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Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006

Land Use, Land Use Change and Forestry

National Greenhouse Gas Inventory Committee

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Foreword

This inventory methodology workbook presents the Australian methodology to estimate greenhouse gas emissions and sinks from land use, land use change and forestry sources. It is part of a series that includes:

Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006: Energy (Stationary Sources)

Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006: Energy (Transport)

Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006: Energy (Fugitive Fuel Emissions)

Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006: Industrial Processes

Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006: Solvents

Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006: Agriculture

Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006: Land Use, Land Use Change and Forestry

Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006: Waste

The development of Australia's inventory methodologies and the compilation of Australia's national inventories are guided by the National Greenhouse Gas Inventory Committee, comprising representatives of the Australian, State and Territory governments.

Units

The units mainly used in this workbook are joules (J), grams (g), metres (m) and litres (l), together with their multiples. Standard metric prefixes used in this workbook are:

kilo (k)	=	10^3 (thousand)
mega (M)	=	10^6 (million)
giga (G)	=	10^9 (billion)
tera (T)	=	10^{12}
peta (P)	=	10^{15}

Basic units used:

gram (g)		
tonne (t)	=	10^6 g
hectare (ha)	=	10^4 m^2
metre (m)		
year (y)		

One gigagram (Gg) equals one thousand tonnes, or one kilotonne (kt). One million tonnes or one megatonne (Mt) is equal to one thousand gigagrams.

Note:
1 Mt = 1 Tg = 10^3 Gg
1 Mha = 10^6 ha
dm = dry matter
t C ha^{-1} = tonnes of carbon per hectare
t C y^{-1} = tonnes of carbon per year

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Introduction

Australia's national greenhouse gas inventory is prepared annually by the Australian Greenhouse Office in accordance with both the IPCC *Revised 1996 Guidelines for National Greenhouse Gas Inventories* (IPCC 1997) and the *IPCC Good Practice Guidance for Land Use, Land Use Change and Forestry* (IPCC 2003) while taking into account Australian conditions. Documenting the methods used in the estimation of emissions for the inventory enhances transparency and improves the comparability of estimates with those reported in the inventories produced by other countries.

The methods used by Australia to estimate annual emissions and removals of greenhouse gases from activities associated with *Land Use*, *Land Use Change and Forestry* (LULUCF) are documented in this workbook. It covers the UNFCCC reporting categories *Forest lands (5A); Croplands (5B) Grasslands (5C), Wetlands (5D), Settlements (5E); Other Lands (5F) and Other (5G).*

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

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 1 and Table 1 shows the representation of land according to the IPCC categories.

Figure 1. Land Use in Australia

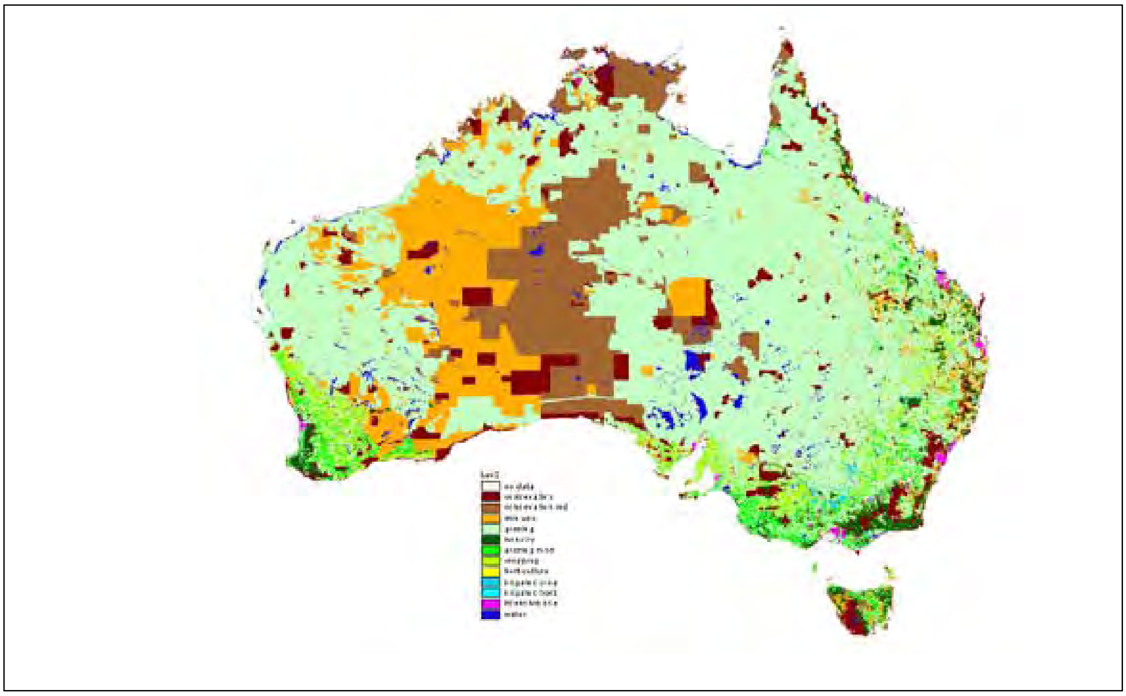


Table 1. Land representation matrix (2005)

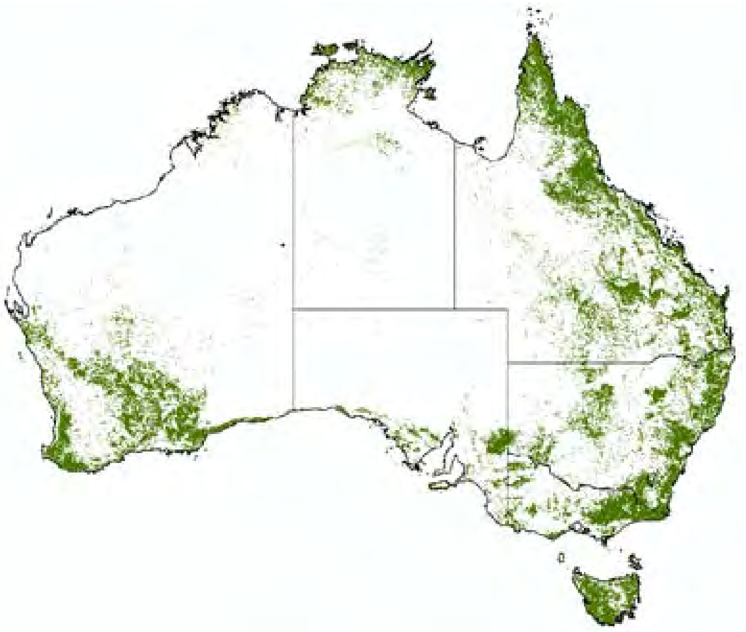
	1990 (Mha)	2005 (Mha)	Net Change (Mha)
Forest lands total	**112.0**	**108.9**	**-3.2**
Forest remaining Forest	111.3	106.2	-5.2
Harvested Native Forests	14.9	14.9	0.0
Plantations	0.8	0.8	0.0
Other Native Forest [(a)]	95.6	90.5	-5.2
Grassland converted to Forest Land	0.1	1.2	1.1
Forest balancing term (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 subracting the forest balancing term.

(c) Total area does not include external territories.

Figure 2. Forest Extent in Australia



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.

Figure 3. Average Annual Rainfall

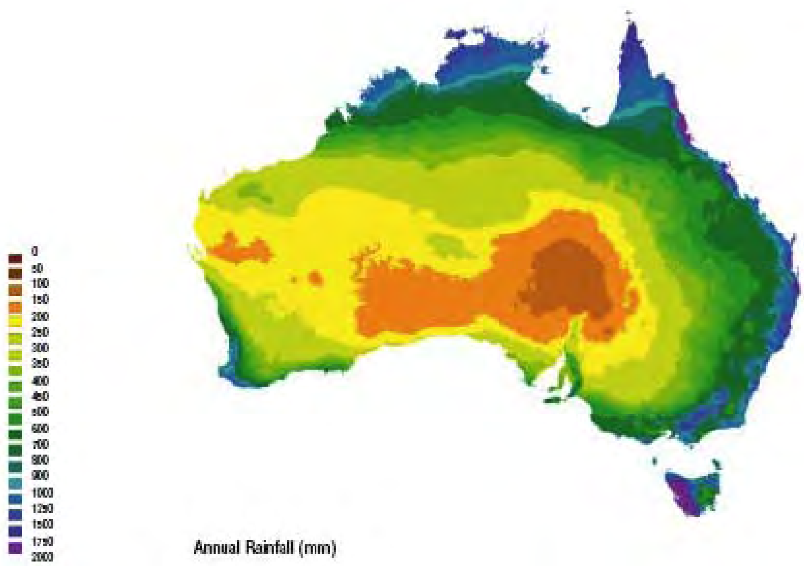
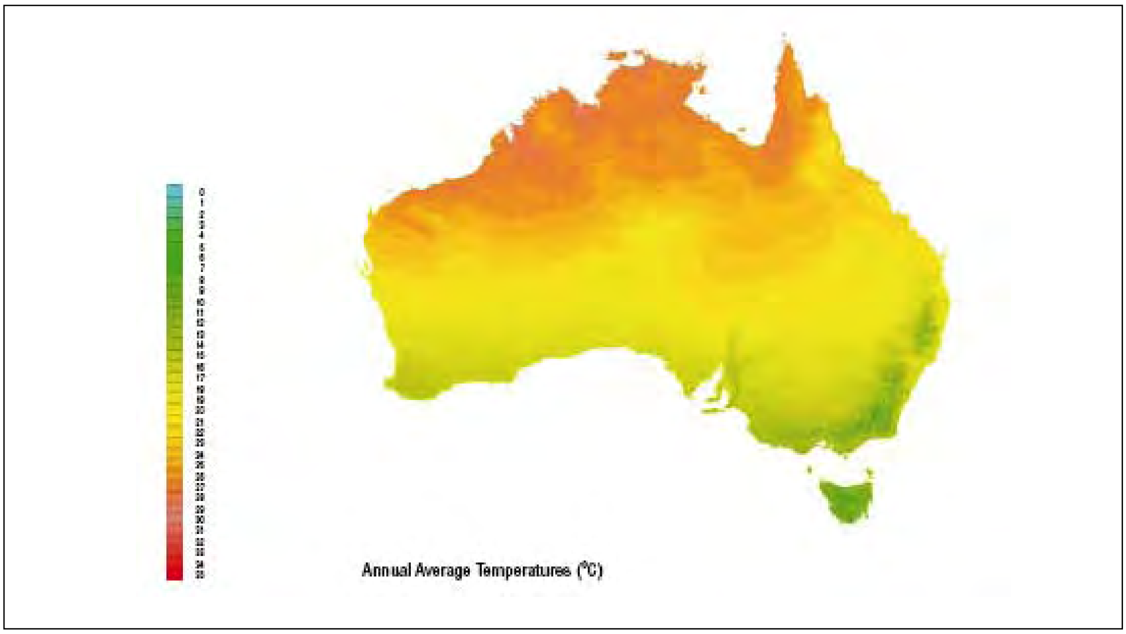


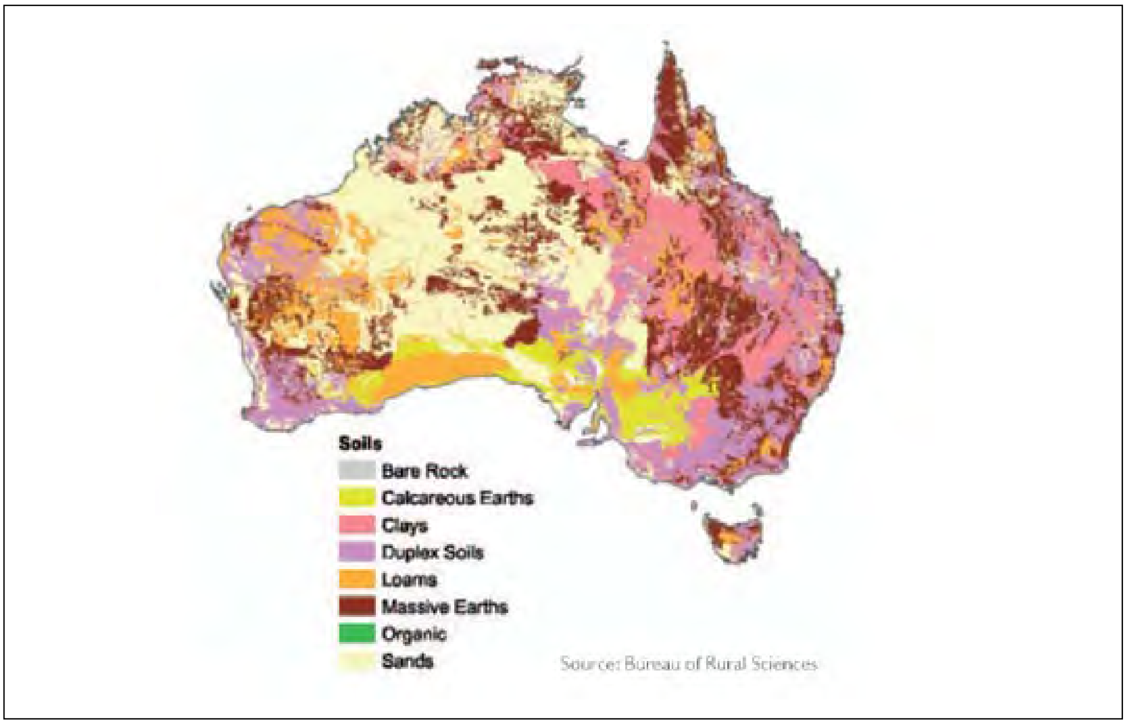
Figure 4. Average Annual Temperature



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 sleep slopes and use of fertilizer (mainly phosphorus and nitrogen).

Figure 5. Soils Map of Australia



General Approach

The Australian LULUCF methodology contains predominantly country specific methodologies and Tier 3 models (Table 2). 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 reconciliation 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 A to D.
Appendix A – Harvested Native Forests for *Forest land remaining Forest land;*
Appendix B – Forest Plantations for *Forest land remaining Forest land* and *Grassland converted to Forest land*;
Appendix C – *Forest land converted to Grassland* and *Cropland;*
Appendix 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 C. Appendix E gives an outline of the current and planned NCAS capabilities for inventory improvements. The methods used to estimate emissions from other activities (not associated with forest conversion) that use interim approaches are described in Appendices A, B and D.

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 2006 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).

Table 2. Summary of methodologies and emission factors

GREENHOUSE GAS SOURCE AND SINK	CO_2		CH_4		N_2O		NOx, CO and NMVOC	
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
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	TI	CS						
2. Land Converted to Cropland	T3	M						
5(V) Biomass Burning - 5.B.2	T3	M	CS	CS	CS	CS	CS	CS
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	CS,T1	IPCC						

CS = country specific, IPCC = 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,

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
- Sensitivity and Uncertainty Testing
- Verification
- Transparency and Peer Review.

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

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 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 B2 of Appendix 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 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 D2 to Appendix D.

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 (Ximines et. al., 2005). This approach could then test both the biomass predictions and replication of the gradient in forest productivity and carrying capacity by model estimates.

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.

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.

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 (A-E).

Forest Definition and Monitoring of Forest Conversion

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.

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.

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.

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 otho-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.

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 x79m) was re-sampled to a 50 x 50m pixel. The Landsat TM (~30 x 30m native resolution) and ETM+ data available after 1988 were produced as 25 x 25m pixels (see details in Appendix 7.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 above.

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.

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 Webbnet 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.

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.

5.A Forest Land

5A.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 5V.

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 A, and the quality assurance programs are also described earlier.

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.

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 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.

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 CO_2 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 ands 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-CO_2 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 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.

The methods being developed as described in Appendix E will provide fully spatially explicit areas of plantations in future inventories. 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.

Fuelwood Consumed

For transparency the CO_2 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 CO_2 emissions.

5A.2 Land converted to Forest Land

Grassland 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 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 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.

5.B Cropland

5B.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 CO_2 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.

5B.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.

5.C Grassland

5B.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-CO_2 emissions are reported in the Agriculture sector.

5B.2 Land converted to Grasslands

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.

5.D Wetlands

5D.1 Wetlands remaining as Wetlands

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

5D.2 Lands 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*.

5E Settlements

5E.1 Settlements remaining as Settlements

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

5E.2 Lands 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.

5F Other Lands

5F.1 Other Lands remaining as Other Lands

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

5D.2 Lands converted to Other Lands

It is assumed that no Lands are converted to Other Lands.

G Other

Harvested Wood Products

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

5(I) N_2O Emissions from N fertilisation

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

5(II) N_2O emissions from Drainage of Soils

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

5(III) N_2O emissions from disturbance associated with land-conversion to cropland

Carbon stock changes due to conversions of Forest Land to Cropland and Forest Land to Grassland are estimated under 5.B.2 and 5.C.2. These carbon stock changes reflect the initial effects of land use conversion and subsequent management. The associated N_2O emissions are comprehensively reported under *Agricultural Soils*.

5(IV) CO_2 Emissions from Agricultural Lime Application

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 ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$) leads to CO_2 emissions as the carbonate limes dissolve and release biocarbonate which evolves into CO_2 and water.

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

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

Where:

E_{ijk} = annual emission of CO_2 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
$P_{ijk=1}$ = fractional purity of dolomite = 0.95
EF_k = IPCC (2006) default emission factor for Limestone$_{(k=1)}$ 0.12 and Dolomite$_{(k=2)}$ 0.13
C_g = 44/12 factor to convert elemental mass of CO_2 to molecular mass.

BIOMASS BURNING (5V)

5A.1 FOREST LANDS - 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 CO_2 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 CO_2 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 modelling 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 recommended by the IPCC (1997, Volume 1, page 2.3)[1].

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

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

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 3 and 4),
Z_{jk} = burning efficiency (Table 5).

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

$$E_{ijkl} = M_{jkl} * CC_{jk} * EF_{ijk} * C_i \quad \text{(Gg)} \qquad (5V\_2)$$

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.

Where: $Eijkl$ = 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 6),
EF_{ij} = emission factor for gas *i* from vegetation (Table 7),
C_i = factor to convert from elemental mass of gas species *i* to molecular mass (Table 8),

and total annual emissions for NO_x and N_2O are:

$$E_{ijkl} = M_{jkl} * CC_{jk} * NC_{jk} * E_{ijk} * C_i \quad \text{(Gg)} \quad \text{(5V\_3)}$$

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 6)
NC_{jk} = nitrogen to carbon ratio in biomass (Table 6)
EF_{ijk} = emission factor for gas *i* from vegetation (Table 7)
C_i = factor to convert from elemental mass of gas species *i* to molecular mass (Table 8),

Table 3. Fuel loads for Prescribed Burning of Forest in Australia

State	ACT[a] FL_{jkl} (Mg/ha)	NSW[a] FL_{jkl} (Mg/ha)	NT[a] FL_{jkl} (Mg/ha)	Qld[a] FL_{jkl} (Mg/ha)	SA[b] FL_{jkl} (Mg/ha)	Tas[b] FL_{jkl} (Mg/ha)	Vic[a] FL_{jkl} (Mg/ha)	WA[a] FL_{jkl} (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 4. Fuel loads for Wildfires in Australia

State	ACT[a] FL_{jkl} (Mg/ha)	NSW[a] FL_{jkl} (Mg/ha)	NT[a] FL_{jkl} (Mg/ha)	Qld[a] FL_{jkl} (Mg/ha)	SA[b] FL_{jkl} (Mg/ha)	Tas[b] FL_{jkl} (Mg/ha)	Vic[a] FL_{jkl} (Mg/ha)	WA[a] FL_{jkl} (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 5. 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. Forest vegetation 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 7. Mean emission factors for carbon and nitrogen trace gases from forest biomass burning

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

Hurst et al. (1996) – mean of 4 Australian temperate forest firest

Table 8. 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

5B.2 and 5C.2 Forest Lands converted to Croplands and Grasslands - Biomass Burning

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-CO_2 gases associated with burning.

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

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

$$E_{ijkl} = FC_{jkl} * EF_{ijk} * C_i \quad \text{(Gg)} \qquad \text{(5V\_4)}$$

and for total annual emissions for NO_x and N_2O are:

$$E_{ijkl} = FC_{jkl} * NC_{jk} * EF_{ijk} * C_i \quad \text{(Gg)} \qquad \text{(5V\_5)}$$

Where: FC_{jkl} = annual fuel carbon burnt in land clearing (*j*=7, *k*=19, *l*=9) (Gg),
EF_{ijk} = emission coefficient for gas *i* from vegetation (*i*= 1 to 5) (Table 7),
NC_{jk} = nitrogen to carbon ratio in biomass (Table 6)
C_i = factor to convert from elemental mass of gas species *i* to molecular mass (Table 8).

Glossary

Anthropogenic consistent with the IPCC GPG 2003, anthropogenic is taken to be all emissions from managed land.

Biomass is the total weight or volume of living organisms present at any one time in a community. For plant communities, it may be divided into aboveground and belowground biomass and is usually expressed as tonnes dry matter per hectare or tonnes carbon per hectare.

Flux is the rate of movement of carbon (in this case CO_2) from one carbon pool to another.

Forest is an area, incorporating all living and non-living components, that is dominated by trees having usually a single stem and a mature or potentially mature stand height exceeding 2 metres, and with existing or potential projective cover of overstorey strata about equal to or greater than 20%. This definition includes Australia's diverse native forests and plantations, regardless of age. It is also sufficiently broad to encompass areas of trees that are sometimes described as woodlands.

Plantation is an area of managed forest where the trees have been planted, rather than via natural regeneration.

Prescribed burning of forests is the intentional burning of forests to reduce the amount of combustible material present and thereby reduce the risk of wildfires. In Australia this is known as 'fuel reduction burning'.

Root-to-shoot ratio is the ratio of the dry mass of plant roots to the dry mass of the aboveground plant parts.

Appendix A
Harvested Native Forests

Background

The model used for the reporting of carbon stock changes and CO_2 emissions from harvested native forests currently only considers the above and belowground biomass and harvest slash. The areas and activities considered in the model are those associated with forest harvesting of Australia's native forests. Changes in dead organic matter, other than that generated as harvest slash, and soil carbon are 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 B describes the methods used for reporting plantations. Together the harvested native forest, other native forests and plantations represent the entirety of reporting of Australia's *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 E.

Growth Modelling

Growth rates (in tC yr^{-1}) are modelled by broad forest types and age classes (Table A1). The total area of each forest type is divided into a series of age classes, each with different growth rates (Table 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 CO_2 removals using a standard conversion rate based on the relative mass of C and CO_2 [4].

The total area of each forest type is 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 CO_2 removals associated with forest growth remain constant through time.

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

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

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

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

Table A1: Growth Rates by Forest Type and Age Classes (t C ha^{-1} yr^{-1}).

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

Table A2: Areas by forest type and age classes (t C ha^{-1} yr^{-1}).

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

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 *various*). 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.

Hardwood slash (m^3) = Roundwood removals (m^3) * Hardwood Slash Ratio (0.9) *[5]*

Table 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 A4).

Model Parameterisation

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

- carbon fraction of biomass;
- carbon to CO_2 conversion;
- partitioning of tree biomass to various components;
- carbon density of wood; and
- decay times of 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 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 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) Snowdon et. al 2000

Carbon to CO_2 conversion

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

Partitioning of Tree Biomass

The three conversion factors used in the model are:

- 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 diverstiy of Australian forest types and silvicultural practices.

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

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