Description	Value	Units
Fraction of carbon dioxide that is carbon, by weight	0.27	
Ratio of belowground weight to aboveground weight for forest ^(a)	0.25	
Ratio of hardwood slash to hardwood roundwood removal, by volume ^(a)	0.90	
Density of carbon in hardwood	0.325	t C / m ³
Time to total decay of hardwood slash (equal amount decays each year)	7	year

(a) Snowden et al. 2000

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

Partitioning of Tree Biomass

The three conversion factors used in the model are:

- > ratio of belowground weight to aboveground weight for forest – 0.25
- > ratio of softwood slash to softwood roundwood removal – 0.9
- > ratio of hardwood slash to hardwood roundwood removal – 0.9

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

Density of Carbon (t C/m³) for Hardwood

The value for the density of carbon (t C/m³) used in this model for hardwood is 0.325. Independent studies by Jaako Poyry (1999 and 2000) derived a basic density value of 630kg/m³ for hardwood. Converted to an equivalent t C/m³ using the carbon content of dry matter as 0.5 (Gifford 2000b), the Jaako Poyry results were equivalent to 0.315 t C/m³ for hardwood. These independent values are similar, and confirm the appropriateness of the value used in the model.