APPENDIX 7.C: FOREST CONVERSION TO CROPLANDS AND GRASSLANDS

Introduction

Emissions estimates from forest land converted to a non-forest land use apply the full capability of Australia's National Carbon Accounting System (NCAS). This capability uses a mass balance, process-based ecosystem model (Tier 3) in a fully spatially explicit land representation (Approach 3). The areas and timing of forest conversion are identified through a national time-series (1972-2005) of Landsat satellite data.

The methods for *Forest land converted to Grassland* and *Forest land converted to Cropland* are reported below. The descriptions are framed around the program areas of the NCAS that provide the needed input data. The final sections describe the development and implementation of the emissions modelling framework.

Land Cover Change

Method Selection

Areas of land cover change[1] that contribute to emissions include those areas with lagged emissions from activities undertaken since the early 1970s. The ability to map land cover change over a 33-year period (1972-2006) is therefore required for a 2005 emissions inventory. With Australia's land area of some 760 million hectares, establishing this record of activity presented many challenges, particularly as areas of change of less than one hectare need to be considered. In response to these requirements, a remote sensing approach using archival coverage of Landsat satellite data of Australia since the early 1970s was used.

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

- Air photographs: The air photograph archive is not uniformly adequate and available across the nation. Also, the use of air photographs presented an excessively intensive analytic task due to the largely manual interpretation required. However, the archive of available air photographs provides a high-resolution calibration and verification tool to support other techniques when used as an independent sub-sample or as instrument 'training' data for satellite-based methods.
- NOAA/AVHRR: Data is generated at a nominal 1.1 km (approximately 120 ha) resolution. With accounting for Deforestation for the purposes of the Kyoto Protocol requiring monitoring at a sub-hectare scale, remote sensing at such a coarse resolution was not adequate.
- Landsat (MSS, TM and ETM+): Data, with comprehensive national coverage of areas with woody vegetation, are available through archives held in the USA and Australia since 1972. The Landsat MSS data (since 1972) can be effectively resampled to a 50 m pixel resolution (4 pixels per ha) and TM (since 1988) and ETM+ (1999-2002) can be resampled to 25 m pixel resolution (16 pixels per ha).

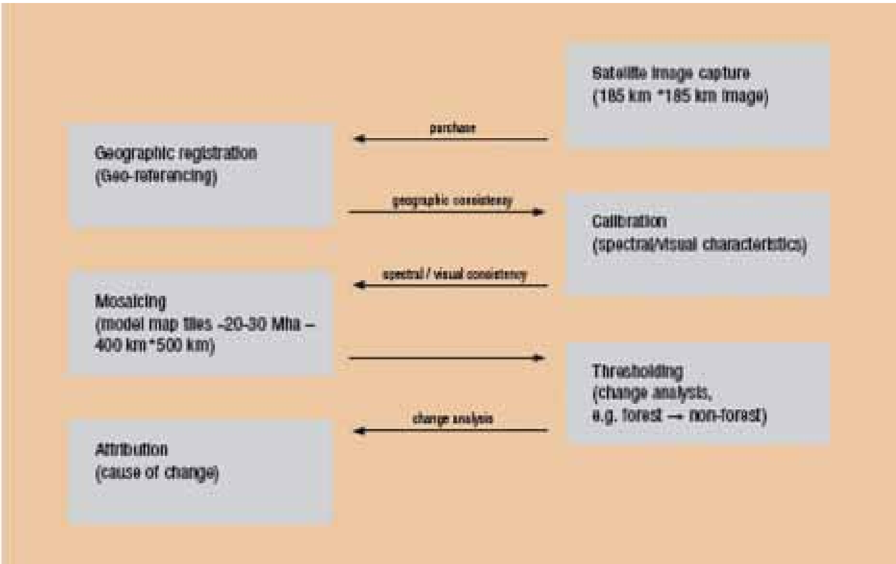
The use of Landsat data to analyse land cover change through time at a fine pixel resolution required a consistent geographically registered[2] and spectrally calibrated[3] reference base (Figure 7.C5). Equally, standard specifications for processing and interpretation (including attribution[4]) of the sequence of Landsat data are needed to achieve a consistent national assessment of land cover change over the 32 year period.

It was also important to move from the 50 m resolution MSS data to the 25 m resolution TM and ETM+ data without assessment of false land cover change being introduced due to instrumentation differences. To do this, a MSS equivalent 1989 image coverage was created from the TM images at 50 m resolution using a subset of the TM spectral bands corresponding to the MSS bands. Land cover change assessments bridging the switch from MSS to TM/ETM+ was then always based upon MSS to MSS and TM/ETM+ to TM/ETM+, across similar image spectra and pixel size. The use of this overlap technique is consistent with the good practice methods recommended by the IPCC for ensuring time-series consistency where the instruments used to collect activity data change or degrade through time (IPCC 2003 page 5.58).

To enable processing of the Landsat data at the scale of implementation required for the NCAS (15 national coverages to give 14 change sequences), there was a need both to refine methods to achieve efficient data processing and to build industry processing capacity. Both advances were required to deliver the NCAS program within available funding resources. The imperative was to deliver quality assured analyses using consistently applied methods at less than 30 per cent of benchmark costs.

The sequence of stages carried out in producing the assessment of an Australia-wide land cover change over the interval 1972 to 2005 is shown schematically in Figure 7.C1.

Figure 7.C1. Land Cover Change Program Conceptual Framework.



Pilot Tests of Image Processing Approach

Pilot tests were used to train and develop industry capacity, refine methods and software and to develop logistical systems to maximise both output and opportunity for progressive quality assurance and quality control (QA/QC). During the pilot testing each contactor involved in the processing was allocated a region in which to carry out all image processing stages. This proved to be a difficult approach under which to implement progressive QA/QC.

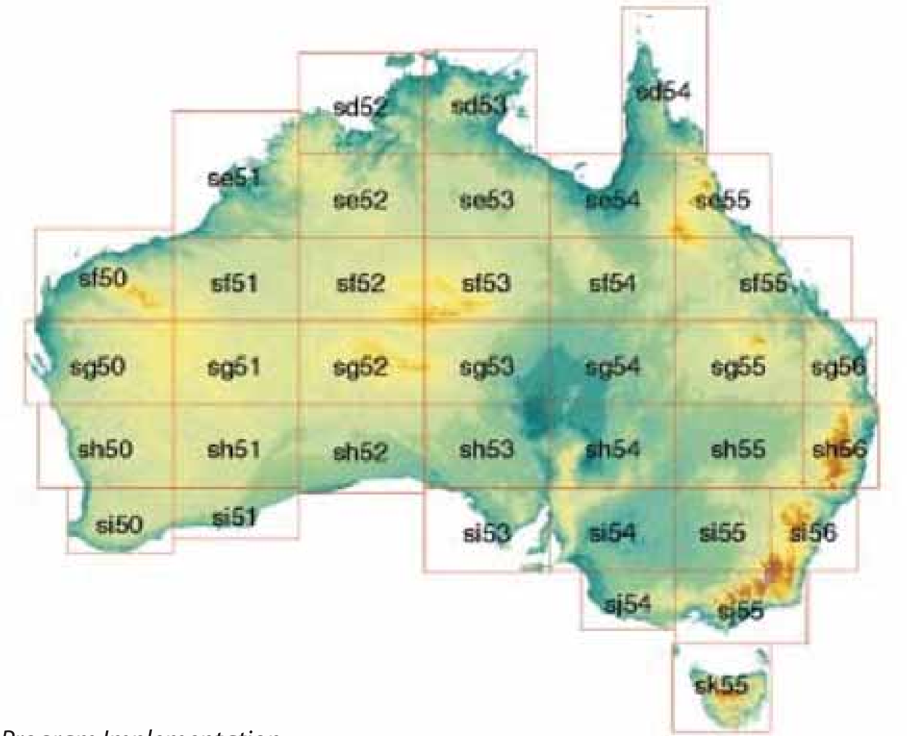
Without the benefit of either iterative QA/QC between the processing stages, or independent cross region comparisons at each stage, both the consistency and quality of the pilot products was variable. This highlighted a risk that problems could occur in early processing stages and flow through the whole processing program. Given the scale, cost and complexity of work, resolving early-stage problems at the end of the program was a high risk operational approach. The results of the pilot studies are published in Furby and Woodgate (2002).

Review of the successes and failures of the pilot studies led to a redesign of the packages of work. In particular, processing was separated into the stages identified in Figure 7.C3 to allow for the central and progressive implementation of a QA/QC program. The QA/QC program was implemented during and at the end of each processing stage. In the revised approach, each of the processing stages is a regionally defined package of work based on 37 1:1,000,000 (1:1 M) map tiles of Australia (Figure 7.C2). The finalised sequence of processing stages was:

> image identification;
> image registration and calibration;
> mosaicing[5] of registered and calibrated images to the single map tiles for each time sequence;
> sun-angle (terrain illumination) correction;
> thresholding[6] through all time sequences; and,
> attribution of change to direct human-induced change.

Additional benefits arising from the pilot studies were that a range of contractors were familiarised with the general approach, a range of regional characteristics identified and improvements made to the efficiency and usability of software systems.

Figure 7.C2. The 37 1:1 M Map Tiles Used in the Program.



Program Implementation

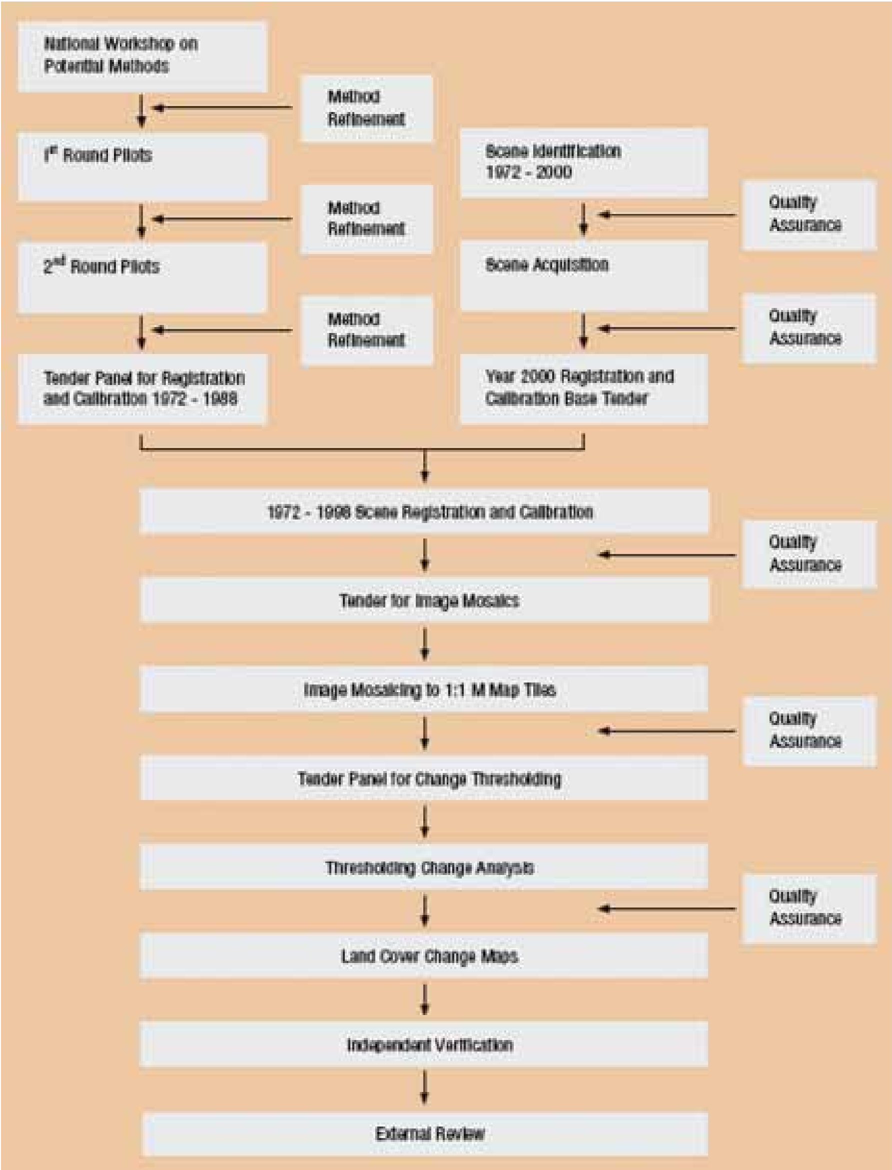
The approach to program administration, revised following the pilot testing phase, provided for centralised progress monitoring and QA/QC at each stage in the processing of the Landsat data. Figure 7.C3 outlines the program stages and their sequence. The finalised program approach maximised quality assurance opportunities, expanded the use of competitive service acquisition and enhanced information flow. A set of 15 national coverages of Landsat data have been compiled at intervals between 1972 and 2006. The sequence of images shown in Table 7.C1 was designed to give maximum temporal resolution immediately before and after 1990, so as to achieve the best possible accuracy of emissions in 1990.

[5] Mosaicing aggregates images into the map tiles shown in Figure 7.C2, removing overlaps in the original 185 km*185 km images.

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

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

Figure 7.C3. Sequence of implementation of the Land Cover Change Program.



The median of the actual capture dates of the approximately 5,000 185 km-by-185 km Landsat images processed for this project are summarised in Table 7.C1. The image selection criteria (Furby 2002) required the images to be within three months of the nominated target date. The precise date allocated to each land cover change (clearing and regrowth) pixel was randomly generated by the *FullCAM* carbon accounting model, within the sequence of coverage dates for the relevant map tile. This method provided a random (unbiased over a large sample) distribution of initialisation dates (timing of land cover change event) for the carbon model, within the constraint of the two dates in the overall interval of the image sequence.

Table 7.C1. Image Sequence.

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

Technical Specifications

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

- the use of a Landsat ETM+ national mosaic (year 2000) as the base for registration and calibration;
- the use of an orbital (earth surface) correction model as implemented through the PCI (PCI Geomatics 2000) software package;
- to use a BRDF (Bi-Directional Reflectance Distribution Function) atmospheric correction model;
- to apply a sun angle correction (Wu et. al., 2004);
- to use 'automated' change thresholding, using derived indices within zones based on specific vegetation and soil characteristics;
- digitising areas of fire scars, later using these as fire masks to differentiate change due to fire from change associated with mechanical land clearing;
- to apply a 'Conditional Probability Network' (CPN[7]) so that the probability of forested condition for each pixel at each time in the image sequence is placed in the context of the preceding and subsequent images; and,
- to use the *FullCAM* model to interrogate the full change sequence of each pixel. The analysis of each pixel by *FullCAM* establishes whether a clearing or regrowth event has occurred between each image sequence for that pixel and allocates a time.

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

Selection of Indices

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

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

Conditional Probability Network

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

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

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

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

Reporting

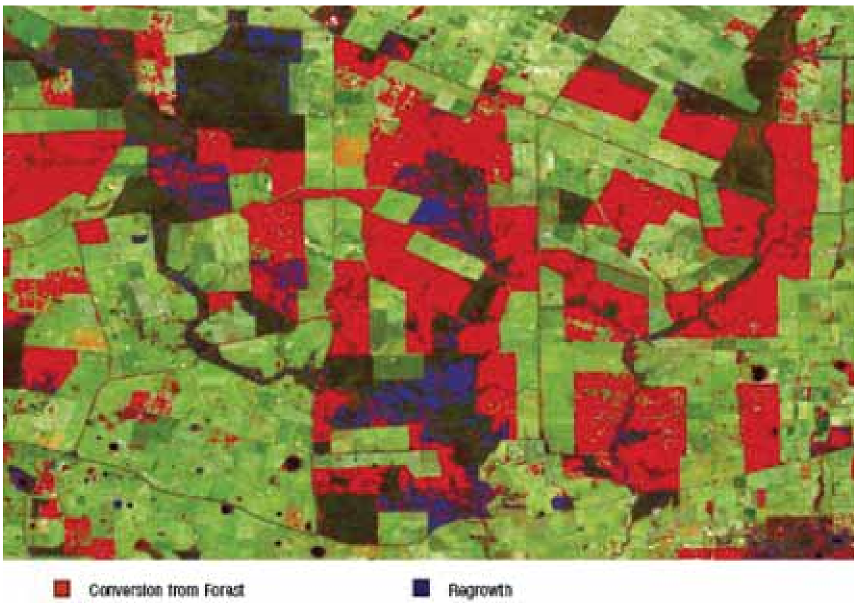
Once a change in forest cover status of each pixel for a point in time is determined, the spatial relationship of each change pixel to other surrounding or nearby change pixels is assessed to identify isolated pixels with forest cover that do not form part of a forest system. This allows for the identification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

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

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

The approach used provides for an analytic unit (pixel) that is approximately 0.06 ha, but a requirement to be spatially related to other change pixels infers that a minimum area of approximately 0.2 ha of forest area (including gaps between trees) is required for inclusion.

Figure 7.C4. An Example Land Cover Change Image.



Attribution of Change

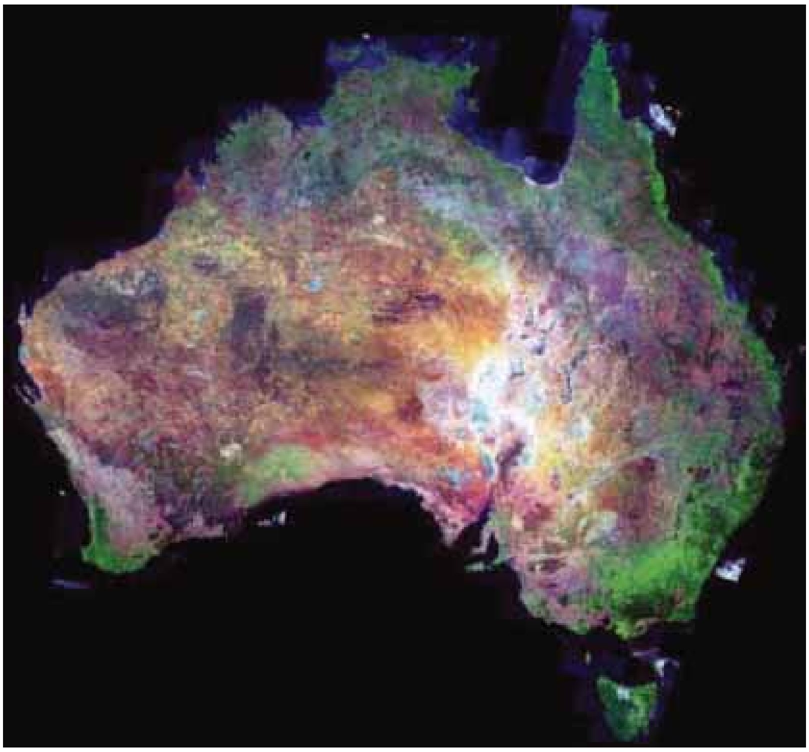
The high resolution spatial assessment (by pixel) across the continent identifies land cover change resulting from many causes. For unique identification of conversion to another land use it is necessary to attribute the change event to a cause and subsequent land use. Examples of forest cover loss events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

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

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

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

Figure 7.C5. The Year 2000 Mosaic Registration and Calibration Base.



Quality Assurance and Quality Control

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

The QA/QC stages applied are:

> independent date and scene quality checking of selected Landsat image scenes;
> image quality checks on the raw data were performed by the Australian Centre for Remote Sensing (ACRES) (the data distributor) under their internal quality assurance program. Additional checking of images (visually) by contractors prior to scene registration and calibration was also undertaken;
> registered and calibrated images and mosaicing products are all checked against published QA/QC standards (Furby 2002);
> during thresholding, several stages of QA/QC were applied. These included the development of cloud and fire masks, selection of indices representing ground conditions for vegetation types of interest in homogenous zones (strata) reflecting similar vegetation and soil types, checking of change maps against raw imagery and air photographs to remove errors of omission or commission in assessing change in forest cover; and,
> visual quality assurance of masks derived to identify direct human-induced change.

Once the processing stages were completed, and the abovementioned QA/QC programs satisfied, a further visual check is carried out by creating 'animations' of land cover change over time. This allowed for review of both the spatial and temporal patterns of change. The methods chosen and implementation of the program were submitted to external (international) review at the conclusion of the attribution (final stage) processing. The review provided re-assurance in the robustness of the technical methods, processing and quality assurance programs.

Continuous Improvement and Verification

To confirm the veracity, and provide for continuous improvement, of the method (and hence the accuracy of the product) a second and independent program of checking Landsat results against high resolution satellite and air photograph interpretation is undertaken on a stratified sampling basis. Prior to adding each update (a new remote sensing layer) to the existing multi-temporal sequence, an independent accuracy, and veracity of method, program is applied to make recommendations on refinement for when statistical processing is rerun to add the additional sequence (Lowell et. al., 2003; Jones et. al., 2004; Lowell et. al., 2005). Such recommendations can be iteratively introduced to the overall analyses across the full data sequence from such progressive QA/QC and accuracy reviews. This system of review and refinement provides for the continuous improvement of the overall land cover change product.

Land Use and Management

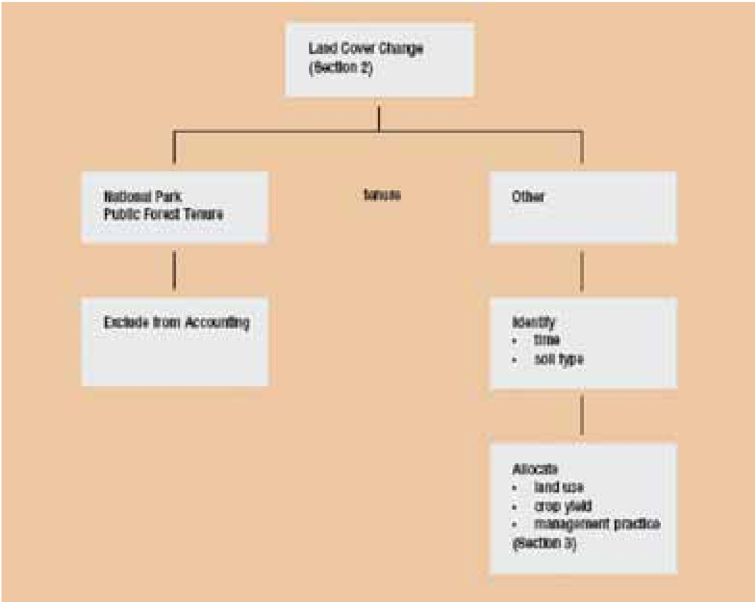
Program Outline

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

With the NCAS land cover change data capable of identifying the location and timing of land cover change events, this information can be spatially overlayed on the soils map derived for the NCAS so that each event can be attributed to a location, time and soil type. Data on management practices are able to be linked to units of land that have undergone forest conversion via unique identifiers of soil type and time. Land use and management types were then apportioned within the soil type strata.

Land tenure is also an important consideration as it informs land use determination. Areas of forest management (commercial harvest) and National Parks are excluded from forest conversion emissions.

Figure 7.C6. Overview of the Land Use and Management Program



To obtain the needed agricultural land use and management information, the NCAS commissioned CSIRO Land and Water to undertake, via survey and literature searches, the collection of relevant information for each Interim Biogeographic Regionalisation of Australia (IBRA) (Thackway and Cresswell 1995) region, by soil type, by crop type and crop regime (rotations), by management type and by time (Table 7.C2). This included time-based crop yield estimation for each identified land use and management type. The results of this study can be found in Swift and Skjemstad (2002), reported by IBRA regions (Figure 7.C7) as a primary stratification, with soil type used as a secondary strata.

Table 7.C2. Example Land Use Table.

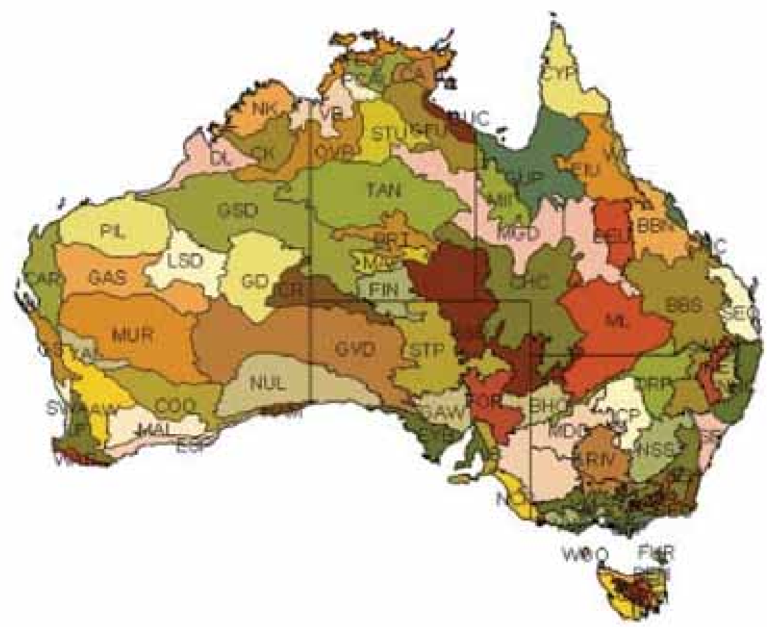
Table A-4 IBRA cell: Darling Riverine Plains
Time period: 1981 - 1982

1 Soil type	2 % of cell	3 Land use (Lu)	4 % of soil	5 Management practices (m.p)	6 % of Lu	7 Phase	8 % of m.p	9 Yield t/ha	10 Residue t*
Clay	75	Developed pre-1970	35						
		Naturally clear at end of the time period	23						
		Uncleared forest at end of the time period	5						
		Developed for pasture	16	stubble burnt - summer	14	crop	50	0.9	
				- autumn	1	pasture	10	2	
						long fallow	40		
				stubble retained	85	crop	50	0.9	
						pasture	10	2	
						long fallow	40		
		Irrigated cotton	3	trash burnt	0	crop	60	3.6	
						cereal	40	0.9	
				trash retained	100	crop	60	3.6	
						cereal	40	0.9	
		Dedicated for pasture	16		100		100	2	
Loam	25	Developed pre-1970	35						
		Naturally clear at end of the time period	0						
		Uncleared forest at end of the time period	22						
		Developed for cropping	19	stubble burnt - summer	14	crop	50	0.6	
				- autumn	1	pasture	10	2	
						long fallow	40		
				stubble retained	85	crop	50	0.6	
						pasture	10	2	
						long fallow	40		
		Irrigated cotton	4	trash burnt	0	crop		0	
						cereal		0	
				trash retained	100	crop		0	
						cereal		0	
		Dedicated for pasture	20		100		100	2	
Sand	0								

Notes: 1981 – Average climatic conditions
1982 – Drought year

Source: Swift and Skjemstad 2001

Figure 7.C7. IBRA Regions.



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

Land Use Data

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

Land Tenure

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

Quality Assurance and Quality Control

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

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

Climate Inputs

Introduction

Model sensitivity testing for the NCAS identified that interannual climate variability has a significant effect on both soil (Janik et. al., 2002) and forest (Brack and Richards, 2002) carbon stock change. The use of long-term (temporal) average and regionally (spatial) averaged climate data was shown to be inadequate to support spatially and temporally disaggregated carbon modelling, frequently generating spurious results when tested. To provide spatially mapped monthly climate data over the modelled period, 1970-2004, the NCAS obtained weather station data from the Bureau of Meteorology for rainfall, minimum and maximum temperature, evaporation and solar radiation. Monthly climate surfaces (maps) for each attribute were derived using the ANUCLIM (McMahon et. al.,1995) techniques.

Raw Data

Within the Bureau of Meteorology database there are approximately 1,200 weather stations recording temperature, 13,000 stations recording rainfall, 300 stations recording evaporation and 700 recording frost days. The digital elevation model used to provide terrain (elevation and aspect) mapping to support the spline functions used in the ANUCLIM software is the version 2.0 of the 9 second (approx. 250 m resolution) national digital elevation model of AUSLIG (2001). Extensive checking of the locational data for the Bureau of Meteorology weather stations included some 2,500 station locations, providing a quality reference set of points from which to spatially interpolate climate surfaces.

Derived Outputs

The weather station climate data is interpolated (modelled) according to mathematical (spline) functions that reflect influences on micro-climate such as elevation. Climate maps are derived at variable resolutions (grid sizes), again using the ANUCLIM software. The list of outputs and their resolution is shown in Table 7.C3. The accuracy of the climate maps is tested by comparison between predicted values and actual weather station data. The climate maps derived for the NCAS (Kesteven et. al., 2004) were independently quality assured by the Australian National University's Centre for Resource and Environmental Studies (CRES). CRES is responsible for the generation of both the AUSLIG digital elevation model and the development and maintenance of the ANUCLIM software. Figures 7.C8 to 7.C11 illustrate national long-term annual average climate maps generated using the ANUCLIM software, noting that the NCAS methods apply the climate maps at the specific spatial and temporal resolutions as presented in Table 7.C3.

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

Table 7.C3. List of Climate Maps Developed for the NCAS

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

Figure 7.C8. Long-Term Average Rainfall.

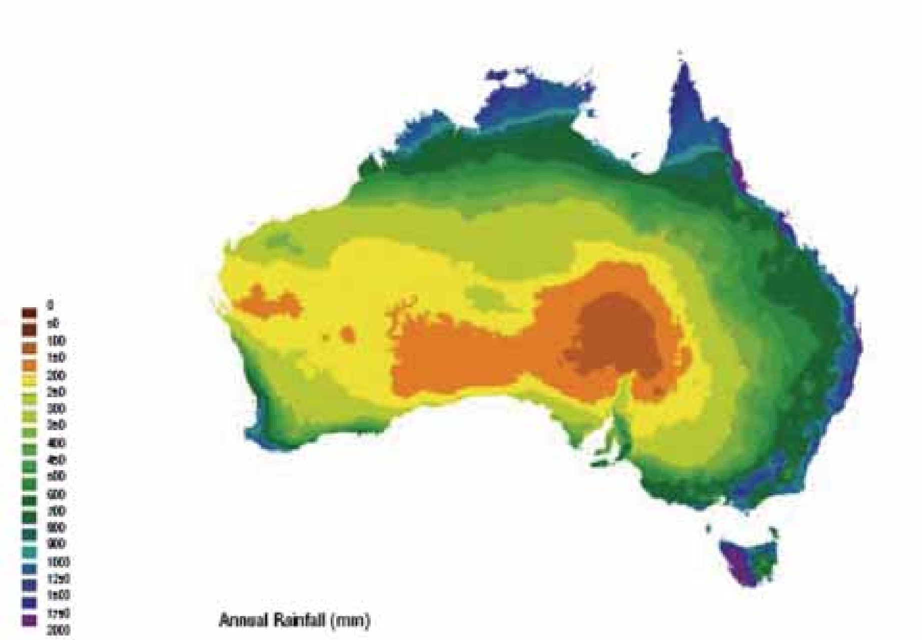


Figure 7.C9. Long-Term Average Annual Temperature.

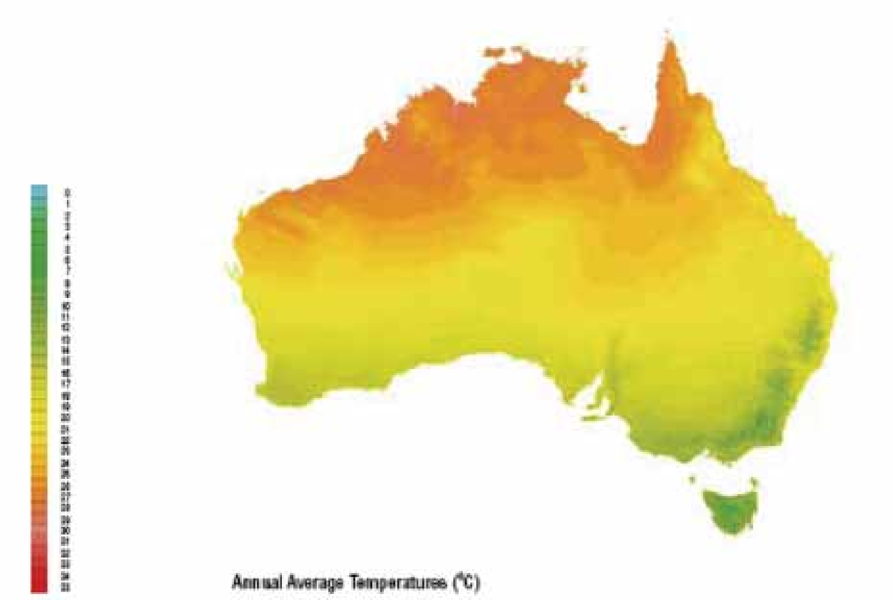


Figure 7.C10. Long-Term Average Annual Evaporation.

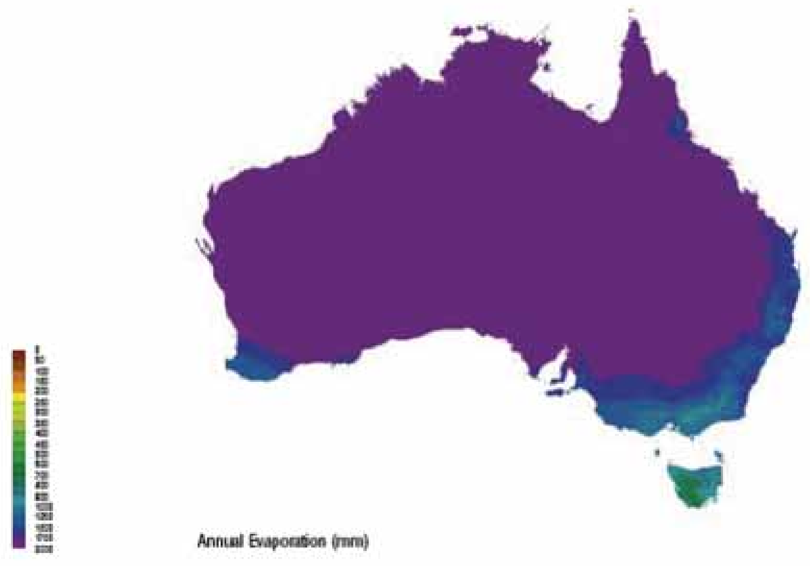
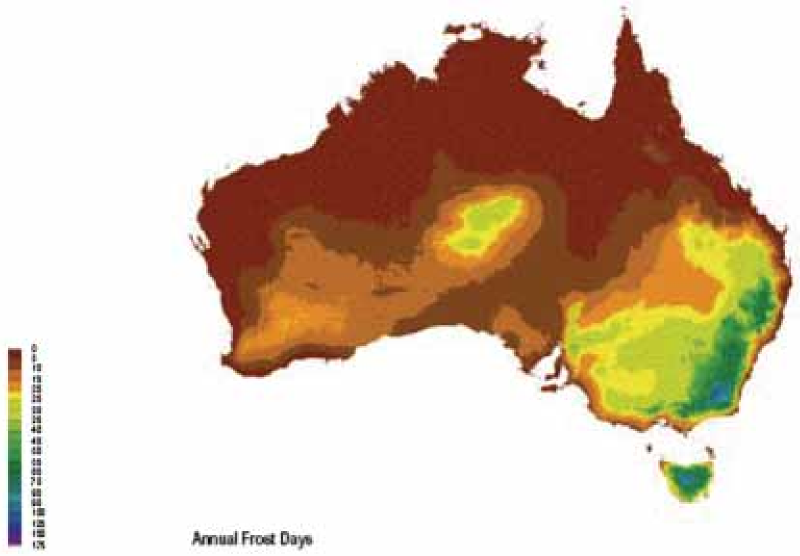


Figure 7.C11. Long-Term Average Number of Frost Days per Year.



Quality Assurance and Quality Control

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

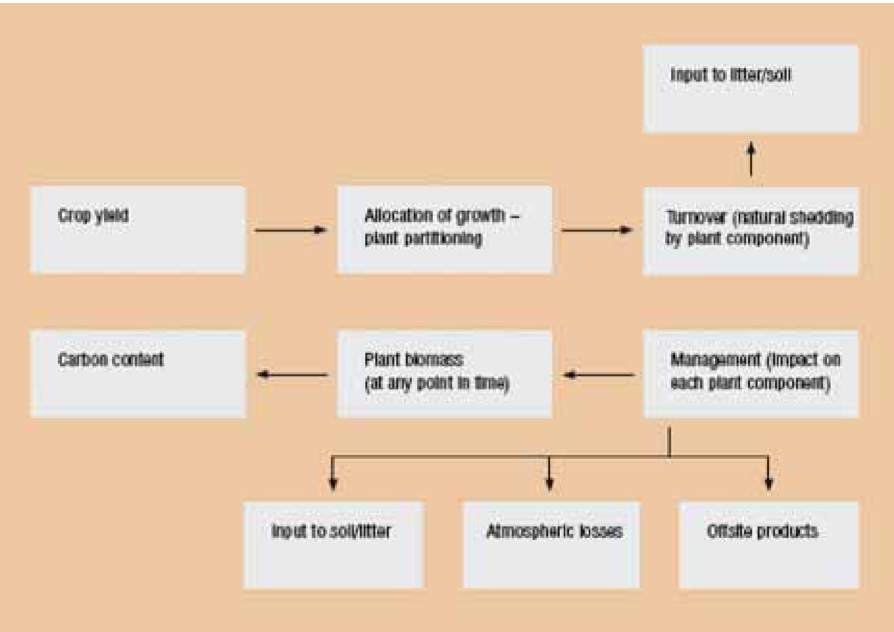
Crop Growth and Plant Parameters

Crop Yield and Residue

In a developmental study for the NCAS, Janik et. al. (2002) showed that the plant residue input to soil carbon modelling was a strong determinant of model outcome. Reliable crop growth information (supported by management practice as it affects residue generation and management) is important to robust soil carbon estimation. Plant residue input to litter and soil carbon pools is a significant determinant of total site carbon and trends in soil carbon over time.

There was no composite source of data suitable to meet the objectives set out above, with the available data frequently requiring supplementation with plant growth model outputs. The information that was available is included in Swift and Skjemstad (2002) and Skjemstad and Spouncer (2002). The accumulated data is contained in the relational database accessed during modelling for each cropping system at the relevant time, IBRA region, and soil type.

Figure 7.C12. Overview of the Crop Growth and Plant Parameters Program.



The available crop data, derived from a variety of sources, is usually expressed in terms of the mass of the saleable product component of growth, e.g., tonnes of grain, cane, leaf yield per hectare or tonnes of total aboveground yield per hectare. Available data has been reviewed to develop the appropriate corrections for each plant type to enable conversion from mass of saleable product to total plant mass.

The amount of plant residue generated over time is dependent on both the crop growth and management practice. The relational database that describes the agricultural management practices, such as the use of fire, is used to determine how much of the crop growth becomes residue for incorporation and decomposition to litter and soil carbon models and how much is taken offsite. The crop types and plant partitioning used in the modelling are shown in Table 7.C4.

Table 7.C4. Plant Partitioning by Crop Type.

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

Carbon Contents of Crop Species

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

Initial Crop Litter Mass and Decomposition Rates

Given both the rapid rates of decomposition of onsite crop material (compared to woody material) and the active management of litter in most agricultural systems, only small initial litter pools have been used in the model initialisation. The decomposition rates applied acknowledge that the crop residues that form the litter generally decompose within 12 months of their generation. The initial masses of litter assigned and their decomposition rates are shown in Table 7.C5.

Crop Turnover Rates

The turnover (natural shedding of material) rates for the crop and pasture species are high given that they are annual by nature. Within the annual constraint, the litter and soil carbon modelling is relatively insensitive to turnover rate. For continuous systems such as grazed pasture grasses there was a need to factor in root sloughing in response to grazing which maintains the relative balance of aboveground to belowground plant mass with grazing. The turnover rates used are shown in Table 7.C6.

Table 7.C5. Initial Litter Mass and Decomposition Rates for Crop Systems.

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

Table 7.C6. Turnover Rates Applied to the Crop Systems.

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

Quality Assurance and Quality Control

There was a surprising sparsity of available data on crop characteristics and likeness of similar crop types was often presumed for plant partitioning, decomposition rate and turnover rate model settings. These conform to published values, but limited empirical data constrains the extent of external quality assurance. Crop yields of saleable commodities were the most readily available data, for obvious reasons, and were generally accessed via published statistics. Beyond quality control of the transfer of data into the model, statements of yield were presumed correct. Additional parameters were independently analysed (e.g., carbon contents) or taken from existing literature. Cross referencing between available source data was the principal method of verification used. Sensitivity analyses were deployed to determine key areas of sensitivity for more intensive investigation.

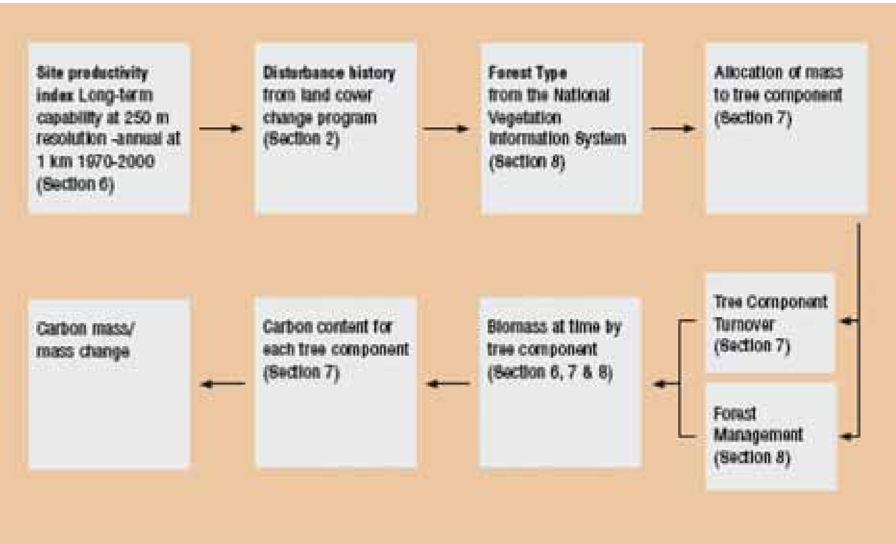
Biomass Stock and Growth Increment

Forest Productivity

The carbon stocks of mature forests and the rates of carbon accumulation in any forest regrowth need to be estimated, and be inclusive of both spatial and temporal variability. At the program outset comprehensive growth data or growth modelling capability (empirical or process-based, as either bole volume or total mass) was not available to support either biomass stock estimation or growth estimates with the required temporal and spatial disaggregation. To derive the spatial and temporal patterns of forest growth, a derivative form of the *3-PG* model (Landsberg and Waring, 1997; Coops et. al., 1998; Coops et. al., 2001) was used to provide relative indices of growth potential (productivity indices[8]) at a 1 km grid scale on a monthly basis since 1970. The model was initialised in 1968 using the NCAS climate data, reaching an equilibrium (for water balance) by 1970.

The site-based, multi-temporal productivity indices were used to predict potential biomass at maturity and to support a generalised empirical growth model. All modelling is done on the basis of aboveground biomass with subsequent corrections to account for belowground (fine and coarse root) material.

Figure 7.C13. Overview of the Forest Biomass Programs (from AGO 2002).



The *3-PG* spatial model, as used in this study, is a truncated version of the full *3-PG* model (Landsberg and Waring, 1997), retaining the essential features of biomass net primary production (*NPP*) estimation,

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

without the carbon partitioning procedures. The essence of the model is the calculation of the amount of photosynthetically active radiation absorbed by plant canopies (*APAR*). The time step is a month. *APAR* is calculated (Equation 1) as half the amount of short-wave (global) incoming radiation (*SWRadn*) absorbed by plant canopies, i.e.,:

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

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

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

There is significant variation in εvalues, but no clear pattern in relation to plant type, so a 'best estimate' value of *1.25 gm Biomass* MJ^{-1} APAR was used. As the resultant NPP is to be used as an index of 'productivity' and not as an absolute mass increase value, precision in the conversion factor is not critical. NPP is applied when there are no constraints on growth, but is reduced by modifiers reflecting non-optimal nutrition, soil water status, temperature and atmospheric vapour pressure deficits.

Calculation of Growth Modifying Factors

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

The modifying factors are:

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

Vapour Pressure Deficit: (*VPD*), acting on stomatal, and hence canopy, conductance. The equation used is:

$$VPDmod = e^{(-0.05 \times VPD)} \quad (2)$$

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

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

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

$$Transpiration = EqEvapn_j \times SWmod_{j-1} \quad (4)$$

$$WaterBal = (Rain \times (1-interception)) - Transpiration \quad (5)$$

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

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

MoistRatio = SoilWaterContent/SoilWaterCapacity	(7)
SWmod = 1 / (1 + ((1-MoistRatio)/0.6)$^{0.7}$)	(8)

The soil water and VPD modifiers are not multiplicative; the lowest one applies. The argument is that if plant growth (conversion of radiant energy into biomass) is limited more by VPD than soil water

(i.e., if VPDmod<SWmod) then soil water is not a limiting factor, even if soil water content is relatively low. The converse applies, that is, if SWmod<VPDmod, soil water is the limiting factor.

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

Tmod = ((Tav - Tlow) / (Topt - Tlow)) x ((Thigh – Tav) / (Thigh – Topt))	(9)

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

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

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

Average daily short-wave incoming (global) radiation was derived from the ANUCLIM package, using the version with rainfall as a co-variate. To account for the effects of slope and aspect on solar radiation the NCAS has derived a ratio of direct/(direct+diffuse) radiation (the effects of slope and aspect apply to direct solar radiation only). Slope and aspect were derived from the AUSLIG (2001) version 2.0 9' digital elevation model (DEM).

Minimum and Maximum Temperature data were derived using the methods described and Tmax, Tmin, Tav and Topt were derived from these values. For the calculation of Frost Days, the NCAS built a climate surface using data from the Bureau of Meteorology, fitted with elevation as a covariate.

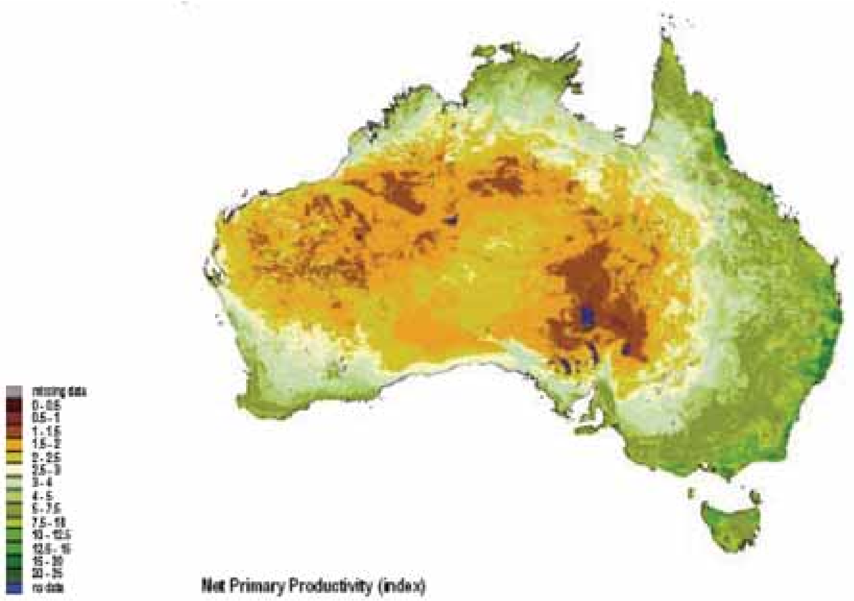
Monthly Average Rainfall for the whole country was taken from the data described earlier. Soil fertility and water holding capacity (SWcapacity) were obtained from the spatial map of Australian soils provided by CSIRO (McKenzie et. al. 2000a).

Potential Biomass at Maturity

In addition to the multi-temporal 1 km grid scale outputs of the model, a 250 m (slope and aspect corrected) long-term average productivity map (Figure 7.C14) was produced using long-term average climate data. This long-term average productivity map was used to define a productivity-to-mass relationship by regressing known measures of aboveground mass (Raison et. al., 2003) against the long-term productivity. Mature masses were defined as having no identifiable major disturbance events since 1970 such as clearing, harvest or fire (Richards and Brack 2004a), and were therefore assumed to have reached biomass production potential (Long-term Aboveground Stand Biomass).

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

Figure 7.C14. 250 m Slope and Aspect Corrected Productivity Index Map



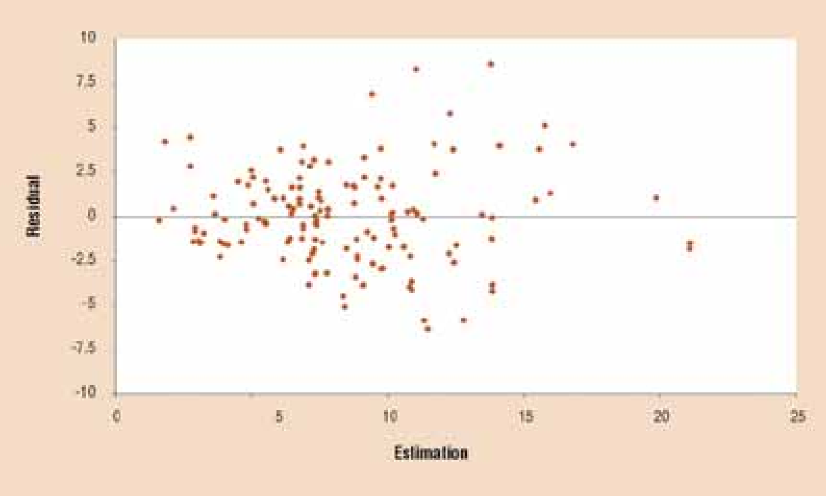
A regression found a significant correlation ($p < 0.01$, $r^2 = 0.68$) between Long-Term Aboveground Stand Biomass (*M*) and Long-Term Average Productivity (*P*). A square root transformation was required to meet assumptions of normality and homogeneity.

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

The goodness of fit of Equation (10) ($r^2 = 0.68$, $p < 0.01$) to the measured data confirms that a robust relationship exists between the productivity mapping and measured aboveground biomass estimates. Biomass at maturity (maximum biomass) at a chosen resolution for the entire continent can then be calculated by applying the relationship (equation) to the productivity index mapping. A key benefit of the hybridisation of process modelling (through the productivity mapping) and empiricism (through known measures) is that estimates will be constrained to actual conditions (measured mass estimates) and actual growth, not that of optimal growth.

While the goodness of fit and lack of bias in error estimates (Figure 7.C15) provides confidence in the application of the Equation (10) as a model to predict biomass at maturity, there is an obvious scatter in the data. This is potentially attributable to either the range of methods used in the field estimation or to an inherent variability between the 'plot' locations used to scale to one ha mass estimates compared to the average condition reflected in the 250 m resolution productivity estimation.

Figure 7.C15. Error Distribution for Equation 10



Biomass Growth Increments

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

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

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

(M) is the maximum long-term aboveground tree stand biomass, and

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

Available data, such as that reported by West and Mattay (1993), suggests the age of maximum current annual increment (CAI) for stem volume is approximately constant for most species and is independent of site productivity. The constant *k* is determined to reflect the age of maximum total aboveground biomass CAI. The value of *k* can be varied for each forest type (community or species) used in the model and is contained within the relational database supporting the *FullCAM* model. A *k* value of 10 has been used which reflects an earlier maximum CAI for total aboveground biomass than for stem volume. This reflects an early bias in allocation to non-stem tree components.

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

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

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

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

This approach provides biomass stock estimates for a given land unit at any point in time that recognize prior forest disturbance, and the rates of growth for a land unit at any point in time, specific to site condition and age.

Optimal growth as often derived from process models has been shown to over-estimate biomass potential (Kurz et. al. 1998). The approach outlined above provides for a hybridisation of empirical constraints with the temporal and spatial variability derived from spatially applied process modelling.

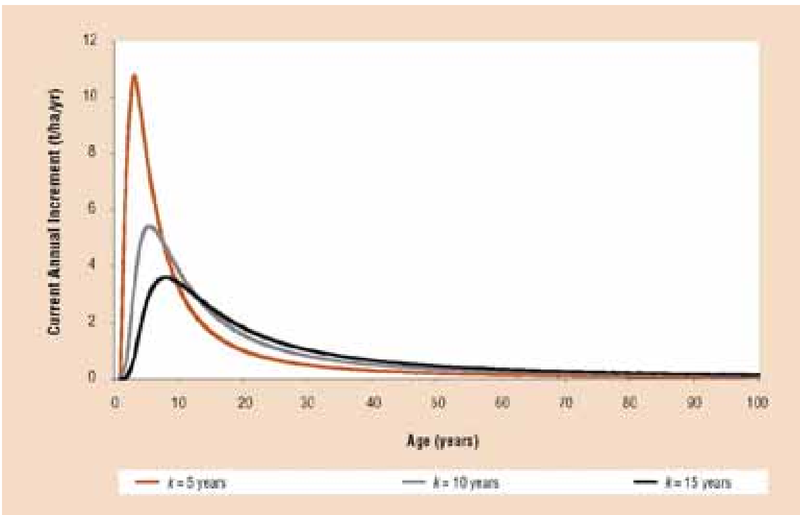
Patterns of growth will show variability according to the spatial and temporal patterns of the main process drivers, e.g., water balance, captured in the productivity modelling. Estimates of biomass in areas of regrowth are then both spatially and temporally relevant.

Figure 7.C16 provides an analysis of the effects of varying age of *k* between the extreme ranges of 5 to 15 years. While the early age growth increments are very sensitive to the age of CAI, even by age 18 there is little difference in the annual aboveground biomass growth increment. Reviews of available data, including that of West and Mattay (1993), suggest that there is little variance from a maximum CAI for stem volume occurring at age 10. No data has been identified that supports significantly earlier or later occurrence in native forests. In plantations where site modification (irrigation, fertilization and soil preparation) is undertaken at an early age (particularly for short rotation pulpwood plantations) the age of maximum stem volume CAI may be reduced. Plantation yield tables can be used to identify any needed modifications (entered through the *FullCAM* database) when such systems are considered in relevant applications of the model.

The findings on age of maximum aboveground biomass CAI are very significant as the 1972 map layer is assumed to represent biomass at maturity. This assumption has been made as no age definition was available for forests in 1972. The model will have largely achieved equilibrium around this assumption by 1989 in that there is a much reduced and consistent growth increment after approximately age 18.

Land cover change events in 1989 and 1990 have the most significant impact on the 1990 baseline emissions for biomass. The assumption of biomass at maturity in 1972 has little potential for over-estimation of biomass carbon stock changes in 1990, and later years. Areas of land cover change between 1972 and 1989 will have new age allocations, while areas not cleared will be at least 20 years old (needing to be at least 2 years old to be identified as forested in 1972) and so will, by 1989, be at or nearing mature biomass and be largely insensitive to age of maximum aboveground biomass CAI.

Figure 7.C16. Effects of Varying Age of Maximum Current Annual Increment



Quality Assurance and Quality Control

Independent QA/QC was undertaken on the development of the multi-temporal productivity indices developed for the NCAS and included review of methods, their application and the plausibility of results. The land cover change data used to determine forest age and the climate data used in the productivity mapping was independently subjected to QA/QC.

Tree Parameters

Introduction

To provide a consolidation and synthesis of available national data on partitioning of growth, carbon content and wood density, the NCAS initiated a range of studies on related topics. Identified priority gaps were supplemented with some additional data collection.

Wood Density

Wood density information has been drawn from Ilic et. al. (2000), a national compendium of wood density information prepared for the NCAS. The data of Ilic et. al. (2000) is presented on a species basis. The wood density assigned to each forest type is an approximate average of the values for species typically represented in each class. One of the key benefits of the direct biomass (rather than volume) modelling approach taken, is that wood density is required only if volume estimates are needed for comparison to forest plot data. Volume is not used in the carbon modelling, but is calculated during the analysis to assist in comparisons between modelled estimates and measured plot data for verification purposes. Plot data for verification is more often available in stem volume than as mass estimates. The wood density values used are shown in Table 7.C7.

Table 7.C7. Wood Density Values for the Major Vegetation Group (MVG) Classes.

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

Tree Partitioning

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

The most important attribute in partitioning is the ratio of belowground biomass to the aboveground composite mass, which is estimated using productivity modelling. There is also a need to apportion materials to different decomposition pools, burning ratios etc. from above–ground components. As land cover change is frequently cyclic (including removal of regrowth), any over- or under-estimates in growth due to the root-to-shoot ratio applied will be largely compensated for by an equivalent over – or under-estimate in amounts of regrowth removed. The partitioning ratios used are drawn from the best available data, largely taken from the synthesis of data compiled by Snowdon et. al. (2000) for the NCAS. The partitioning used for each forest type is shown in Table 7.C8.

Tree Carbon Contents

The carbon content of the estimated biomass (dry matter) is needed to derive a carbon mass equivalent from the biomass modelling. Studies by Gifford (2000a) and Gifford (2000b) for the NCAS considered the carbon content of various tree components, for a range of species and across a range of environments. Drawing on this work, the carbon contents used in this analysis are shown in Table 7.C9.

Table 7.C8. Partitioning of Biomass by Major Vegetation Group (MVG) Class

Name	Yield Allocation to Stems fraction)	Yield Allocation to Branches (fraction)	Yield Allocation to Bark (fraction)	Yield Allocation to Leaves (fraction)	Yield Allocation to Coarse Roots (fraction)	Yield Allocation to Fine Roots (fraction
Rainforest and vine thickets	0.78	0.06	0.06	0.01	0.06	0.03
Eucalyptus Tall Open Forest	0.67	0.09	0.10	0.02	0.08	0.04
Eucalyptus Open Forest	0.45	0.12	0.10	0.02	0.25	0.06
Eucalyptus Low Open Forest	0.45	0.12	0.10	0.02	0.25	0.06
Eucalyptus Woodland	0.44	0.15	0.10	0.02	0.23	0.06
Acacia Forest and Woodlands	0.42	0.15	0.10	0.02	0.25	0.06
Callitris Forest and Woodlands	0.42	0.15	0.10	0.02	0.16	0.15
Casuarina Forest and Woodland	0.42	0.15	0.10	0.02	0.25	0.06
Melaleuca Forest and Woodland	0.42	0.15	0.10	0.02	0.25	0.06
Other Forests and Woodlands	0.42	0.15	0.10	0.02	0.25	0.06
Eucalyptus Open Woodland	0.41	0.18	0.10	0.02	0.23	0.06
Tropical Eucalyptus woodlands/grasslands	0.41	0.18	0.10	0.02	0.23	0.06
Acacia Open Woodland	0.22	0.165	0.10	0.025	0.42	0.07

Name	Yield Allocation to Stems fraction)	Yield Allocation to Branches (fraction)	Yield Allocation to Bark (fraction)	Yield Allocation to Leaves (fraction)	Yield Allocation to Coarse Roots (fraction)	Yield Allocation to Fine Roots (fraction
Mallee Woodland and Shrubland	0.22	0.165	0.10	0.025	0.42	0.07
Low Closed Forest and Closed Shrublands	0.22	0.165	0.10	0.025	0.42	0.07
Acacia Shrubland	0.22	0.165	0.10	0.025	0.25	0.24
Other Shrublands	0.22	0.165	0.10	0.025	0.25	0.24
Heath	0.00	0.3	0.18	0.03	0.25	0.24
Chenopod Shrub, Samphire Shrub and Forbland	0.00	0.3	0.18	0.03	0.25	0.24
Mangrove, tidal mudflat, samphire and bare areas, claypan, sand, rock, salt lakes, lagoons, freshwater lakes	0.167	0.167	0.167	0.167	0.167	0.167
Unclassified Native vegetation	0.39	0.14	0.09	0.02	0.25	0.11

Table 7.C9. Carbon Contents of Tree Components

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

Table 7.C10. Tree Component Turnover Rates

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

Tree Component Turnover Rates

Tree component turnover rates determine the inputs to litter, while soil organic matter is largely derived from root turnover (the balance coming from litter decomposition). Litterfall (leaf), branch and bark shed and root turnover have been determined from available literature. The rates applied are in Table 7.C10. These draw heavily on the rates determined by Paul et. al. (2002b) in a model calibration study for the NCAS.

Quality Assurance and Quality Control

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

Forest Parameters

Introduction

The National Vegetation Information System (NVIS, see NLWRA 2001) provides a composite of the best available vegetation mapping in Australia. Various forest characteristics (e.g., as forest floor coarse woody debris and litter) are associated with the forest types extracted from the NVIS. The rates of decomposition of this material, new inputs and management activity affect changes in mass over time.

Forest Type Mapping

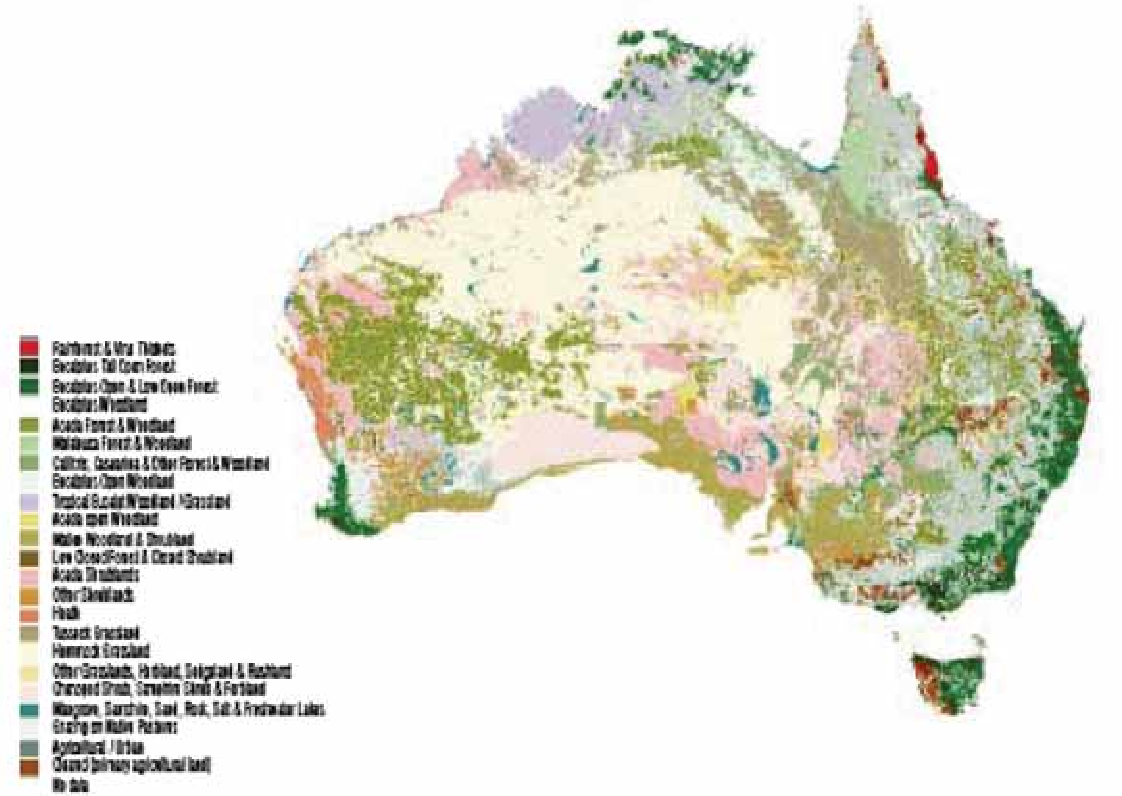
As part of the commitment to national natural resource mapping undertaken for Australia's National Land and Water Resources Audit (NLWRA), a National Vegetation Information System (NVIS) was compiled. The NVIS collates and provides, in a consistent taxonomy and classification, the best available vegetation maps from all available sources. Six levels of information are available (Table 7.C11).

Table 7.C11. National Vegetation Information System (NVIS) Hierarchical Classifications.

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

For the purposes of carbon accounting Level III, the Major Vegetation Grouping (MVG) categories were applied. These vegetation types are described in Attachment 7.C1.

Figure 7.C17. Major Vegetation Groups (MVG).



In addition to the 'current' vegetation mapping which represents a composite of recently collected data, the NVIS also modelled forest distributions to infer a pre-European settlement (1770) vegetation map. Some of the land clearing identified by the land cover change program pre-dated the current vegetation mapping (generally 1990 onwards) which meant that areas identified as cleared land in the NVIS could have been forested between 1972 and the NVIS map date. In these instances, the vegetation type allocation was drawn from the 1770 modelled (inferred) vegetation map. While the forest potential maximum (at maturity) biomass and growth rates are largely independent of forest type, other tree characteristics are specific to forest type. Wood density, partitioning of mass to different tree components and the age of maximum current annual increment (CAI) for growth are forest type dependent.

Forest Litter

Initialisation of the forest litter stock in the model (coarse woody debris and fine litter) draws upon assessments carried out for the NCAS in conjunction with the soils measurement program (Murphy et. al., 2002, Griffin et. al., 2002, Harms and Dalal 2002 and Harms et. al., 2005) and a separate study by Mackensen and Bauhus (1999). Sites used in these studies were widespread amongst the areas primarily cleared for agricultural purposes. Additional data was drawn from literature where available. The values used are shown in Table 7.C12. Debris mass is converted to carbon assuming a carbon fraction of 0.45.

Forest Residue Management

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

Table 7.C12. Initial Forest Litter Values (t dry matter ha^{-1})

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

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

Litter decomposition rates have been extracted from available information including the study undertaken by Mackensen and Bauhus (1999) for the NCAS. The rates applied are shown in Table 7.C13. There are few studies in Australia of litter decomposition rates with most work being focused on wood product longevity trials. The data was supplemented with some limited chronosequence work on paired sites, but the main focus of this work was on modelling rates that coincided with measures of litter mass when the models were run over extended periods so that a reasonable balance between turnover (input to litter pools) and decomposition of litter pools was achieved.

Table 7.C13. Litter Decomposition Rates for Tree Components.

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

Quality Assurance and Quality Control

The vegetation mapping provided by the NVIS has been compiled under a major national program with contributions made by relevant data holding groups, in particular State and Territory Governments.

Forest floor litter (coarse and fine) has been estimated using standardised methods as published in the NCAS Technical Reports 14 (McKenzie et. al., 2000b) and 31 (Snowdon et. al., 2001). Available data conforms to these methods and has been checked for plausibility on entry to the NCAS system and subsequently to the *FullCAM* model.

Soil Carbon

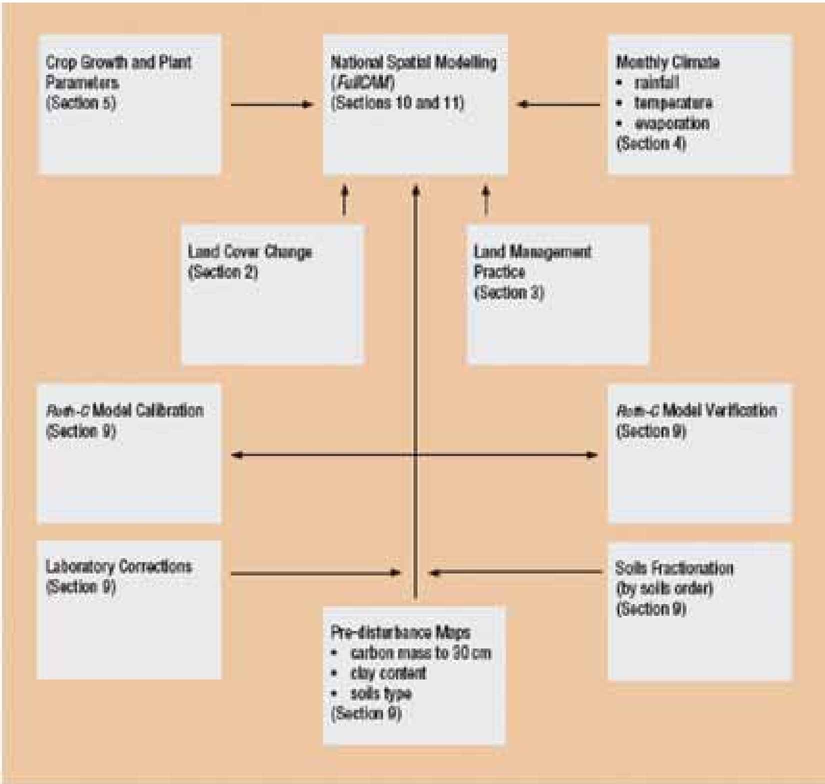
The Soil Carbon Program

In order to perform spatially and temporally disaggregated accounting for soil carbon, it was necessary to calibrate and verify a robust and widely applicable soil carbon model. The overall soil carbon program developed both resource inventory (mapping) descriptions and model calibration and verification. The integrated soil carbon program for the NCAS is shown in Figure 7.C18.

Model Selection

On the basis of previous successful testing in a range of environments in Australia, the *Roth-C* (Jenkinson et. al., 1987, Jenkinson et. al., 1991) soil carbon model was chosen (Webbnet Land Resources Services Pty. Ltd. 2000) for implementation in the NCAS and integrated into the *FullCAM* model (Richards 2001b).

Figure 7.C18. The NCAS Soils Program (from AGO 2002).



Soil Mapping and Inventory

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

The mapping of soils units was completed at a level of precision which could be supported by available data. This approach led to variable resolutions in the mapping, generally determined by the regional data availability and heterogeneity of soils landscape. The results of this project are reported in Webbnet Land Resource Services Pty. Ltd. (2002). Figure 7.C19 shows the pre-disturbance map derived.

In conjunction with the development of the pre-disturbance soil carbon map, a map of clay content was also developed (Figure 7.C20) using the same map base. The mapped soil units provide pre-disturbance carbon (organic) content, clay content and soil type. The soil types (Table 7.C14) allow for the mapping to subsequently (via the *FullCAM* relational database) be ascribed proportions of the starting carbon within the pools described in the soil carbon model. These pools are defined by their differing turnover times (resistance to decomposition). The proportion of material in each soil pool (fractionation) was established by laboratory analysis of soil samples held in CSIRO and State/Territory Government archives.

Figure 7.C19. Pre-Disturbance Soil Carbon Map.

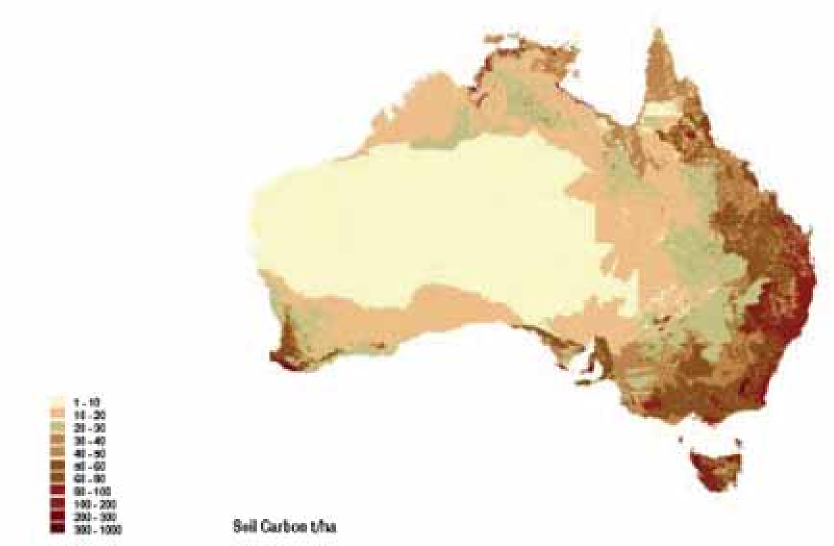
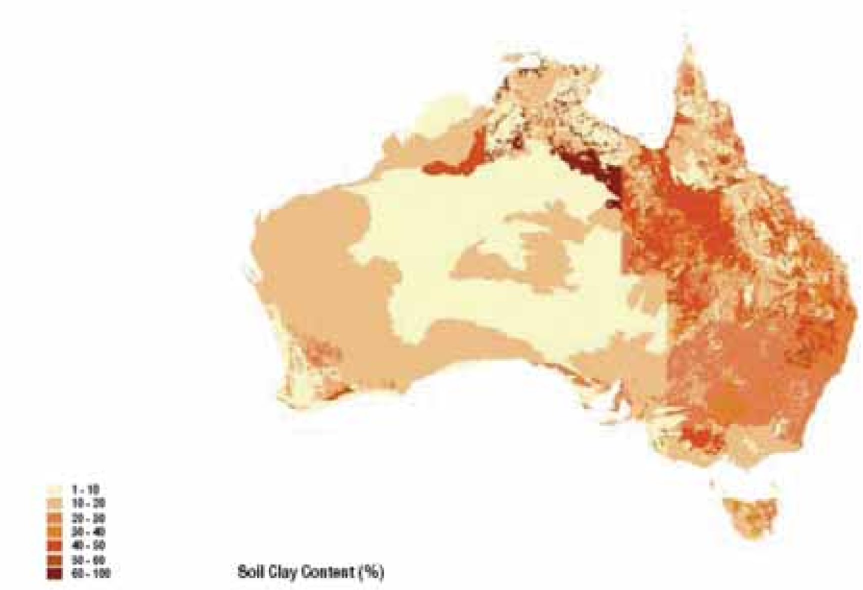


Figure 7.C20. Clay Content Map.



Soil Carbon Model Development

Early policy and technical analysis of the requirements for the carbon accounting under the IPCC Inventory Guidelines, the Kyoto Protocol, and of the national data and methodological capacity available for the task, led to the development of a model-based methodology underpinned by the Roth-C soil carbon model. The background to the selection of methods and design of the program can be found in Webbnet Land Resource Services Pty. Ltd. (2000). The model calibration and verification program identified available long-term field trial data, a subset of which had sufficiently detailed and complete long-term data to enable calibration of the model against long-term field measurements. Only a minimum of data supplementation was accepted at these calibration sites. Other sites with incomplete long-term data, but providing a robust temporal pattern of carbon change under known treatments and climate, were used for model verification (Skjemstad and Spouncer 2002).

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

Table 7.C14. Soil Classification Used in the Modelling.

Soil no.	Location	Soil type
s1	TAS	Structured earths
s2	TAS	Bleached sands with subsoil pans
s3	TAS	Other soils
s4	NSW	Clay
s5	NSW	Loam
s6	NSW	Sand
s7	QLD	Duplex – woodland
s8	QLD	Clay – brigalow and gidgee
s9	QLD	Clay – open downs
s10	QLD	Clay – brigalow and belah
s11	QLD	Gradational
s12	QLD	Clay
s13	QLD	Other soils
s14	QLD	Gradational – spinifex
s15	QLD	Clay – mitchell grass (30%) and gidgee
s16	QLD	Duplex – black spear grass & a\b woodland
s17	QLD	Duplex
s18	QLD	Gradational and duplex
s19	QLD	Clay – gidgee
s20	QLD	Open downs
s21	QLD	Earths
s22	QLD	Sands and loams
s23	QLD	Clays and red loams
s24	NT	Kandosol
s25	NT	Other

Soil no.	Location	Soil type
s26	NT	Tenosol
s27	SA	Sub area 1 -DD
s28	SA	Sub area 2 – Lb5
s29	SA	Sub area 3 – Sandy
s30	SA	DD2/Lb5/E6
s31	VIC	Deep sands s32 VIC Calcarosols
s33	VIC	Cracking clays
s34	VIC	Yellow duplex soils
s35	VIC	Leached sands
s36	VIC	Brown duplex soils
s37	VIC	Black duplex and gradational soils
s38	VIC	Red-brown earths
s39	VIC	Bleached sands
s40	VIC	Organic soils
s41	VIC	Gradational Red earths
s42	VIC	Non-Cracking clays
s43	VIC	Red duplex soils
s44	VIC	Organic loams
s45	VIC	Red earths
s46	VIC	Brown earth
s47	VIC	Grey Cracking Clays
s48	WA	Coloured sands
s49	WA	Gravels
s50	WA	Loams and clays
s51	WA	Non saline wet
s52	WA	Other
s53	WA	Pale sands
s54	WA	Sandy duplexes
s55	WA	Saline

Both the model calibration and verification studies are reported in Skjemstad and Spouncer (2002). The reports of the paired site studies can be found in Harms and Dalal (2002), Murphy et. al. (2002) and Griffin et. al. (2002). Given the diversity of systems tested and the inherent problems with paired sample approaches, the model results were surprisingly good, with the only model parameter altered from the *Roth-C* recommended defaults being the decomposition rate for Resistant Plant Matter (*RPM*) (from 0.30 to 0.15). Occasional site failures, where modelled results were inconsistent with the paired sample measures, were generally readily attributed for identifiable reasons, to poor site pairing in the paired sample analysis.

Quality Assurance and Quality Control

The data for the development of soil type maps was extracted from the best available resource inventory information held by State and Territory Governments and was subjected to expert review prior to entry into the development of the maps. The clay contents were also taken from these inventories and supplemented with available research data as part of the same process. Carbon contents were corrected to methodological standards where the initial method of measurement was known, otherwise the data was considered unusable.

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

The Model Framework

Introduction

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

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

> the physiological growth model for forests, *3–PG* (Landsberg and Waring 1997, Coops et. al. 1998, Coops et. al. 2001);
> the carbon accounting model for forests, *CAMFor* (Richards and Evans 2000a);
> the carbon accounting model for cropping and grazing systems, *CAMAg* (Richards and Evans 2000b);
> the microbial decomposition model *GENDEC* (Moorhead and Reynolds 1991; Moorhead et. al., 1999); and,
> the Rothamsted Soil Carbon Model, *Roth-C* (Jenkinson, et. al., 1987, Jenkinson et. al., 1991).
> These models have been independently developed for the various purposes of predicting and accounting for:
> soil carbon change associated with agriculture and forest activities (in the case of Roth-C);
> the determination of rates of decomposition of litter (in the case of *GENDEC*); and,
> the prediction of growth in trees (in the case of *3-PG*).

CAMFor and *CAMAg* are carbon accounting models developed by the NCAS through which it is possible to assess the impacts of management practices, such as fire, decomposition, harvest, cropping, and grazing, to externally generated growth and decomposition rate inputs. In preparing these models for integration into *FullCAM*, each model (except for *CAMAg*) was translated from original source code to a common Microsoft Excel spreadsheet format. The Excel workbooks used only sheet-based formula with no 'Macros' or other code applied. This provided a consistent and transparent model platform from which to review and integrate the various models. Having a consistent structure and format for the models allowed for the independent calibration of various models while providing for ease of later integration. The transparency of the development process also facilitated review at a detailed level.

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

Sub-model Selection

The need to develop an integrated model was highlighted during the International Review of the NCAS Implementation Plan for Phase 1 of the 1990 baseline. The review report is contained in the NCAS Technical Report No. 11 (AGO, 2000b). Most germane among the Review recommendations was a need to take a holistic approach, with modelling and measurement continuous across all carbon pools and cognisant of the transfers between pools. Other recommendations from the Review which had direct implications for the development of the NCAS, and therefore *FullCAM* were:

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

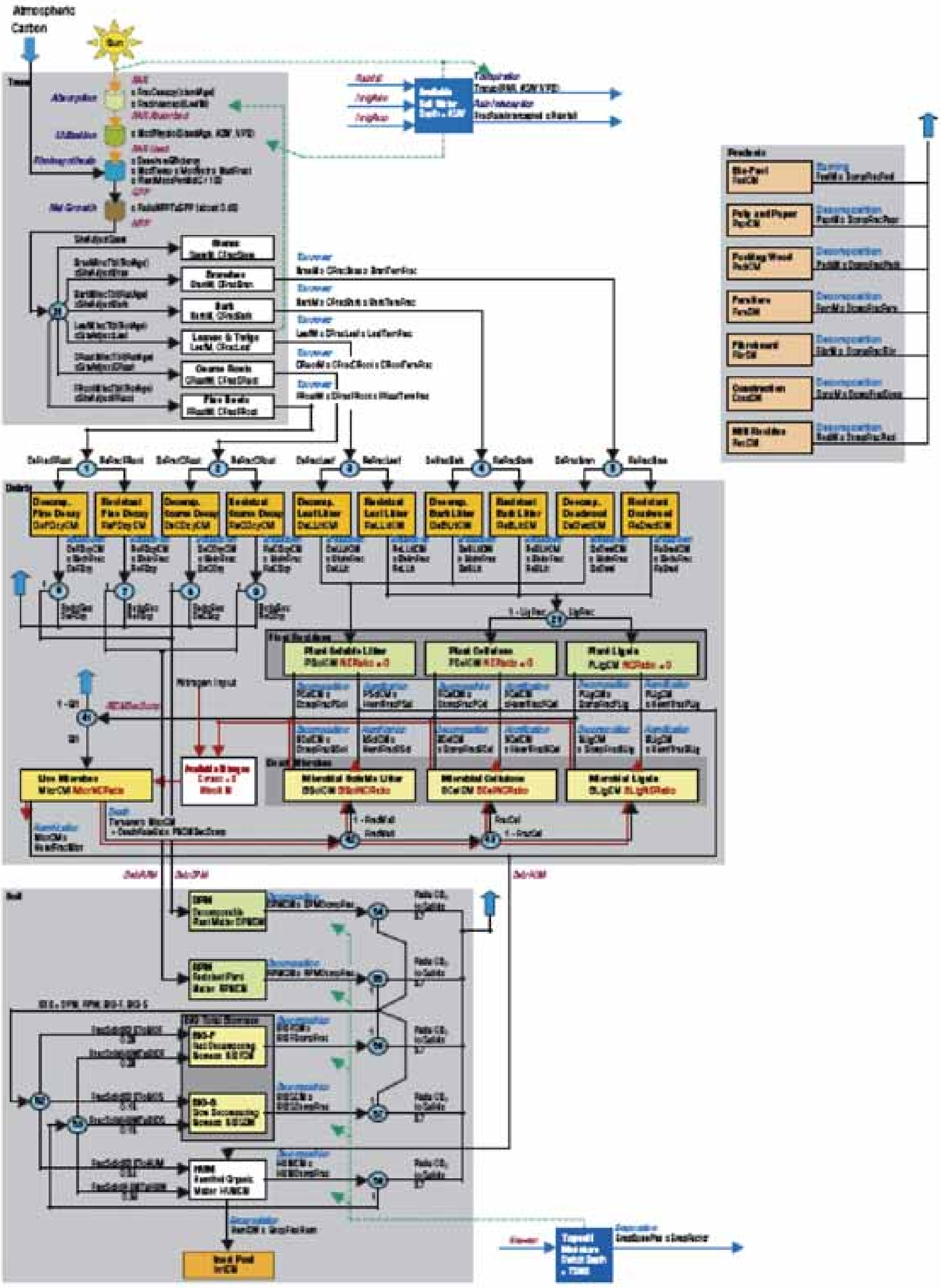
Strategies for data accumulation and assimilation into models capable of both continental and project scale carbon accounting (largely directed at satisfying the requirements of the Kyoto Protocol) were developed. Strategies were also developed to guide the fundamental data collections (field and analytic protocols), research program (targeted research objectives) and model calibration (including sensitivity and uncertainty analysis). The *CAMFor* and *CAMAg* models were developed to account for the impacts of management actions and events such as fire. *CAMFor* (Carbon Accounting Model for Forests) (Richards and Evans, 2000a) was developed within the NCAS to provide capacity for both project and continental scale accounting. *CAMFor* was originally an Excel based model which has its conceptual foundations in the CO_2 Fix model (Mohren and Goldewijk, 1990).

CAMAg (Carbon Accounting Model for Agriculture) was also developed for the NCAS (Richards and Evans, 2000b). *CAMAg* performs similar functions to *CAMFor*, but operates in agricultural systems. *CAMAg*, unlike *CAMFor*, was developed with direct integration of the *Roth-C* model. Testing of the replication of the models in their new format was undertaken through comparison of results between original and derived models using the same model parameters.

Model Development

When there was confidence that the Excel developmental models were giving the same results as the original source code versions, the Excel models were fully documented and returned for verification to the original authors or host organisations. Modifications were considered only subsequent to this initial review. Modifications were made for a variety of reasons including efficiency in code (computational speed and resources) and in recognition of Australia's different biophysical conditions.

Figure 7.C21. The Forest 'Side' of the FullCAM Model.



The subsequent integration into a single compendium of the various sub-models was initially undertaken in Excel as a test version. The prototype forest model derived, *GRC3* (Richards and Evans 2000c) (Figure 7.C21), was subsequently tested by CSIRO (Paul et. al., 2002a).

The NCAS provided considerable investment into the calibration of each of the models for the range of conditions and management practices present throughout Australia. Over a 2–3 year period the total investment, including the data collection and process understanding for model calibration needed to ready the model for initial national application, was in the order of $9M AUS. Model calibration included the collation of a series of previous (quality audited) site measurements and the undertaking of additional field work and laboratory analyses. Separate data sets were maintained for model calibration and verification of model results.

The subsequent implementation of the calibrated sub-models in a spatial version of *FullCAM* uses a range of spatially continuous and frequently multi-temporal input data layers. This includes data such as that on land cover change, climate and soil type described in previous sections.

The Component Models

<u>3-PG</u>

The adopted version of *3-PG* is that described as Version *3-PG*pjs 1.0 (Sands 2000). In its original form, this is an Excel version of the model supported by Visual Basic Macros. This was translated into a consistent sheet-based and formula-driven (no Macros) model. Subsequent changes were made to this model to enable spatial application reflecting the previous version development by Coops and Waring (2001) and Landsberg and Kesteven (2001).

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

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

<u>CAMFor</u>

The *CAMFor*, forest carbon accounting model, has its origins in the 1990 *CO_2* Fix Model of Mohren and Goldewi$_{jk}$ (1990). The published Fortran code for this model was converted to an Excel spreadsheet (sheet based, formula driven) format as reported in Richards and Evans (2000a). A subsequent series of modifications was made including:

> the introduction of an inert soil carbon pool, recognizing the nature of the carbon in Australian mineral soils, the high charcoal content and the potential long-term protection of fine organic matter through encapsulation and absorption by clays;
> addition of a fire simulation capacity that could deal with stand-replacing and/or regenerating fires, being either forest floor fires largely removing litter or crown fires affecting the whole tree;
> the wood product pool structures and life cycles were modified to reflect those cited in the NCAS Technical Report Number 8 (Jaakko Poyry 1999);
> greater resolution was added to the component distinctions of the standing tree material, splitting coarse and fine roots, branch and leaf material;

- the potential to override the soil carbon model component by directly entering either field data or externally modelled inputs, and,
- an added capability to use primary data of aboveground mass increment for accounting, as an alternative to stem volume increment.

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

- net primary productivity (NPP) derived from 3-PG with feedback from management actions (thinnings, etc.) specified in CAMFor;
- a generalised productivity-driven growth model;
- measures of aboveground biomass increment; and,
- measures of stem volume increment.

Material entering the forest debris pool (aboveground coarse and fine litter) and the belowground forest decay pool (root material belowground shed by live biomass) is accounted in either a decomposable or resistant fraction, with the potential to apply distinct decomposition rates to each. If the *3-PG* and *CAMFor* models are used together, information flowing from *3-PG* to *CAMFor* is the total *NPP*, as reflected in whole tree productivity. Rules for the allocation to various tree components and for the turnover rates that will affect the standing mass increment at any one time (change in mass as opposed to a total productivity change) are specified within a *CAMFor* table. Neither *CAMFor* nor *3-PG* (in this form) deals with number of stems, but work on proportional change to mass per unit area. Thinning activities such as harvest or fire, which are specified in *CAMFor*, are treated as a proportional decrease of biomass and are reflected as an equivalent proportional decrease in canopy cover within *3-PG*.

CAMAg

Within *FullCAM*, *CAMAg* serves the same roles for cropping and grazing systems as *CAMFor* does for forests. The *CAMAg* model reflects the impacts of management on carbon accumulation and allocates masses to various plant product pools and to decomposable and resistant organic residues. Yields need to be prescribed in the model, as either aboveground, total or product mass – as do above-and belowground turnover rates. With both *CAMFor* and *CAMAg* embedded within *FullCAM*, it is possible to represent completely transitional activities – afforestation, reforestation and deforestation (change at one site) – or a mix of agricultural and forest systems (e.g., agroforestry, discrete activities at separate sites). Under afforestation and reforestation there is a gradual change from the carbon pool characteristics of the original pasture or cropping system, with the mass of organic matter derived from those systems decomposing and decreasing with declining input. For deforestation, the same applies, but with a large residue of decomposing woody material being the primary change remaining within *CAMFor*.

Within *FullCAM*, *CAMFor* and *CAMAg* can be proportionally represented (as under afforestation, reforestation and deforestation) as the source of carbon input according to the relative proportions of canopy cover under each of the forest (*CAMFor*) and non-forest (*CAMAg*) categories. This also provides capacity for ongoing mixed systems such as agroforestry.

GENDEC

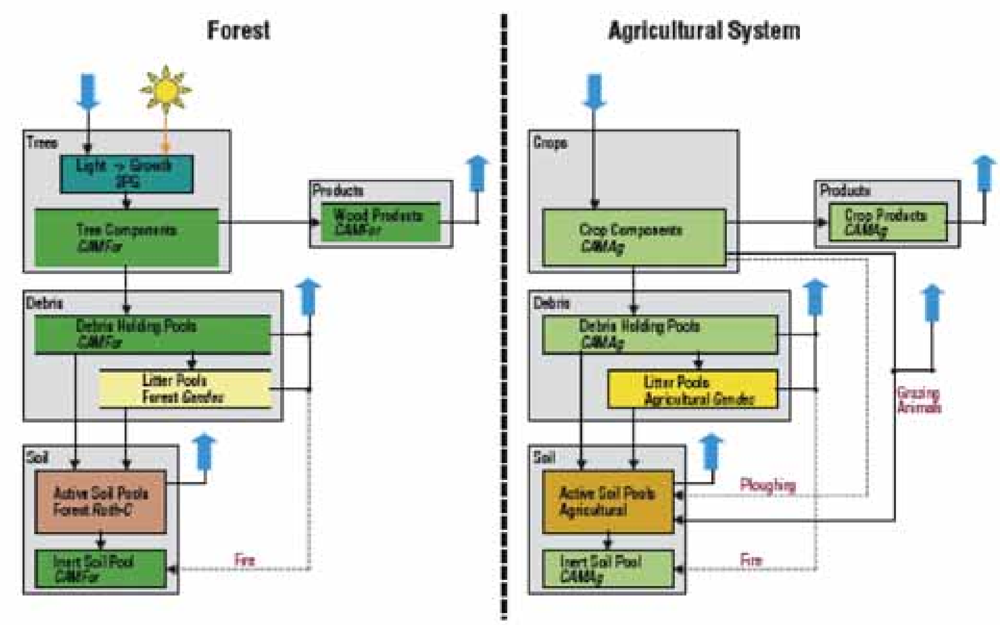
GENDEC is a microbial decomposition model, developed by Moorhead et. al. (1999), which considers the environmental and biological drivers of microbial activity, namely temperature, moisture and substrate quality. *GENDEC* addresses both carbon and nitrogen, relying on nitrogen-to-carbon ratios throughout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

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

Roth-C

The Rothamsted soil carbon (*Roth-C*) model treats pre-determined masses of plant residues which are then split into decomposable and resistant plant material. Required model inputs include the fractionation of soil carbon into various soil carbon pools, generally defined by classes of resistance to decomposition. Turnover rates for each fraction are determined by rainfall, temperature, ground cover and evaporation. For situations where calibration data is available, it is preferable that the Roth-C model be used in conjunction with *CAMFor*. It is a more robust soil model than the simplistic soil carbon routines contained within *CAMFor*. As calibration data is readily available for agricultural systems, *Roth-C* has already been directly integrated into *CAMAg*. *CAMAg* must be operated in conjunction with the *Roth-C* model.

Figure 7.C22. Overview of the FullCAM Model.



Quality Assurance and Quality Control

The development of the *FullCAM* model included the incorporation of previously calibrated and verified models. Testing of integrations was performed using beta versions of transparent Excel modelling. Several independent studies to test and calibrate the model were completed on various parts, integrations and applications of the models. Wide-scale application in government programs (e.g., the Commonwealth Governments Greenhouse Gas Abatement, and Bush for Greenhouse Programs) and commercial application along with independent reviews provide confidence in the robustness of the models.

The NCAS Implementation of FullCAM for Land Use Change Accounting

Information Inputs to FullCAM

The implementation of *FullCAM* includes the sub-models of *CAMFor*, *CAMAg* and *Roth-C*. The *3-PG* model is used independently in a modified form to provide annual productivity maps (relative indices on a scale of 1-30) which are averaged from monthly surfaces and drawn in as grids to the spatial application of *FullCAM*. Tree growth is established using the growth formula described previously. To support this form of *FullCAM* model implementation, a series of tabular and spatial databases are used, including:

Maps

- thirteen sequences of both clearing and regrowth 1972-2005 (25 m);
- an initial 1972 forest/non-forest mask (25 m);
- 408 (34x12 months) rainfall maps of Australia (1 km);
- 408 average temperature maps of Australia (1 km);
- 34 (annual) top-soil moisture deficit maps of Australia (1 km);
- a long-term average productivity (index) map of Australia (250 m);
- 34 (annual) productivity maps of Australia (1 km);
- a soil clay content map of Australia (250 m);
- a pre-disturbance soil carbon content map of Australia (250 m).
- a maximum forest biomass (biomass at maturity) map of Australia (250 m); and,
- a forest type (MVG) map of Australia (200 m).

Tabular Data (from the *FullCAM* relational database)

- forest type attributes (partitioning, density etc.);
- forest litter amounts and characterisation;
- land use allocations (proportions of land which has been cleared allocated to each land use category by soil type by time);
- soil fractionation scheme for each soil type;
- crop type attributes (harvest index, yield etc.); and,
- crop management (activities, sequencing and timing for land use systems etc.).

Policy Parameters

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

The non-CO_2 gas accounting has not yet been developed to the same degree as other elements of the NCAS. However, the *FullCAM* model does output a comprehensive account of the amount of biomass burnt, to which the existing NGGI emissions factors are applied. Appendix E of this report describes in outline the program being developed for non-CO_2 greenhouse gas accounting capability of the NCAS.

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

Model Outputs

The *FullCAM* model has been developed to provide a variety of outputs, having particular regard to the requirements of the 1996 IPCC (Revised) Guidelines and associated Good Practice Guidance. These are of three general types including point-based, tabular and spatial. As well as being able to operate independently as a point-based model, when applied spatially (Figure 7.C23) *FullCAM* is able to generate point-based models (Figure 7.C24) from the spatial surfaces. These can be output, at a user specified frequency, across the model spatial surface and perform a valuable role in point-based verification of the spatial model implementation.

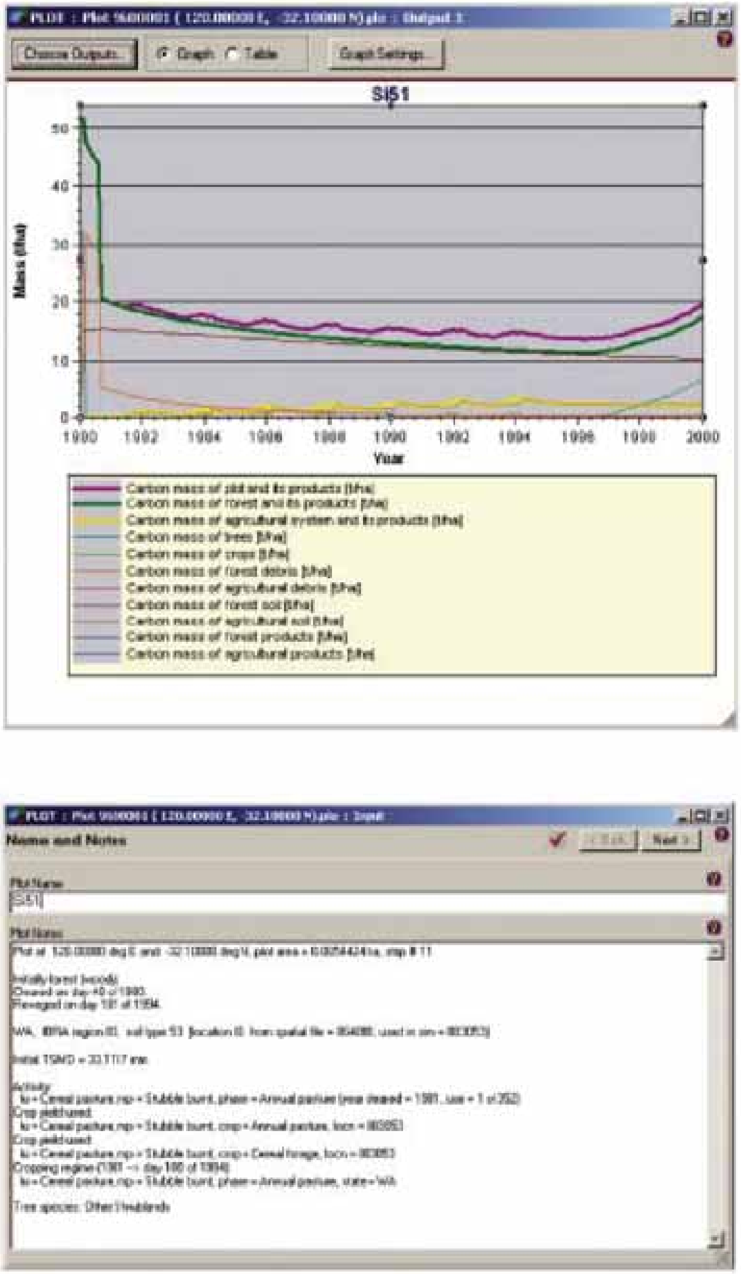
The point-based models provide detail of all data drawn from spatial layers as well as constants set through the model interface and those parameters drawn from the relational database. Outputs can be graphical or tabular and can (optionally) describe the stock in all carbon pools, all pool transfers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

Figure 7.C23. Spatial Carbon Stock Change Output (100 m Grids)

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

Tabular results output by the *FullCAM* model include summaries of input data across the spatial surface, for example, the areas of land cover change (clearing, regrowth, reclearing[9]) each year. The tabular carbon outputs include the total change in carbon stock (including all onsite and offsite carbon pools) due to the modelled activities for each 25 m pixel under consideration. Other carbon outputs include the change in tree mass (of each of above-and belowground), crop mass (total), soil carbon and offsite carbon mass. The amount of biomass burnt is also reported. Spatial 100 m resolution (1 ha) output grids are in a format easily read by most GIS systems. The available spatial outputs are total carbon stock, tree carbon mass, soil carbon mass and product carbon mass (for any point in time). Change over a period of time can be determined by differencing carbon stock maps at the beginning and end of the period under consideration. The 100 m spatial output is used to maintain a manageable output file size as there is the potential to generate many outputs by time and by carbon pool.

Figure 7.C24. An Example Point-Based (25 m Grid) Model Output from Western Australia.



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

Quality Assurance and Quality Control

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

Uncertainty

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

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

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

Variability in growth over time and wood density were shown to be the most sensitive factors in biomass estimation. Variability in growth has been accommodated via the multi-temporal productivity mapping which is used to 'moderate' growth according to the prevailing climate (as is reflected in the temporal variability in the productivity mapping). The method used in this application of *FullCAM* to estimate biomass and biomass increment provides a direct measure of aboveground mass, so no measure of wood density is required to convert volume into mass. This approach is described in Richards and Brack (2004a). As shown in Snowdon et. al. (2000) there is limited information available on root-to-shoot ratios for tree species. The adopted ratios represent the best estimates from the variable data available. There is no cause, from the data available, to presume that there is any bias introduced, despite the evident lack of precision (variability) in the data.

The low sensitivity of the modelling to the root-to-shoot ratio is largely due to the compensatory effects of regrowth. As regrowth is accounted for in the modelling, over- or under-estimates in losses due to forest conversion will be compensated for by a symmetrical over- or under-estimate in regrowth.

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

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

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

ATTACHMENT 7.C1: MAJOR VEGETATION GROUPINGS CLASSIFIED BY THE NATIONAL VEGETATION INFORMATION SYSTEM

Group 1. Rainforest and Vine Thickets

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

Group 2. Eucalyptus Tall Open Forests

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

Group 3. Eucalyptus Open Forests

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

Group 4. Eucalyptus Low Open Forest

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

Group 5. Eucalyptus Woodlands

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

Group 6. Acacia Forests and Woodlands

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

Group 7. Callitris Forests and Woodlands

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

Group 8. Casuarina Forest and Woodland

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

Group 9. Melaleuca Forest and Woodland

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

Group 10. Other Forests and Woodlands

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

Group 11. Eucalyptus Open Woodland

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

Group 12. Tropical Eucalyptus Woodlands/Grasslands

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

Group 13. Acacia Open Woodland

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

Group 14. Mallee Woodland and Shrublands

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

Group 15. Low Closed Forests and Closed Shrublands

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

Group 16. Acacia Shrublands

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

Group 17. Other Shrublands

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

Group 18. Heath

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

Group 19. Tussock Grassland

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

Group 20. Hummock Grassland

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

Group 21. Other Grasslands, Herbland, Sedgeland and Rushland

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

Group 22. Chenopod Shrub, Samphire Shrub and Forbland

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

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

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

APPENDIX 7.D: HARVESTED WOOD PRODUCTS

Introduction

Wood product carbon emissions are considered under the 1996 (Revised) IPCC Guidelines for the United Nations Framework Convention on Climate Change (IPCC 1997) and associated Good Practice Guidance (IPCC 2003) and are reported in the *Land Use, Land Use Change and Forestry* component of Australia's National Greenhouse Gas Inventory where they arise from the service life of products. Emissions from landfill are reported under the Waste section of the inventory.

A national database of domestic wood production, including import and export quantities, has been maintained in Australia since 1944. This consistent and detailed collection of time-series data provides a sound basis for the development of a national wood products model. Jaakko Poyry Consulting were initially engaged by the National Carbon Accounting System (NCAS) of the Australian Greenhouse Office to develop a national carbon accounting model for wood products, and that work provides the precursor model to that adapted and described here. The model development is reported in detail in the National Carbon Accounting System Technical Reports No. 8 (Jaakko Poyry 1999) and No. 24 (Jaakko Poyry 2000). Updates and model refinement were subsequently undertaken by MBAC Consulting in conjunction with the NCAS. Jaakko Poyry subsequently provided a quality assurance review of the model.

Accounting Approaches

Accounting approaches for carbon emissions from timber harvesting and wood products considered include emissions from wood products in Australia (wherever the source). This approach accounts for emissions from all wood products within Australia, regardless of their country of origin. Exported wood products are not accounted for and are the responsibility of the importing country. The amount of material exported is deducted from the total production, with total imports added, to derive the amount of material available for emissions within Australia. The origin of imported wood products is not tracked. However, the total flow of imported wood products into various pools within Australia is monitored.

Model Components

Information has been obtained and examined under the following components of the model:

- log flow from the forest: current annual production data were obtained by species groupings, and product classes, e.g., sawlogs, veneer logs, pulp logs, roundwood and other, e.g., sleepers;
- fibre flow from processing: data on the intake of raw materials to the various processing options and the output of products and by-products have been used in the model to estimate the total tonnes of carbon produced each year under various end product classes;
- import and export quantities of wood products;
- recycling;
- entry and decomposition in landfill;
- use for bioenergy; and,
- other losses to atmosphere.

Life Cycles and the Wood Products Carbon Pool

Estimates of the life cycles appropriate for each class of wood product have been made and methods for estimating the initial pool of carbon, as represented by wood products in use since 1943, have been proposed. Annual log removals data are available through the Australian Forests Products Statistics published quarterly by the Australian Bureau of Agricultural and Resource Economics (ABARE). Data are also available through the

Levies Management Unit of the Department of Agriculture, Fisheries and Forests, on behalf of the Forest and Wood Products Research and Development Corporation (FWPRDC). Log removals data are also published by the relevant State Forest Services and these provide a valuable crosscheck on ABARE data.

Cypress pine removals are included under the total for coniferous logs and a separate figure is not provided. It is necessary to extract cypress pine volume and analyse separate from softwood sawmilling because:

> Cypress pine is a significant source of wood products;
> Cypress pine is a native conifer and softwood sawmilling largely refers to exotic species plantations; and,
> Cypress pine is a denser wood than exotic pines and is used by a totally separate industry supplying different products to the market.

A Cypress pine figure can be developed from the ABARE information by applying a conversion factor to sawnwood consumption and applying a conversion factor to convert back to equivalent log removals.

Wood Flow

The model develops wood flows separately for each sector and these are integrated to account for cross-linkages. This is particularly important in the accounting for waste or by-products which are themselves used as resources for other segments of the industry. In conjunction with the carbon pool and life cycle of timber products, this model enables the total and projected carbon pools to be estimated.

In broad terms, the components of the models developed for each sector are similar, using:

> an estimate of raw materials input, whether of sawlogs, woodchips ex-sawmill, or pulp logs;
> an estimate of the products of processing, e.g., "x"% sawdust, shavings or sander dust for on site energy generation or compost, "y"% woodchips for other manufacturing processes, "z"% of sawn timber products, panel products, paper, etc.;
> an estimate of the proportion of products by product categories, depending on whether their expected end-use is long-term or short-term; e.g., framing timber, dry dressed boards, cases and pallet stock, panel products for use in house construction, panelboards for use in furniture and cabinets, newsprint paper, writing and printing paper, etc;
> a final figure for total Australian consumption by end use categories, converted to wood fibre content (oven-dry weight) and to tonnes of carbon;
> import and export data were obtained from the ABARE reports by end use categories; and,
> details of the flows are shown in Attachment D1.

Treatment of Bark

There has been no accounting for bark in this study. All bark is regarded as being a component of logging slash (harvesting residue) and accounted for under in-forest logging operations, for the following reasons:

> logs are sold with log volumes recorded on an underbark basis;
> in most hardwood operations, logs are debarked in the field;
> in softwood operations, it is estimated that some bark is lost prior to the logs reaching the mill. Most of this loss occurs during the mechanised delimbing and log docking operations; and,
> most softwood bark recovered at the mill is used for garden mulch which it is considered would have decay characteristics similar to that of logging slash.

Softwood bark is a significant source of carbon with total bark varying from about 35% of underbark log volume (not oven dry weight) in Caribbean pine to 20% in radiata pine and hoop pine. It is likely that, in the future, an increasing proportion of softwood bark will be used in the co-generation of energy and it may be reasonable to review this proposal should the situation change.

Basic Density and Carbon Content

Basic density and carbon content estimates are relevant to all of the processing options and the choice of values adopted has a significant bearing on the final outcome. In the case of all sawn timber, treated softwood and hardwood poles, etc., weighted basic densities for the species involved have been applied across each category. Basic density is defined as oven dry weight divided by green volume and the values adopted have been based on Ilic et. al. (2000). For board products and paper, however, the situation is different because all have been subjected to varying amounts of compression during manufacture and to compensate for this, their basic densities have been adjusted accordingly from the air-dry density of the finished products.

Carbon content is defined variably throughout the literature with values ranging from 0.4 to 0.53 of the oven dry (bone dry) weight. A figure of 0.5 has been adopted as a starting point to use in the model as a median value extracted from Gifford (2000a).

Table 7.D1: Basic Densities, Moisture and Carbon Contents

Carbon Fractions	
Description	**Value**
Fraction of softwood sawmilling dry matter that is carbon, by weight	0.50
Fraction of particleboard dry matter that is carbon, by weight	0.40
Fraction of MDF dry matter that is carbon, by weight	0.40
Basic Densities *	
Description	**Value kg/m3**
Density of softwood sawmilling	460
Density of hardwood sawmilling	630
Density of cypress sawmilling	600
Density of plywood (softwood and hardwood) and veneer	540
Density of particleboard	520
Density of MDF	600
Density of hardboard	930
Density of softboard	230
Density of pulp and paper: Paper	1,000
Density of pulp and paper: Softwood	430
Basic Densities *	
Density of pulp and paper: Hardwood	500
Density of pulp and paper: Waste paper	1,000
Density of pulp and paper: Pulp	1,000
Density of paper and paperboard imports and exports, on average	1,000
Density of chips and logs for export: Softwood logs	415
Density of chips and logs for export: Hardwood logs	630
Density of hardwood poles, sleepers and miscellaneous	790
* Basic density = (mass of oven dry wood in kg) / (volume of green wood in m^3)	
Moisture Content of Green Wood	
Description	**Value**
Ratio of weight of water to weight of wood substance in softwood chips	1.10
Ratio of weight of water to weight of wood substance in hardwood chips	0.90

Apart from the assumptions concerning basic density and carbon content, the other manufacturing assumptions were developed from interviews with representatives from the various industry associations and individual sawmilling companies. The issues addressed included:

- recoveries of green sawn timber, sawdust and chip;
- actual sawn sizes and corresponding dressed sizes; and,
- the range and proportions of products produced.

For the softwood sawmilling industry, for example, weighted averages of the information received have provided realistic assumptions. The same applies to the other species/industry sectors, with the exception of hardwood sawmilling.

Wood Flows from Processing

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

- Softwood sawmilling;
- Hardwood sawmilling;
- Cypress sawmilling;
- Plywood;
- Particleboard and medium density fibreboard (MDF);
- Pulp and paper;
- Preservative treated softwood;
- Hardboard;
- Hardwood poles, sleepers and miscellaneous; and,
- Export of woodchips and logs.

Softwood Sawmilling

The softwood sawmilling industry in Australia is largely based on plantations of exotic pines, although the native pine, hoop pine, is grown in southern Queensland. Most plantations were initiated around the 1930s. Early development was slow, but momentum was gained in the 1960s and 1970s.

Softwood processing has become very efficient, highly mechanised and well integrated industry, comparable with any of its overseas counterparts. Most softwood mills are large, with up to 500,000 m^3/year log intake. Most of the sawn timber is seasoned and dressed. Value-adding options such as machine stress grading, glue lamination and finger jointing are common.

Nearly all softwood mills are now operating on zero waste, with all slabs and edgings being chipped for paper pulp or panelboard feedstock and the sawdust and shavings being used for boiler fuel to provide energy for kiln drying. In some cases, some of this material is sold for composting, but this is unlikely to continue if the co-generation of electricity becomes more financially attractive.

A basic density of 415 kg/m^3 is used. This is sourced from Ilic et. al. (2000) and Gardner and Ximenes (*pers. comm.*); and is based on a weighted average of the respective densities of radiata pine, slash pine, Caribbean pine and hoop pine that are harvested.

The destinations of sawlogs and sawn timber products were sourced from representative sawmills in South Australia, Tasmania, Queensland and the ACT and from Pine Australia. Import and export figures were derived from ABARE 2006b.

Hardwood Sawmilling

The hardwood sawmilling sector is quite different from the softwood sector being characterised by a large number of small mills; even the very few large hardwood mills are much smaller than the average softwood mill. In recent years, the hardwood industry has undergone considerable change in response to reductions in their traditional resource base and to the impact that softwood framing has had on the traditional green hardwood framing market and also due growing restrictions in the utilisation of native hardwood forests.

As indicated earlier, the hardwood plantation resource is expanding and removals from hardwood plantations have been included in the total hardwood removals. Most of this material is currently of pulp log quality, but more sawlogs will be harvested as the resource matures. There is a reasonable degree of integration in the hardwood industry, however integration is difficult for the smaller more remote mills.

The hardwood sawmilling industry is far more complex and varied than any of the other sectors. There are at least 10 major species throughout the country, all having different densities and shrinkage rates, and to a great extent having different end uses. This sector has not been addressed in nearly the same detail as was applied to the softwood sawmilling sector and the outcome should be regarded as indicative only.

Assumptions on the product out-turn from hardwood sawmilling were sourced from the Victorian Association of Forest Industries and a large sawmilling company operating mills in Queensland, NSW and Tasmania. Sawlog volumes produced and import/export data have been sourced from ABARE.

A basic density of 630 kg/m^3 is assumed for hardwood sawlogs. This is an average of the following ten commonly logged hardwoods: spotted gum (*Corymbia maculata*), blackbutt (*Eucalyptus pilularis*), rose gum (*E. grandis*), jarrah (*E. marginata*), karri (*E. diversicolor*), mountain ash (*E. regnans*), alpine ash (*E. delegatensis*), silvertop (*E. sieberi*), brown barrel (*E. fastigata*) and messmate stringybark (*E. obliqua*). The basic density assumed for poles and sleepers is 790 kg/m^3. This is an average of spotted gum, ironbark and blackbutt - the main species used.

Hardwood chips are lower in average density than either sawlogs or poles and sleepers as they contain a wider range of species as well as younger regrowth and plantation material. An average basic density of 570 kg/m^3 is assumed. This is sourced from Chin (*pers. comm.*) of CSIRO.

Cypress Sawmilling

The Cypress sawmilling industry is restricted to the native cypress pine forests in Queensland and New South Wales. The quantity of logs removed is small and the data are currently included in the coniferous forest information in the ABARE quarterly reports (ABARE 2006b).

The industry consists of several relatively small, low technology mills operating on a scattered resource. Because of the distances involved, integration with other processing sectors is difficult; however some Cypress pine chips are being used in panelboard manufacture. The products are principally green framing and high value flooring and dressed panelling.

Plywood (Softwood and Hardwood) and Veneer

The Australian plywood industry is based principally on plantation grown softwoods and about 8% hardwoods, both native and plantation grown. Large, high quality logs for which premium prices are paid, are preferred. In volume terms, the plywood industry is small, but it uses high technology and produces a variety of products.

In addition to plywood veneer, sliced or rotary peeled decorative veneer is produced in small quantities for furniture, door and panel overlays. This production is not recorded separately by ABARE. Jaakko Poyry

Consulting (2000) estimated annual production is less than 10,000 m^3. Data sources used in the model for plywood were from ABARE and the Plywood Association of Australia.

Particleboard and Medium Density Fibreboard (MDF)

The characteristics of these two wood panelboards are different, but their feedstock and end use product categories are similar. Their densities are, however, different. Particleboard and MDF plants are large-scale operations and they are usually located close to their resource. Both require low cost material as input using either small logs unsuited to sawmilling, or woodchips produced as a by-product of sawmilling. Most of the feedstock is from softwood plantations, although some regrowth hardwood is being used in a plant in Tasmania and some cypress pine is being used in a plant in Queensland. In terms of trade, Australia is a net exporter of particleboard and MDF. The industry source used for information on processing assumptions in the model was the Australian Wood Panels Association.

Pulp and Paper

Pulp and paper plants are very large-scale industries requiring large volumes of low cost resource. Plantation grown softwood fibre provides the major resource but hardwood and recycled fibre is also important. Accounting for this sector is complicated by the fact that recycled fibre is exported and pulp is imported. Australia has five pulp and paper mills.

While ABARE data provides some information, the Pulp and Paper Manufacturers Federation of Australia (PPMFA) provided a more detailed source of information. The production figures used are derived from assumed raw material usage and conversion figures rather than reported industry figures. This is important for modelling wood flows through the product cycle and is consistent with the approach used in the model for other industry sectors, apart from export woodchips, which uses ABARE statistics for export quantities in bone dry tonnes.

The model-derived paper production estimates are 15% lower than the ABARE or PPMFA figures. The reason for this is that the model calculates the wood-only raw material requirements for pulp and paper in "oven dry tonnes" while pulp reported figures are in "air dry tonnes" which contain approximately 10% moisture and 2-25% of non-wood fillers depending on the process.

A complicating factor in the assumptions on waste with the pulp and paper stream is the fact that mills vary dramatically in their recovery according to type. Kraft pulp mills typically have a low yield of fibre (@ 50%) whereas thermo-mechanical mills have a high yield (@ 95%). The manufacture of recycled paper also results in a lower yield of fibre. Based on weighted inputs, a yield of 70% has been adopted.

Preservative Treated Softwood

Both hardwood and softwood can be preservative treated, but only softwood has been allocated a separate category. This is because treated sawn softwood has some use categories which are different to untreated softwood, whereas hardwood is usually treated so that the sapwood can be protected against borer attack and its use is then the same as for untreated hardwood.

Treated softwood poles and posts have also been included with sawn softwood, but treated hardwood poles and piles have been included with sleepers and other miscellaneous hardwood products. The ABARE statistics do not list treated timber of any description. The information used in the model has been obtained from the Timber Preservers Association of Australia.

Hardboard

The hardboard industry in Australia is quite small, with only two plants in operation. One is at Ipswich (Queensland) and the other is at Raymond Terrace (NSW). Hardwood is used for feedstock, sourced from pulp logs and sawmill residue.

The technology is quite old, but the products are unique and have niche markets that are likely to endure the competition from other panel products. Both hardboard producers were contacted during the study for manufacturing assumptions.

Hardwood Poles, Sleepers and Miscellaneous

The existing stock of hardwood transmission poles in Australia is reputed to number about 6,000,000 and production is estimated to be about 100,000 poles per annum, equivalent to about 75,000 m^3 of log. Railway sleepers also represent a considerable resource, and although concrete sleepers are now used for all new work, timber sleepers will continue to be used for the maintenance of secondary lines. 'Miscellaneous' includes a range of products such as mining, fencing and landscaping timbers. The log removals information for this group is conflicting and difficult to uncover. A provisional constant of 184,400 m^3 has been proposed for use in the model and further work is recommended.

Log and Woodchip Exports

<u>Woodchip Exports</u>

Export woodchips constitute a significant proportion of the annual harvest from Australian forests. The ABARE quarterly forest products statistics report both bone dry tonnes (BDt) of softwood chips and BDt of hardwood chips exported. The model uses the ABARE reported export figures directly in bone dry tonnes.

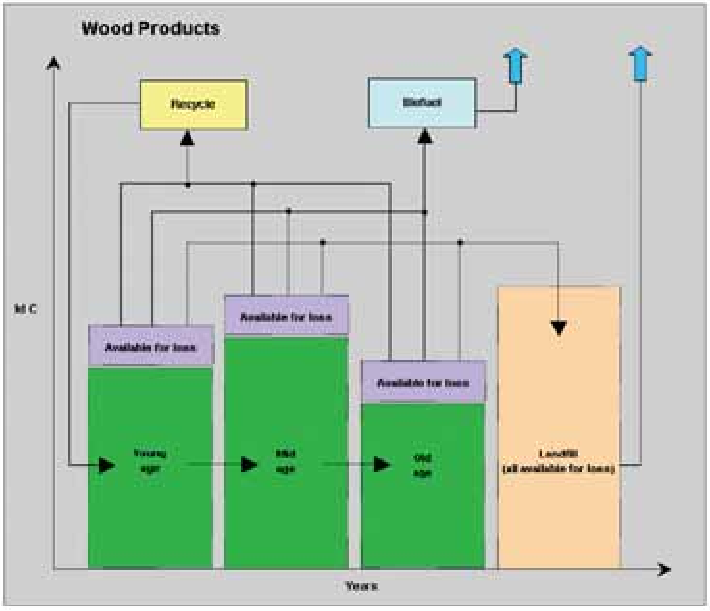
<u>Log Exports</u>

Total exports of coniferous logs reported by ABARE consist of both sawlog and pulp log. New South Wales exports approximately 7,000 m^3 of short length poles / year.

Life Span of Timber Products (Recycling and Landfill)

The life span of wood products must be taken into account when ascertaining the quantity of carbon stored in timber products. Considerable attention has been given to subdividing the various timber products pools into different classes based on product and decay rates. The decay rates used assume that losses of material from service life will increase with product age. Therefore the entry and exit of material from production to loss from each product pool is tracked and aged according to three age classes; young, medium and old. The proportion of material lost from each pool may vary (e.g., there may be little loss from young pools (excluding those to the medium age class)). Material is lost at a constant rate and may be placed in landfill, recycled, used for bioenergy or lost to the atmosphere (e.g., burnt with no energy capture) (Figure 7.D1).

Figure 7.D1. Structure of the Wood Products Model



For shorter-term products, the impact of the size of previous stocks is fairly slight as the recent additions to the pools have the major impact. For long-term products, an estimate of the size of the initial pool is essential, but difficult. The size of the housing pool uses housing starts data. Other pools are also only estimates. The proportion of the pool that has been derived from Australian-grown wood is required in order to implement an approach that separately deals with imported wood products. However, this component is difficult to estimate and estimates should be treated with some caution.

Life Span Pools Assumed for the Carbon Model

Very short-term products – Pool 1

Softwood – pallets and cases.

Plywood – formboard.

Paper and paper products.

Age: young = 1; medium = 2; old = 3

Short-term products – Pool 2

Hardwood – pallets and palings.

Particleboard and MDF – shop fitting, DIY, miscellaneous.

Hardboard – packaging.

Age: young = 3; medium = 6; old = 10

Medium-term products – Pool 3

Plywood – other (noise barriers).

Particleboard and MDF – kitchen and bathroom cabinets, furniture.

Preservative treated pine – decking and palings.

Hardwood – sleepers and other miscellaneous hardwood products.

Age: young = 10; medium = 20; old = 30

Long-term products - Pool 4

Preservative treated pine – poles and roundwood.

Softwood – furniture.

Hardwood – poles, piles and girders.

Age: young = 20; medium = 30; old = 50

Very long-term products – Pool 5

Softwood – framing, dressed products (flooring, lining, mouldings).

Cypress – green framing, dressed products (flooring, lining).

Hardwood – green framing, dried framing, flooring and boards, furniture timber.

Plywood – structural, LVL, flooring, bracing, lining.

Particleboard and MDF – flooring and lining.

Hardboard – weathertex, lining, bracing, underlay.

Preservative treated pine – sawn structural timber.

Age: young = 30; medium = 50; old =90

A specified proportion of material may be lost annually (an exponential loss) from each age class of each product pool. The amount lost from each age class for each product pool can be capped and different proportions can be lost according to age. This feature of the model provides for 'steps' in product loss rather than functioning on either a simple linear or exponential loss applied to a whole product pool, irrespective of the average age of the pool. If inputs vary over time the average age of products will vary, and this is represented by the amounts of material in each age class of each product pool.

Initial Stock Assumptions

Input data is available for the model since 1944 and this has the benefit of allowing the model to establish new equilibrium pools as the input material may be 'turned-over' several times prior to an equilibrium stock being reached for recent years. Initial stock estimation (for 1944) is more important for Pool 5 as this material may remain in use.

Model Calibration

Once the data on production inputs, processing flows and initial stocks is determined other model calibration requirements include:

- the age at which material moves from young to medium and medium to old pools;
- the amount of each age class for each product pool exposed to loss;
- the rate of loss from each age class in each product pool;
- the fraction of losses from each age class in-each product pool to each of landfill, recycling, bioenergy and the atmosphere; and,
- the rate of loss from landfill.

The model estimates used are presented in Tables 7.D2 and 7.D3.

Table 7.D2. Decomposition Rates and Maximum Possible Loss

Pool	YOUNG		MEDIUM		OLD	
	Loss Yr -1	Max. Possible Loss (%)	Loss Yr -1	Max. Possible Loss (%)	Loss Yr -1	Max. Possible Loss (%)
1	1.0	0.60	0.500	0.65	0.333	0.90
2	0.333	0.30	0.167	0.50	0.100	0.90
3	0.10	0.15	0.050	0.65	0.033	0.45
4	0.05	0.25	0.033	0.65	0.020	0.80
5	0.033	0.20	0.020	0.55	0.011	0.95

Table 7.D3. Fraction of Losses from Product Pool to Landfill, Recycling and Biofuel

Pool	Landfill	Recycling	Bioenergy
1	0.44	0.49	0.04
2	0.75	0.20	0.05
3	0.95	0.05	0
4	0.85	0.15	0
5	0.85	0.10	0.05

To understand the impact of uncertainties, *Monte Carlo* analyses using the Palisade @Risk software (Palisade 1997) was applied. This approach is also able to identify model sensitivities. Through this, it is possible to identify where uncertainty in parameter estimation may be most significant in terms of a probability distribution of expected outcomes, and to focus future data collection on areas that will have greatest impact on reducing uncertainties.

Model Results

By integrating the carbon pools and life cycles of wood products, the model enables the total carbon pools and emissions to be estimated. In broad terms, the components of the models as described for each sector are similar, using:

- an estimate of raw materials input, whether of sawlogs, woodchips ex-sawmill, or pulp logs;
- an estimate of the products of processing, e.g., "x"% sawdust, shavings or sander dust for on site energy generation or compost, "y"% woodchips for other manufacturing processes, "z"% of sawn timber products, panel products, paper, etc;
- an estimate of the proportion of products by product categories, depending on whether their expected end-use is long-term or short-term;
- a final figure for total Australian consumption by end use categories, converted to wood fibre content (oven-dry weight) and to tonnes of carbon; and
- import and export data were obtained from the ABARE 2006b by end use categories.

Table 7.D4 shows the annual additions and losses and carbon pool sizes.

Table 7.D4. Carbon Stock and Emissions Outcomes (ktC)

Year	Domestic Production of New Wood Products kt C	Imports of New Wood Products kt C	Exports of New Wood Products kt C	Increase Due to New Wood Products kt C	Carbon Pool (excl. landfill) kt C
1990	4,878	817	1,438	4,257	78,925
1991	4,859	726	1,592	3,993	79,916
1992	4,909	787	1,619	4,077	80,914
1993	5,174	825	1,706	4,293	82,029
1994	5,365	826	1,856	4,334	83,197
1995	5,587	990	2,184	4,393	84,374
1996	5,511	777	2,001	4,287	85,386
1997	5,636	839	2,135	4,339	86,404
1998	6,131	909	2,608	4,431	87,493
1999	6,033	894	2,468	4,459	88,559
2000	6,228	1014	2,620	4,622	89,721
2001	6,845	948	3,136	4,657	90,858
2002	7,156	938	3,088	5,006	92,223
2003	7,675	1,010	3,596	5,090	93,647
2004	7,709	1,110	3,531	5,288	95,097
2005	7,581	1,166	3,611	5,368	96,460

Uncertainty Analysis

With the consistent and comprehensive monitoring of wood production in Australia since 1944, and the confidence in this data gained through cross-verification with other datasets, little uncertainty will likely be derived from the production data. The most likely sources of uncertainty will be derived from the allocation to decomposition and recycling pools, and the rates of decomposition in those pools. To test the relative importance of the pool ages and decomposition rates *Monte Carlo* analyses were implemented using the @ Risk add-in software (Palisade 1997) to the Excel spreadsheet wood products carbon model. The principal model parameters of interest are the decomposition rates within pools (e.g., losses from service life and landfill) and transfers (e.g., to recycling, bioenergy and landfill). *Monte Carlo* analysis samples values from within specified ranges (probability distributions) for nominated parameters within repeated applications of the model. Probability distributions for values within ranges for each variable can be nominated, as can positive and negative correlations between variables so that sampling can reflect these correlations. In this application the nominated probability distributions were 'triangular', that is, values within the ranges sampled formed a triangular distribution around a central expected value. No correlations between variables were specified, so that value selection was random within the triangular probability distributions.

The life cycle pools affected and the distributions of their possible values for the *Monte Carlo* analyses are shown in Tables 7.D5, 7.D6, 7.D7 and 7,D8. Distributions of possible outcomes were stabilised over 100,000 model iterations. The Tornado Graph (Figure 7.D2) shows the relative importance of each input variable to the overall uncertainty in the model outcome.

Table 7.D5. Pool Age Uncertainty Ranges Used in the Monte Carlo Analysis

Life Cycle Pool	Lower Bound (yrs)			Expected Value			Upper Bound (yrs)		
	Young	Medium	Old	Young	Medium	Old	Young	Medium	Old
Very Short Term	0.5	1	2	1	2	3	1.5	3	4
Short Term	1	3	5	2	6	10	3	9	15
Medium Term	5	15	20	10	20	30	15	25	40
Long Term	15	20	40	20	30	50	25	40	60
Very Long Term	20	40	75	30	50	90	40	60	105

Table 7.D6. Decomposition Rate Uncertainty Ranges used in the Monte Carlo Analysis

Age	Pool	Lower Bound	Expected Value	Upper Bound
Young	1	2.000	1.000	0.667
	2	1.000	0.333	0.333
	3	0.200	0.100	0.067
	4	0.067	0.050	0.040
	5	0.050	0.033	0.025
Medium	1	1.000	0.500	0.333
	2	0.333	0.167	0.111
	3	0.067	0.050	0.040
	4	0.050	0.033	0.020
	5	0.025	0.020	0.017
Old	1	0.500	0.333	0.250
	2	0.200	0.100	0.067
	3	0.050	0.033	0.025
	4	0.025	0.020	0.017
	5	0.013	0.011	0.010

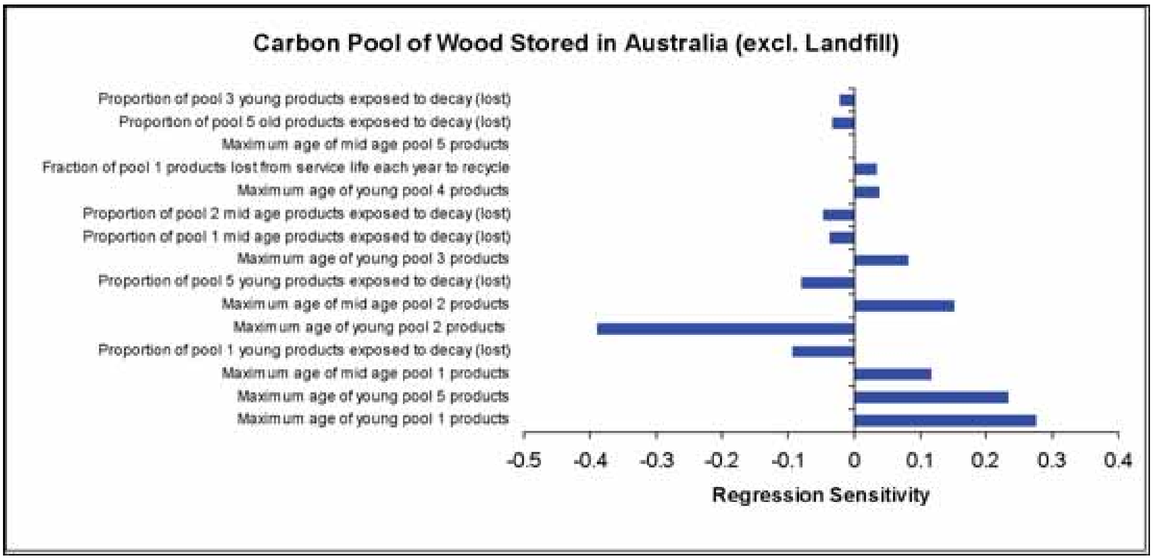
Table 7.D7. Pool Fractions Exposed to Decomposition Uncertainty Ranges Used in the Monte Carlo Analysis

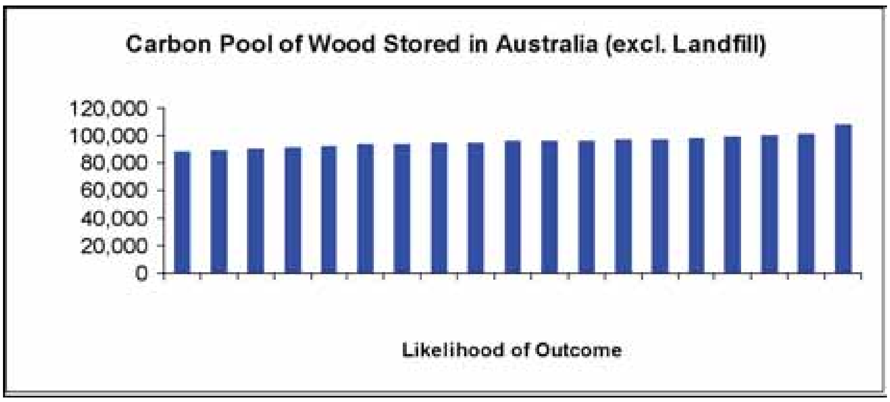
Age	Pool	Lower Bound	Expected Value	Upper Bound
Young	1	0.500	0.600	0.700
	2	0.250	0.300	0.350
	3	0.120	0.150	0.180
	4	0.225	0.250	0.275
	5	0.175	0.200	0.225
Medium	1	0.550	0.650	0.750
	2	0.400	0.500	0.600
	3	0.550	0.650	0.750
	4	0.550	0.650	0.750
	5	0.450	0.550	0.650
Old	1	0.800	0.900	1.100
	2	0.800	0.900	1.100
	3	0.400	0.450	0.500
	4	0.700	0.800	0.900
	5	0.800	0.950	1.150

Table 7.D8. Destination Fraction Uncertainty Ranges Used in the Monte Carlo Analysis

Age	Pool	Landfill			Recycle			Biofuel		
		Lower Bound	Expected Value	Upper Bound	Lower Bound	Expected Value	Upper Bound	Lower Bound	Expected Value	Upper Bound
Young	1	0.380	0.440	0.500	0.450	0.490	0.530	0.630	0.040	0.050
	2	0.600	0.750	0.900	0.180	0.200	0.220	0.040	0.050	0.060
	3	0.800	0.950	1.100	0.400	0.050	0.060	-	0	-
	4	0.700	0.850	1.000	0.130	0.150	0.170	-	0	-
	5	0.700	0.850	1.000	0.090	0.100	0.110	0.040	0.050	0.060

Figure 7.D2. Results of the @Risk Sensitivity Analyses

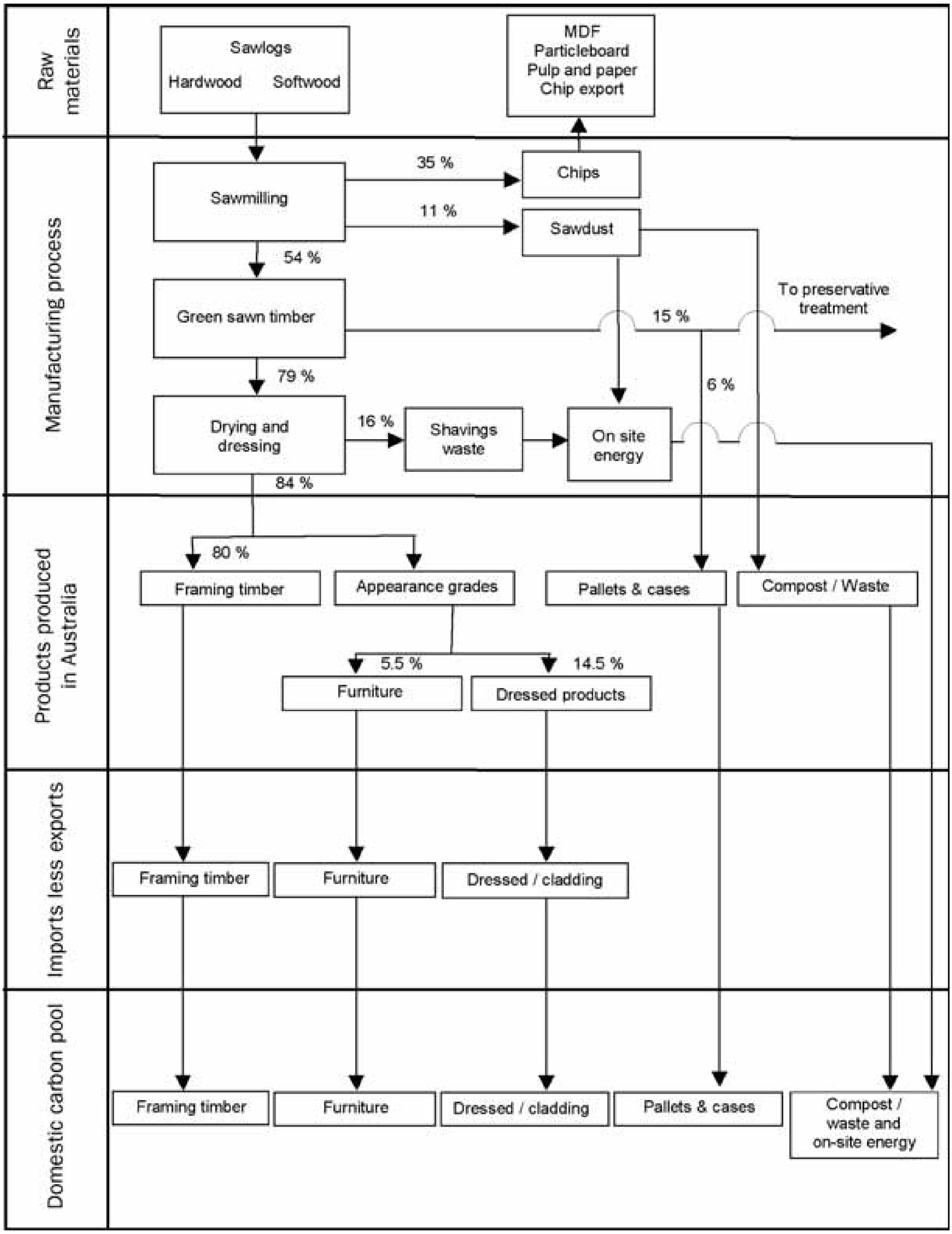




The effects of uncertainty in the carbon stock estimates in 1990 and 2004 national harvested wood product emissions estimates can be derived by looking at the annual stock change for the 0.10, 0.50 and 0.90 levels of confidence in potential stock outcome.

ATTACHMENT 7.D1: WOOD FLOWS BY SECTOR

Figure 1: National Carbon Accounting Model for Wood Products - Sawmilling Wood Flows *



* Percentages shown for softwood sawmilling, refer to model for hardwood and cypress pine

Figure 2: National Carbon Accounting Model for Wood Products - Wood Flows in Preservative Treated Products

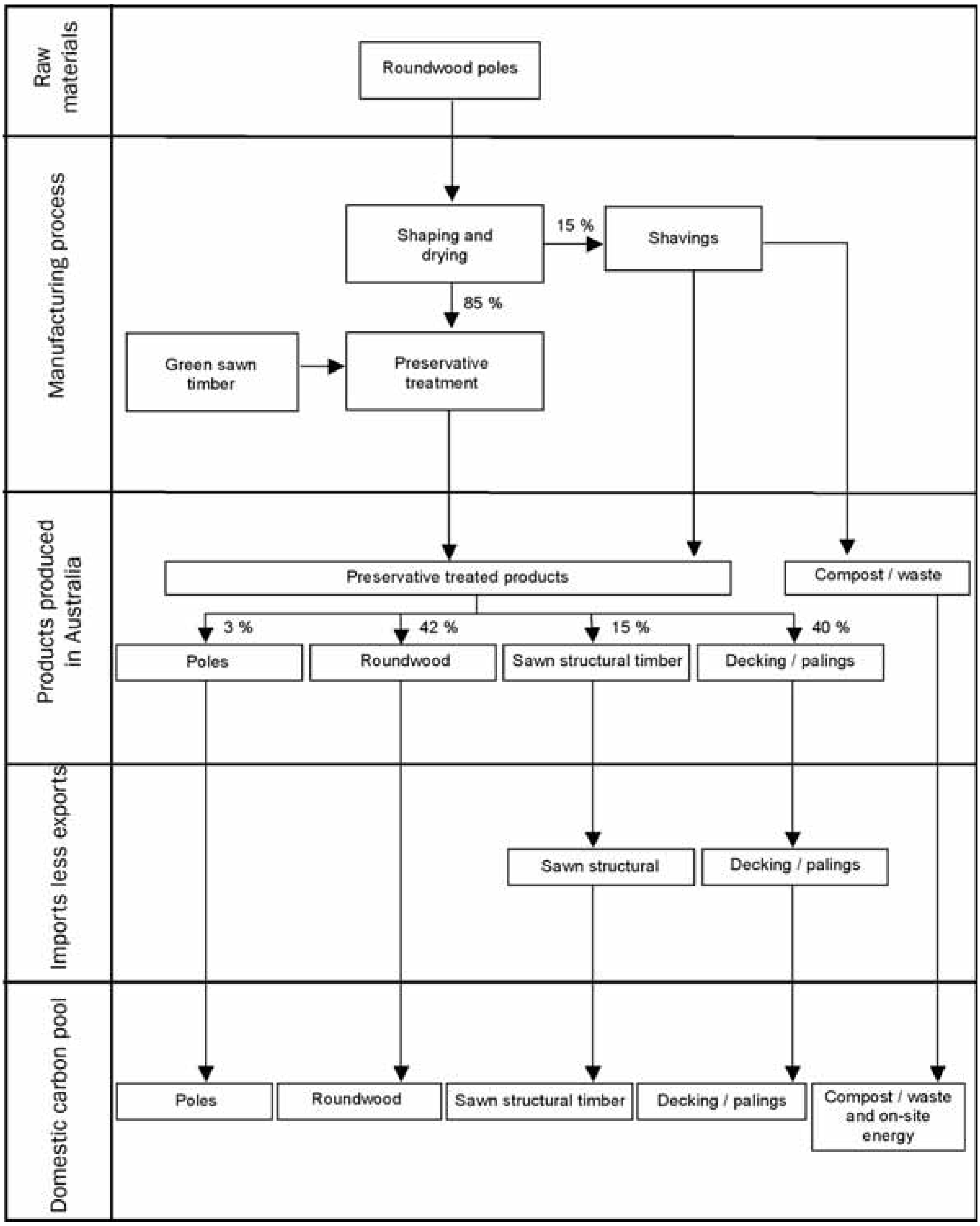


Figure 3: National Carbon Accounting Model for Wood Products - Wood Flows in Plywood Production

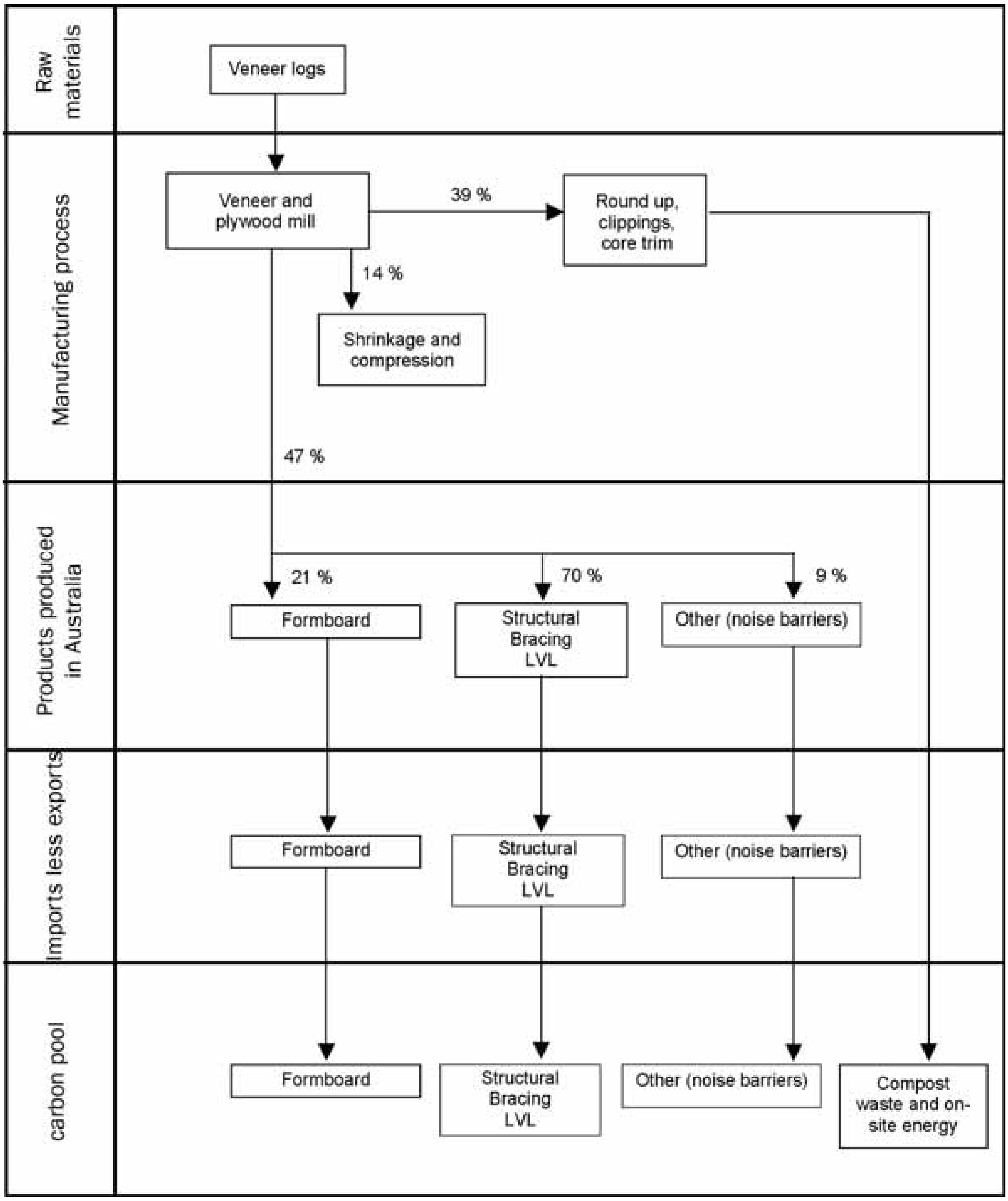
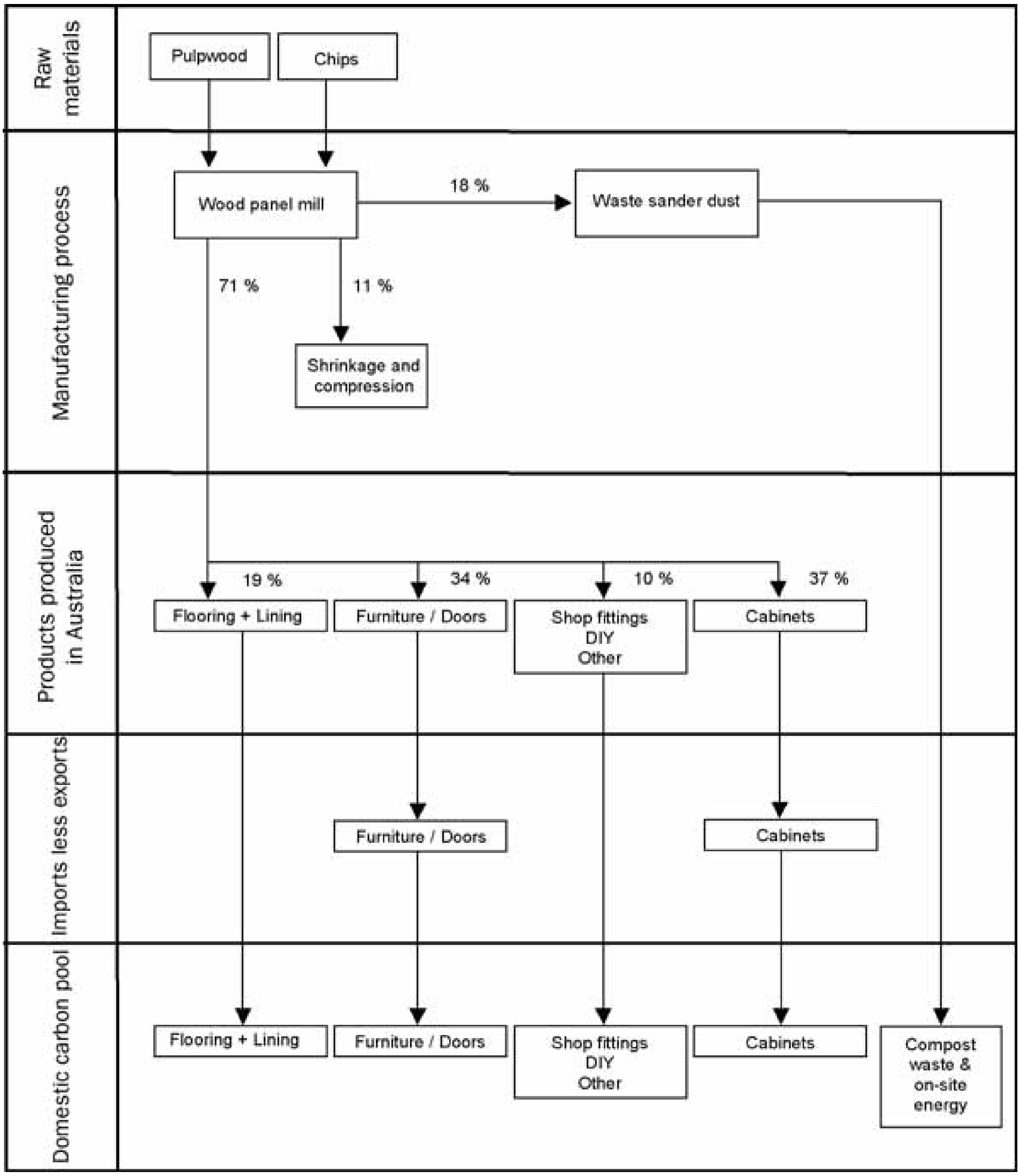


Figure 4: National Carbon Accounting Model for Wood Products - Wood flows in MDF and particleboard manufacture *



* Percentages shown for particleboard manufacture – see model for details on MDF

Figure 5: National Carbon Accounting Model for Wood Products - Wood Flows in Pulp and Paper Manufacture

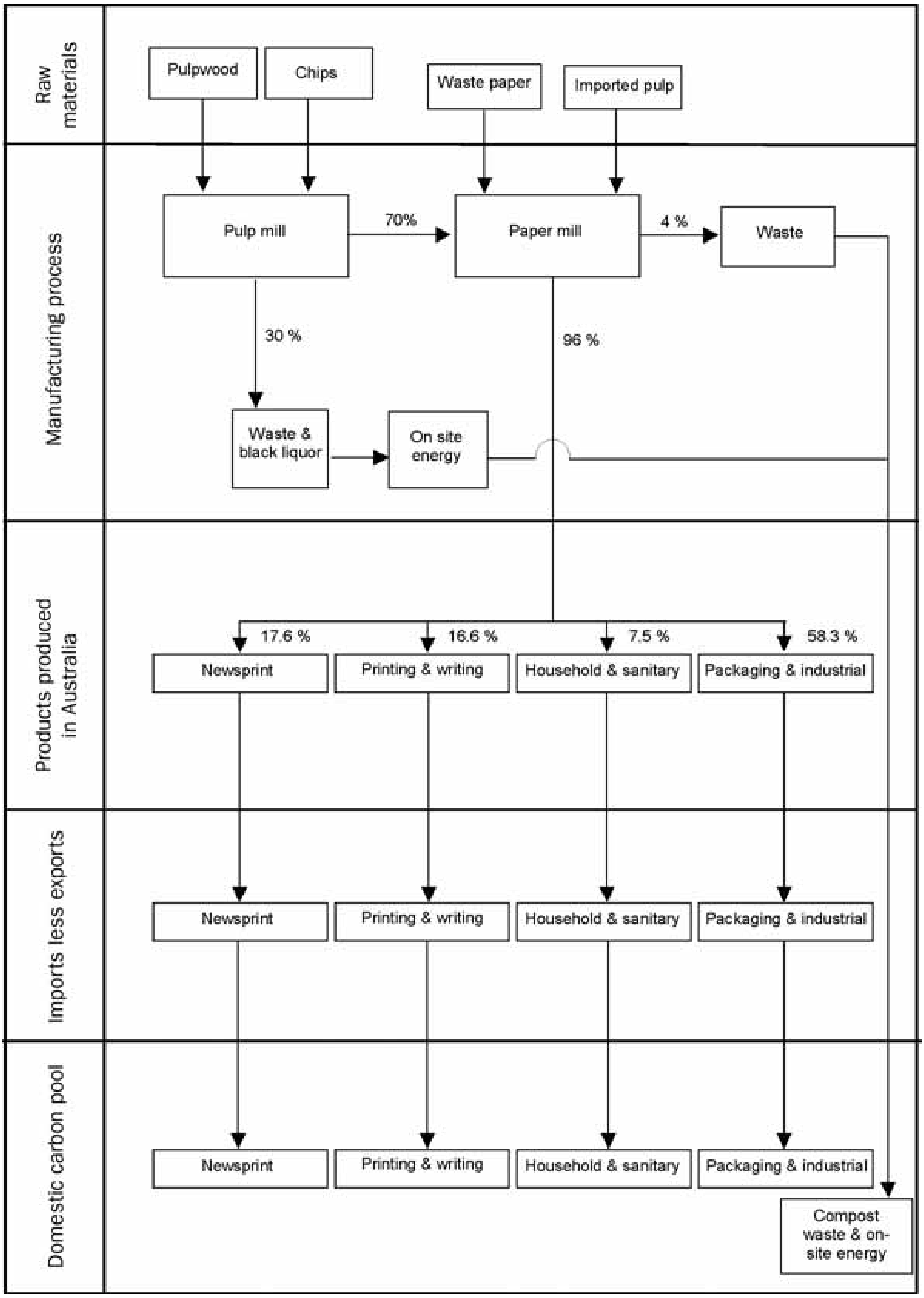
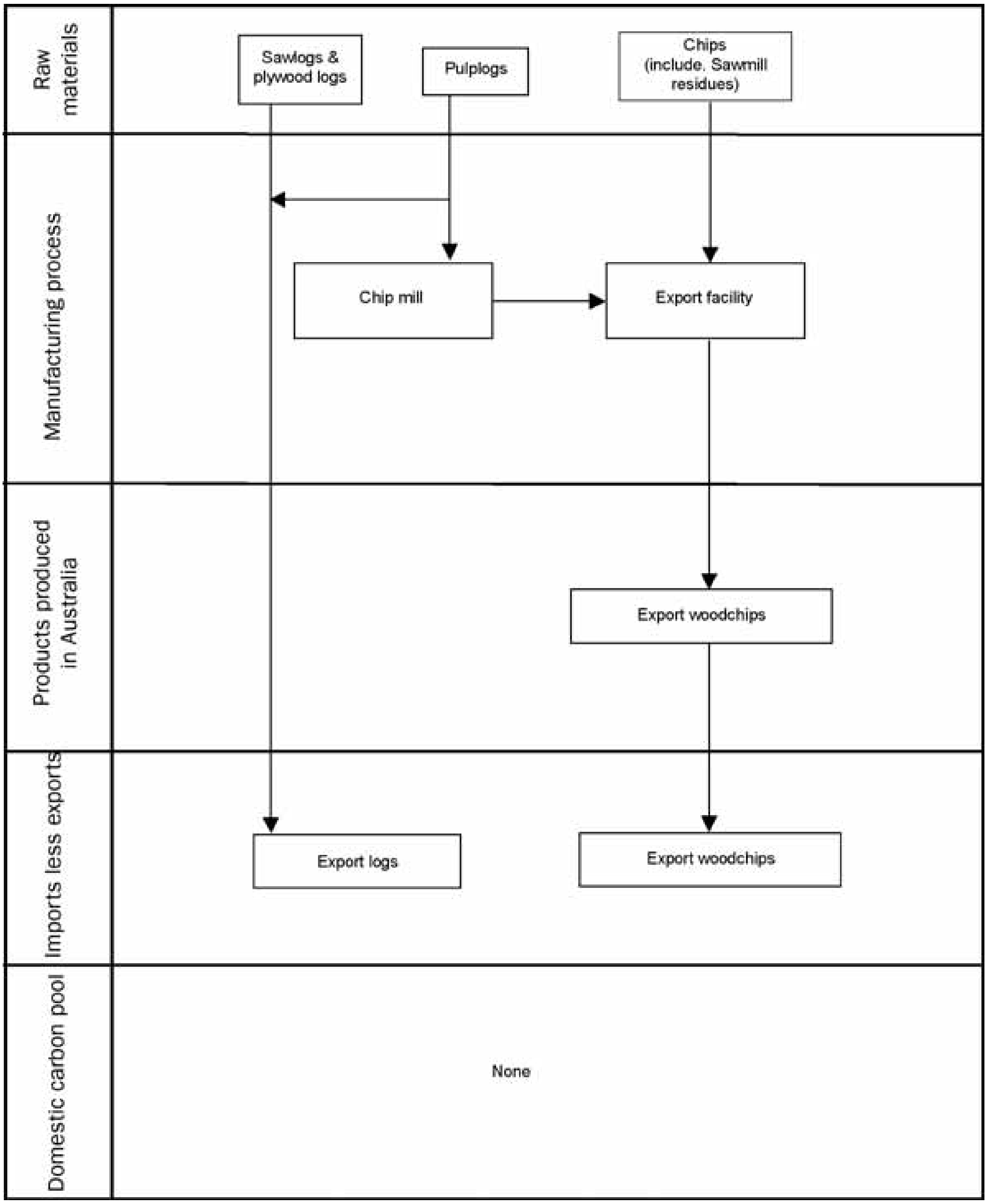


Figure 6: National Carbon Accounting Model for Wood Products - Wood flows in export woodchips and logs



Attachment 7.D1 – Quality Assurance

JAAKKO PÖYRY

JP MANAGEMENT CONSULTING (ASIA-PACIFIC) PTY LTD
Suite 902, 492 St. Kilda Road
MELBOURNE, VIC 3004
Australia
Tel. +61 3 9867 2700
Fax +61 3 9867 2744
Email: steven.king@poyry.com.au

Date October 4, 2004

Page 1 (2)

REVIEW OF WOOD PRODUCTS MODEL – UPDATE 2004

Dear Gary

As agreed Jaakko Pöyry Consulting has reviewed the 2004 update of the AGO's Wood Products Model. The update was made by MBAC Consulting in June 2004.

The focus of Jaakko Pöyry Consulting's work was to check that the updated data were consistent with our understanding of the wood products' industry production, import and export statistics and to consider if any recent changes in the industry necessitated adjustments to assumptions or the structure of the model. However, the underlying integrity of the model's calculations has not been checked.

Pulp and paper worksheet

We have no significant concerns about the updated statistics added to the pulp and paper worksheet. The base data entered since 1998 is consistent with the data collected and published by APIC and changes in the industry over the last six years do not require any changes in the assumptions.

In particular, it was considered that the start-up of the new Visy pulp and paper mill at Tumut may have changed the destination fraction of Raw Material for the industry (rows 38 – 40). However, a check of this indicated the destination fraction of wood to pulp had only changed from 71% to 69% with the start-up of the Visy mill, so that the estimate in the model of 70% remains valid.

Some minor points to note are as follows:

- The industry body which is the reference source for the pulp and paper data, has now changed its name from APIC to A3P, so this could be noted to assist in locating data for any subsequent update.
- Similarly, it is noted that the data listed under a particular calendar year in the model, is actually the data for the financial year commencing 1st July in that year. This is unlikely to have any significant impact on the outputs of the model, but again could be noted to assist in any subsequent update.
- Notes by MBAC refer to correcting some of the units from $1000m^3$ to tonnes. In fact the units for wood volumes entered in rows 25 – 30 which are sourced

from APIC still need to be shown as kilotonnes rather than 1000m^3. (That is the numbers entered in the model are in fact kilotonnes.)

The model structure and calculations obviously makes a number of simplifications to the overall complex product flows that occur in the industry. This has introduced some small errors or inconsistencies in the model which are noted below. Overall, the carbon from pulp and paper is possibly overstated by 10%, but given the level of assumptions in the model, this is probably not that significant.

- Some of the data in the model is in dry tonnes and some is in air dried or "as produced" tonnes. Typical moisture content of paper is 4-8%, which could be allowed for in the model.
- Some paper, particularly, printing and writing grades has a significant content of filler or pigment, up to 20%, which is not allowed for. Averaged over all grades, filler content is probably about 3%.
- Waste paper is treated like pulp in that losses to waste stream are only 4%, (row 43). In fact average losses in converting waste paper to recovered fibre for use on the paper machine are 12%.
- While the model requires inputs for each specific grade of paper (newsprint, tissue, printing and writing, packaging) in fact all of these grades are considered to have the same input of raw materials, so that the model actually treats them all the same.
- The model does not make any allowance for consumption growth in the future. A typical figure for paper grades is approximately 2%.

Solid wood worksheets

The inputs and percentages of product recovery, residues, domestic market, imports and exports all seem to be in the right order of magnitude and appear to be based on reasonably reliable data sources.

Though it has been noted that there are no inputs recorded for hardboard since 1999, in the covering explanation for that table it is stated that "no data reported in ABARE Statistics; assumed to be included with MDF from 1999 on". JPC is aware that there are two operating hardboard mills in Australia (Weathertex located at Raymond Terrace, NSW – production 14,000 tonnes per annum & Australian Hardboards located at Ipswich, Qld – production 42,500 tonnes per annum). Including those hardboard mills volumes in with MDF will distort the MDF statistics.

Yours sincerely

Steven W. King

Steven King
Consultant