# Forest Resource and Management Evaluation System (FRAMES)

**A Report on its**
**Development and Implementation**
**to 30 June 2016**

Forestry Corporation of NSW

*Note: References to Forestry Corporation of NSW (FCNSW) in this document may also apply to previous entities (Forests NSW, State Forests) which existed prior to corporatisation on 1/1/2013.*

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## 1 Background

FCNSW's strategic planning system for native forests is known as Forest Resource and Management Evaluation System (FRAMES). FRAMES was developed within the framework of the Comprehensive Regional Assessment (CRA) process, leading to Regional Forest Agreements (RFAs). FCNSW commenced the development of FRAMES in 1997 following the Interim Forest Assessment. FRAMES development has been under continuous review by the FRAMES Technical Committee of the Resource and Conservation Assessment Council.

Additionally, external independent reviews of FRAMES have been conducted by:

- Dr Brian Turner 1998
- Dr Jerry Vanclay 2002
- Dr Cris Brack 2009 (River Red Gum)
- NSW Auditor General's Performance Audit *Sustaining native forest operations* 2009
- FRAMES review for Boral 2010
- URS North Coast Resources Review 2012
- Dr Cris Brack 2016 (review of implementation in Cypress)

All found that the FRAMES model design, structure and operation provided a solid and reliable basis for strategic yield prediction.

The key role of FRAMES is to inform land use decision making processes by modelling the availability of large high quality (HQ) sawlogs at a strategic level, and to provide an on-going capability for growth and yield modelling in native forests. The information generated by FRAMES contributed to negotiations for the 1999 RFAs for the Upper North East and Lower North East CRA regions (now North Coast), as well as for the 2000 Southern RFA (which excluded Eden Management Area) and Western and Riverina Forest Agreements. These areas are predominantly multi-aged native forest areas. An alternative system was used for the Eden RFA, where the forest and management system is more akin to even-aged management.

FRAMES has undergone a process of continual improvement since its inception, with development direction arising from the findings of various internal and external reviews, as well as technological advances and the availability of new resource management information. This process has ensured that FRAME continues to provide relevant strategic timber resource modelling for native forests in NSW.

FRAMES estimates log supply by grade at a strategic level. Model outputs include projected log quality and indicative species mixes, presented in multi-year (typically five year) planning periods over a 100-year modelling horizon. Information from FRAMES has focused on log availability, without explicit linkage to economic parameters or spatial accuracy. Tactical level allocation (1-5 years) and detailed annual plans of operations have occurred at the regional level, with only limited interaction with FRAMES strategic level analyses. Recent technological advances have improved the scope for much tighter integration between strategic and tactical planning, which will significantly improve the utility of FRAMES for detailed wood supply planning.

Two significant events occurred in 2009: a comprehensive North Coast Timber Supply Strategy was completed and the NSW Auditor-General conducted a performance audit on the capacity of FCNSW to meet its Wood Supply Agreement (WSA) obligations. These events triggered a series of improvements to FRAMES. It is primarily these improvements and what they mean to the performance of FRAMES that are documented herein.

This document provides a summary of the status of FRAMES in 2009, and reports the improvements in FRAMES that have occurred since that time. It is intended to ensure corporate retention of the knowledge of FRAMES and its capabilities, and to document the development process that has led to its present structure and operation.

While an important part of the timber supply, particularly on the North Coast, hardwood plantations are modelled independently of the native forest resource using different methodology. They are not considered in this document.

## 2 FRAMES Structure and Operation to 2009

### 2.1 Framework

The main components of FRAMES and associated information flows are shown in Figure 1. below.

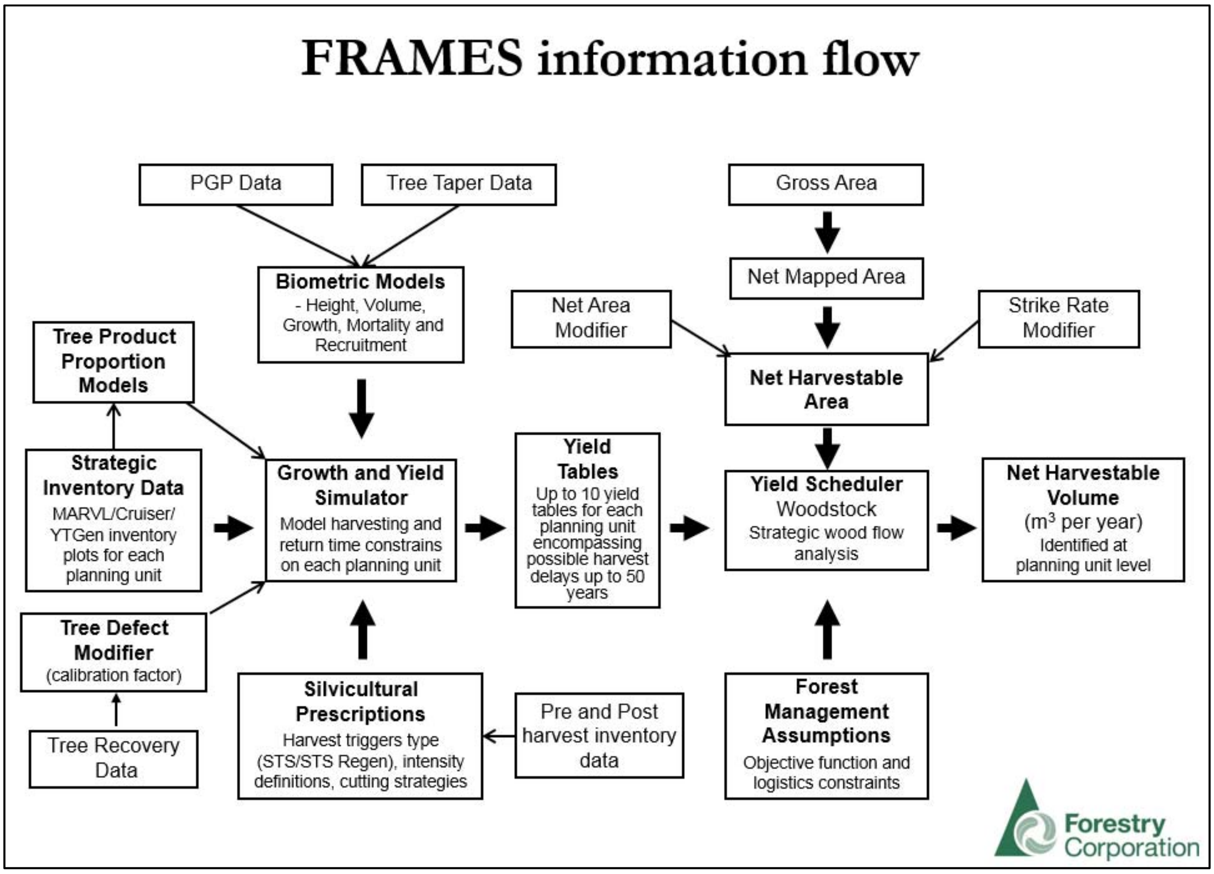


**Figure 1. Schematic diagram of FRAMES structure**

Key components of FRAMES are:

(a) A Geographic Information System (GIS) is used for calculation of net harvestable area, to provide spatial data for modelling and planning, for forest stratification and for visualising forest management and operations across the estate.

(b) Inventory data, comprising both strategic inventory plots (more than 3,700 plots across the state providing a snapshot assessment of current forest condition) and more than 900 Permanent Growth Plots that are specifically measured for tree growth modelling.

(c) A Growth and Yield Simulator models tree growth, potential availability by log grade over time, what might be harvested at any point in time and how the stand responds to harvesting in terms of future growth. The Growth and Yield Simulator incorporates a range of biometric functions and models, silvicultural systems and factors to account for internal defect and other harvesting losses.

The simulator produces per hectare estimates of log grades at nominated points in time under specified forest management systems for designated forest strata.

(d) A Yield Scheduler (Remsoft® Woodstock) applies the per hectare data from the simulator to the net harvestable area from the GIS to produce estimates of harvestable volume by log grade. It seeks to optimise the combination of harvest volume by log grade, location and species groups to achieve the specified objective of maximising sustainable, even-flow wood supply, while meeting defined constraints.

## 2.2 GIS and Area

The GIS comprises all spatial data used to underpin calculations of net harvestable area, as well as data to stratify the forest estate to improve the precision of estimates of log supply.

Estimation of net harvestable area is undertaken as follows:

(a) Gross area of forest potentially available for harvesting is calculated, most commonly on a compartment basis. Compartments are typically an area of forest around 200 ha in size bounded by well-defined geographic features that subdivide the forest estate into manageable planning units.

(b) Net mapped area is then calculated, which reduces the gross area by removing mapped non-harvestable features including:

- EPA exclusions for filter strips, wetlands and Inherent Erosion Hazard Class 4.
- NPWS exclusions for rainforest, high conservation value old growth forest, riparian buffers, wetlands, heaths, rocky outcrops, rare non-commercial forest types, wilderness and mapped species-specific habitat.
- FCNSW exclusions for non-commercial forest, physically and economically inaccessible areas, forest management zoning (FMZ) exclusions, steep areas and for Southern Region, road buffers.
- All exclusions are managed at a spatial resolution of 5x5 m grid cells.

(c) Net harvestable area modifiers are then applied to the net mapped area to account for unmapped exclusions:

- Net Harvest Area Modifiers (NHAMs), account for unmapped drainage lines and buffers, unmapped steep areas and unmapped inaccessible areas. NHAMs are implemented as a variable probability of harvesting from within the net mapped area. Studies of harvest extent across the landscape identified that slope and distance from "hard" (non-harvest) boundary are the main features influencing NHAMs. The probability surface utilises these inputs at a 5x5 m grid cell resolution across the landscape. The net harvestable area of each grid cell is determined by multiplying the grid cell area ($25m^2$) by the probability value for the cell.
- Strike Rate Modifiers, implemented as a percentage reduction in harvestable area arising from the impact of unmapped Threatened Species Licence conditions and derived from the outcomes of threatened species surveys in recently harvested compartments.

**Figure 2** (below) describes how net harvestable area is derived:

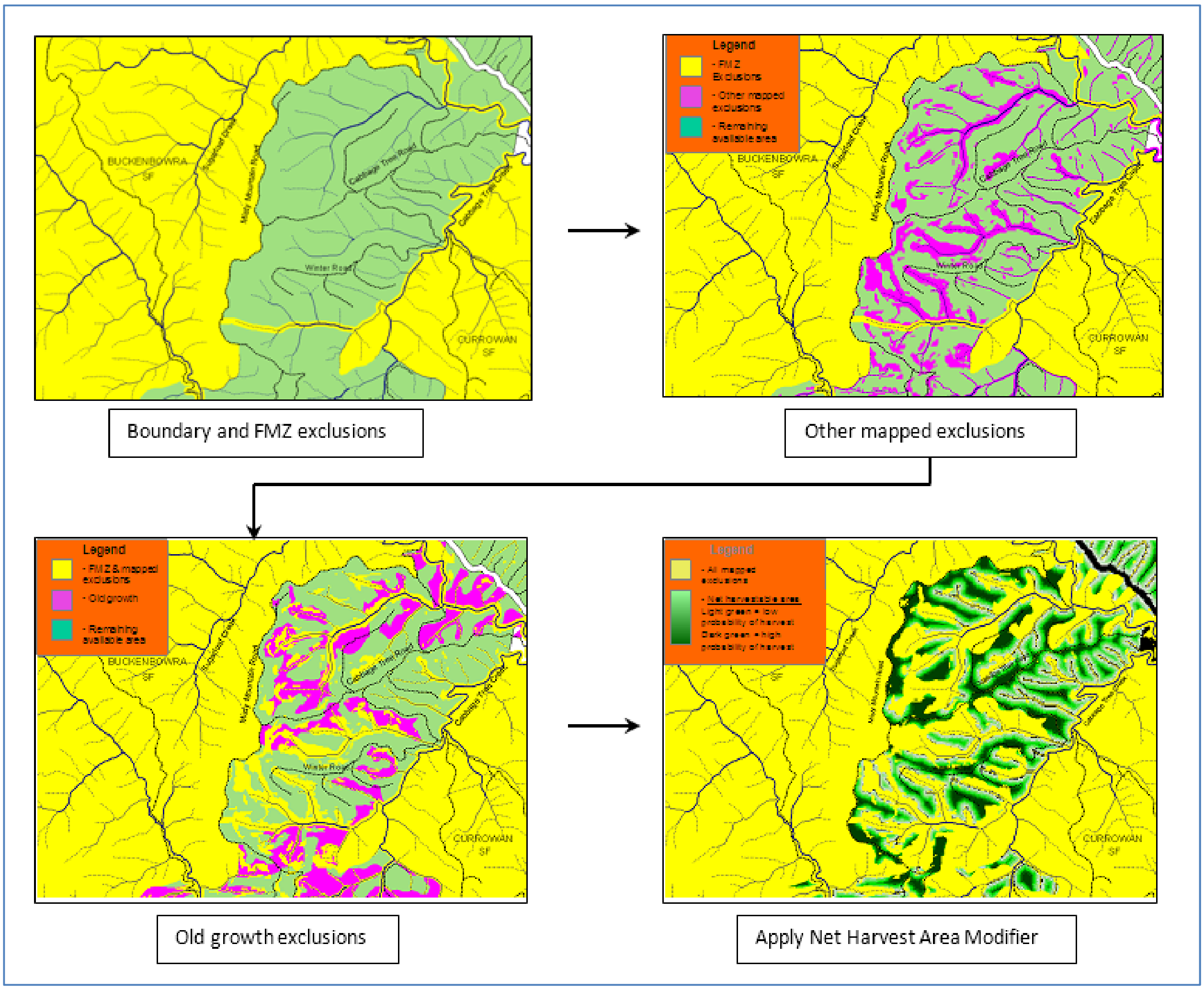


**Figure 2. Derivation of net harvestable area**

Spatially-based stratifications of the forest estate are used to:

- Identify, map and analyse data for specific geographic or management zones.
- Group parts of the forest estate into particular aggregations, such as species groups or distance from markets, or for assessment and planning of access for harvesting.
- Group the forest estate into strata to improve the efficiency of use of inventory data for estimations of log supply, by reducing the variability of estimates. Up to 2009, the standard stratification on the North Coast was Price Zone, which combined Yield Association (itself an aggregation of species types) with economic haulage zone and log price category.

## 2.3 Inventory

Strategic inventory data is used to quantify the standing timber resource and provide the base data for modelling future growth and yield. It provides information at a very high level and has low spatial resolution. The sample population for the inventory plots is the net mapped area. No plots are located in areas mapped for exclusion from harvesting.

The inventory provides log grade data via stem classification of inventoried trees that enables classification of logs into high quality (HQ) sawlogs, low quality (LQ) sawlogs, pulpwood and waste. The objective of the inventory process is to provide a strategic level snapshot within ±30% of the population mean for total standing high quality timber volume with a 95% confidence level.

Historic “price zones”, which are similar areas of forest type and management history, are of a sufficient size, 5,000 – 30,000 hectares, to provide meaningful estimates of precision for strategic inventory plots.

Within strata, 0.1 ha plots were located using systematic sampling with a random start. All trees greater than 10 cm diameter overbark at breast height (DBHOB; 1.3m above ground) were measured using MARVL inventory data format (Method for Assessing the Recoverable Value of Logs; Deadman and Goulding 1979). Recorded data comprised species, DBHOB, MARVL tree quality information, heights for a subsample of trees and plot habitat and accessibility features. Sampling intensity varied depending on the value of the resource being sampled:

- 1 plot per 125 ha for the Blackbutt-dominated forests in the former Central Region
- An average of around 1 plot per 250 ha for forests from the Great Dividing Range eastwards and in the Riverina Red gum forests
- Around 1 plot per 500 ha for Western Cypress forests.

The classification of trees into log grades using MARVL continued up until 2005-6. Use of MARVL comprises classifying each inventoried tree into log sections meeting specific quality parameters. MARVL was upgraded to ATLAS Cruiser and implemented by FCNSW in native forests from 2005. Cruiser classified the full length of the tree separately for each of the parameters that affect the grade of the log (particularly sweep, branches and defect). Cruiser is more objective in stem quality classification than MARVL and increases the scope for analysing the inventory data for a range of log grade products of different specifications. Cruiser is backwardly compatible with MARVL, so MARVL inventory data was converted to Cruiser format for consistent management of inventory data in FRAMES.

### 2.4 Growth and Yield Simulator

The core components of the Growth and Yield Simulator are:

- Individual and stand tree growth
- Mortality
- Recruitment (tree additions due to natural and harvest-related regeneration)
- Tree volume and taper
- Proportioning of trees into log products
- Modifying volumes by log grade to account for actual harvesting and log grading practices (theoretical volumes, especially for higher grades logs, are rarely achieved in practice).

Comprehensive documentation of the derivation of all these models can be found in the following reports, which are available in FCNSW Visual Vault database:

- Biometric Models - Upper North East and Lower North East CRA Regions. A project undertaken for the Joint Commonwealth NSW Regional Forest Agreement Steering Committee as part of the NSW Comprehensive Regional Assessments - Project number NA13/FRA, February 2000
    - Review of Tree Volume Equations used in the Yield Simulator, Lawrence, July 2003
    - Revised Diameter Increment Models for North Coast Timber Study, Muhairwe September 2003
- Biometric Models - Southern CRA Region (South Coast and Tumut Sub-Regions). A project undertaken for the Joint Commonwealth NSW Regional Forest Agreement Steering Committee as part of the NSW Comprehensive Regional Assessments - Project number NA13/FRA, July 2000

- o Basal Area and Diameter Increment Model Revisions, Muhairwe 2007
  - o Recruitment and Mortality Models revisited for South Coast, Muhairwe 2007
  - o Taper and Volume Evaluation for South Coast, Muhairwe 2007
  - o Tree product proportionment equations for South Coast Native Forests, Muhairwe 2007
  - o Diameter Increment Model Review for Alpine Ash, Muhairwe 2009
- Native Forests Growth and Yield Simulator Western Region, February 2003.
- Review of Eden Native Forest Growth Models, March 2015

### 2.4.1 Individual and stand tree growth

Growth models were developed using data from permanent growth plots, research plots and continuous forest inventory plots, and were supplemented by specific time series of strategic inventory plots where available and appropriate.

Diameter growth models typically relate predicted annual increment in DBHOB to then current DBHOB for groups of species that grow in similar ways. As was common at this time, basal area (BA) increment was constrained at the stand level, based on a logistic equation where growth is a function of stand density and maximum carrying capacity of the site. Basal area is the term used in forest management to define the area of a given section of land that is occupied by the cross-section of tree trunks and stems at breast height (1.3m). BA has been found to be a fundamentally important measurement in modelling tree and stem volume and tree growth.

Predicted height was derived from DBHOB and site height (a measure of inherent site productivity). Examples of modelled diameter growth is shown in F**igure 3** below.

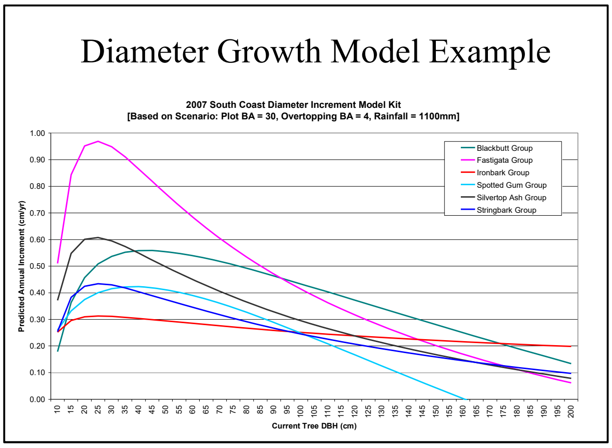


Figure 3. Examples of Diameter growth model used in FRAMES

### 2.4.2 Mortality

The natural tree mortality model simulations tree loss arising from:

- Natural mortality arising from fire, insect attack, wind and other natural causes
- Harvest mortality
- Harvest damage (degrade).

The model calculates the probability of tree survival as a function of tree DBHOB and the stand basal area of trees ≥30 cm DBHOB.

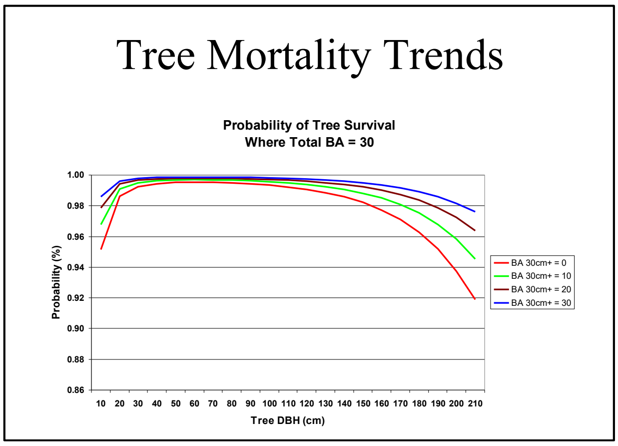


Figure 4. Examples of mortality models used in FRAMES.

The probability of a tree being subject to harvest mortality is a function of tree size, stand BA, intensity of harvesting (the ratio of harvested BA to total stand BA) and slope. Separate models were developed for each of three quality classes:

- Preferred high quality trees
- Other species capable of producing high quality logs and all trees capable of producing low quality logs
- Non-commercial eucalypt and non-eucalypt species.

### 2.4.3 Recruitment

Recruitment models predict the number of new trees of 10 cm DBHOB or larger that arise from regeneration during a time period. These 'new trees' are then incorporated into the population and modelled for future growth and yield. Prediction of recruitment occurs in a two-stage process:

- A logistic function is used to predict the probability that no recruitment of new trees had occurred, as a function of the number of years of the prediction period, the current number of stems/ha in the 10-15 cm DBHOB class and the BA of trees ≥30 cm DBHOB.
- Once the probability of recruitment occurring is calculated, the second stage of the model determines the number of recruits. The number of recruits is a function of number of stems/ha in the 10-15cm DBHOB class, the number of stems/ha in the 15-20cm DBHOB class and the number of stems/ha in the ≥30 cm DBHOB class.

Analyses of recruitment within Yield Association indicated no significant changes over time other than for the Blackbutt Moist and Blackbutt Dry yield associations. For these yield associations, the proportion of the principal species appears to decrease at the expense of more shade tolerant species such as Turpentine. Insufficient data have been available to quantify the relationship.

### 2.4.4 Tree volume and taper

Tree volumes are estimated using volume and taper equations. Tree taper equations reflect the diameter profile (shape) of the tree from its base to tree tip, and are used in conjunction with volume equations to determine total volume and composition of log products obtainable from a tree.

Taper equations have been developed separately for the commercially important native species such as Blackbutt, New England Blackbutt, Spotted Gum, Flooded Gum and Tallowwood. Composite equations were developed for other species. Tree taper is predicted as a function of species, DBHOB, dominance class and silvicultural history (stocking/density). These can then be used to predict the underbark stem diameter at known heights in the tree for a given tree species, DBHOB and height.

The information from the taper equation, together with assumptions about the stem shape between two predicted points, was used with the volume equation to calculate the total volume and volume between any two heights on a tree. Huber's formula was used for volume calculations.

### 2.4.5 Proportioning of trees into log products

MARVL inventory analysis software was used to determine total and product volumes of trees assessed during Inventory. MARVL utilises compatible volume and taper equations to determine the volume of the entire stem and sections of the stem. It then uses a log bucking optimising algorithm which calculates the optimal blend of log products cut from each log, maximising the value recovery based on user-defined log specifications and relative values.

Log product length and diameter specifications were used with the taper and volume equations and MARVL to determine the total merchantable volume and volume by grade which can be recovered from a given tree.

MARVL was replaced by ATLAS Cruiser in 2005 and all inventory data was converted to Cruiser format. The use of Cruiser permitted more accurate specification of log grades and more consistency between grading of inventoried trees and actual log grade production. One of the limitations of Cruiser is that it models log grades using log diameter underbark at the small end of the log (SEDUB) rather than at the centre of the log (CDUB), whereas log sales by grade are based on CDUB. While CDUB can be estimated by Cruiser, this limitation has led to small errors in the prediction of log grade volumes compared with actual production.

Prediction of volume by log grades from inventory data becomes less meaningful as trees are grown forward for estimating future log supply. FRAMES used inventory data for grade prediction for the first 15 years of the simulation, and then used tree product proportionment models (TPPs) for grade prediction from year 16 onwards. TPPs predict the proportion of total stem volume in specified High Quality (HQ) Large (i.e. ≥40 cm CDUB, estimated as equivalent to ≥35 cm SEDUB), HQ Small (i.e. ≥25 cm SEDUB), Low Quality (LQ) and pulpwood log grades, for stems of a specified DBHOB. TPPs were developed by analysing the proportions of stem volume by these grades all plot within the inventory database.

There are separate TPPs for trees classified as high quality (capable of producing at least one HQ log ≥ 10 cm SEDUB), trees classified as low quality (capable of producing at least one LQ log ≥ 10 cm SEDUB and trees classified as pulp (only capable of producing pulpwood). Trees that were not capable of producing any merchantable log products are classified as "W" and have all stem volume assigned to waste). As an example, "H" trees of 50 cm DBHOB might be predicted to yield on average 40% of their volume in HQ Large logs, 15% as HQ Small logs, 5% as LQ logs, 20% as pulpwood logs and the remaining 20% as waste. TPPs provided the conversion factors for total stem volume into log grades for prediction of future volume by log grade after 15 years from the commencement of the simulation.

### 2.4.6 Modifications to predicted harvestable volumes per hectare by log grades

The processes described in section 2.4.5 needed further modification to provide a more realistic assessment of log volumes by grade produced from harvesting operations. The calculations in section 2.4.5 represent a "best case" scenario and do not take account of several issues:

- Unseen internal defect that is only apparent after felling the tree, which downgrades log quality
- Harvesting damage

- Incorrect or conservative log grading.

To address these issues, in 2007 a FRAMES-specific project was undertaken for the North Coast to quantify the relationship between assessed log quality in standing trees and actual harvested log yield by grade. This 'Recovery' study identified that external features on desirable species such as Blackbutt are reasonably reliable indicators of defect, with only 30% of the HQ Large log volume down-graded to lesser value products. The internal quality of species such as Turpentine and Grey gum however are inherently more unpredictable, with 64% of the HQ Large log volume being down-graded. Around 20% of this down-grade went into HQ Small logs, 5% went into LQ logs and the remainder went into pulpwood and waste. The modification factors included in FRAMES used the results of the project to reallocate a percentage of volume from HQ Large logs into HQ Small, LQ and pulpwood logs.

### 2.4.7 Harvestable volume per hectare

Harvesting event specifications involve defining the type of silviculture to be applied in a simulated harvest event - thinning, single tree selection (STS) or Australian Group Selection (AGS) - and estimation of a range of parameters to be applied to the harvested stand.

The key variables for thinning were:

- Minimum retained BA
- Minimum harvest volume required to trigger a thinning event.

The key variables for STS were:

- Maximum BA percentage removal in a harvesting event
- Minimum number of years before a subsequent harvesting event
- Maximum percentage of trees removed by DBHOB class (10-30 cm, 30-50 cm, 50-70 cm and 70-100 cm and 100cm +) for each of four tree quality classes (H, L, P and W)
- Minimum number of retained trees per hectare for the same DBHOB and tree quality classes
- Whether HQ trees were harvested as a priority or whether harvesting priority was based on tree size
- The minimum harvestable volume required to trigger a harvesting event. In 2005/6, user-selectable variables were introduced into the silvicultural prescription specification in FRAMES to split into two classes the minimum harvestable volume per hectare that must be achieved before a harvesting event is triggered. The classes were specified as "Easy Access" and "Difficult to Access". This change was implemented because, in practice, a higher availability of harvestable sawlog volume was required on "Difficult to Access" sites to economically justify a harvesting operation, compared to "Easy Access" sites. Separate volume triggers were set for areas where access was classified as "Easy Access" and areas classified as "Difficult to Access".

An example prescription for STS Moderate might specify that HQ trees ≥70 cm were modelled as harvested first, then in turn LQ trees ≥70 cm, Pulpwood ≥70 cm and Waste ≥70 cm, then trees 50-70 cm in the same four classes in turn, with an overall maximum basal area removal of 30%, no return harvesting in less than 10 years, a minimum of 15 $m^3$/ha of harvestable from Easy Access areas and a minimum of 25 $m^3$/ha of harvestable volume from Difficult to Access areas, and no trees >150cm to be harvested.

The key variables for AGS were:

- Gap size
- Proportion of net area modelled as harvested in each gapping event
- Proportion of net area reserved from harvesting due to gap layout dynamics

- Number of gapping events and the number of years between gapping events.

The sequence of actions within the Growth and Yield Simulator were as follows:

(a) Check if the inventory plot meets the minimum user-specified reasons for harvesting to occur. If not, go to step (g).

(b) Identify which specific trees in the plot data met the harvesting rules.

(c) Add volume and log proportioning to the modelled harvest yield tables.

(d) Remove modelled harvested trees from the list of trees to be subject to future growth.

(e) Model harvesting damage to the retained trees.

(f) Reset the minimum harvest return time.

(g) Grow the relevant inventory plot data forward in one yearly increments using the biometric models specified in sections 2.4.1 to 2.4.3.

(h) Go back to step (a) and repeat.

Modelled harvestable volume per hectare from all plots within a given stratum (in this case, a Price Zone) were averaged and then applied to the net harvestable area of that stratum to produce modelled harvestable volume by log grade by year for that stratum.

## 2.5 Yield Scheduling

Native forests in NSW are highly variable, in terms of species, size classes, quality, distance from mills, accessibility and density of harvestable logs. Hence it is necessary to schedule the harvesting of potential volume by log grade derived as set out in section 2.4, so as to ensure as far as is practical that there is adequate log supply of the right type, in the right place and at the right time, both now and into the future.

Woodstock is the yield scheduling process used to determine the source of logs from within the forest estate to be harvested each year. Potential volume by log grade derived from section 2.4 was modelled within the Woodstock linear programming framework. The objective was to maximise the net present value (NPV) of the harvesting schedule. Value was calculated as average delivered log price for a Price Zone, less average harvesting and haulage costs for that Price Zone. NPV was maximised subject, as far as was practical, to meeting specified log supply of HQ logs for the period of the Wood Supply Agreements, minimising variation in annual supply of all sawlogs and keeping annual variation in supply of HQ logs to ±10% over 100 years.

## 2.6 Limitations of FRAMES to 2009

### 2.6.1 Limitations in GIS and area

Data layers for roads, stream lines, topography, property boundaries and related cadastral information were drawn from NSW Land and Property Information GIS data. While these data are being progressively improved, data for forest areas was largely based on aerial photo interpretation (API). API is subject to considerable error when attempting to map ground level information through a forest cover. Consequently, data layers of the types described above produce significant on-ground errors including:

- Incorrect location, type and even existence of streams and roads
- Incorrect classification of topography as to suitability or otherwise for harvesting or access
- Incorrect planning of harvesting tracks
- Incorrect boundary locations.

All these on-ground errors made accurate harvestable area calculation from those GIS layers problematic.

Data layers for mapped information such as high conservation value old growth, rainforest and forest types (i.e. amalgamations of species that typically grow at the same location) were also derived from API. These data are also subject to on-ground error in seeking consistency between modelled growth and yield and actual harvested volumes at strategic and tactical level.

There were no GIS layers that provide spatial information about forest stand condition, such as structure, height, density and crown condition. Gathering such data using API is very time-consuming and expensive. However, these data greatly assist in stratifying the forest into more uniform groups, which in turn enables more accurate group-specific modelling of growth and yield. In turn, this facilitates spatial estimation of current and future yields, which transforms FRAMES from a strategic level system to a more tactical level system.

No systematic approach was used to map areas actually harvested or to reconcile differences between FRAMES predictions and actual harvesting events.

### 2.6.2 Limitations in inventory

Price Zone is of limited value as a stratification for volume per hectare estimates. Variability in volume per hectare within a Price Zone was too high to permit any specificity in spatially-based volume estimates. An alternative stratification more closely linked to volume per hectare was required, such as a structural classification based on stand density and canopy height.

Log volume is calculated in FRAMES using SEDUB and converted into CDUB via a taper equation. CDUB is the basis for sale of logs under Wood Supply Agreements (WSAs). A more direct estimation of CDUB was desirable.

Measurement of inventory plots was falling behind schedule, for both remeasurement of existing plots and establishment of new plots.

Inventory plot measurement systems and technology were becoming dated and inflexible, limiting modelling options, which in turn reduced accuracy of log grade prediction.

Inventory data did not classify forked trees/stems accurately.

### 2.6.3 Limitations in the growth and yield simulator

NHAM and SRM components of FRAMES required updating to reflect more recent harvesting conditions, systems and regulations.

Losses in harvestable volume through internal defect, grading and other harvesting losses required more comprehensive analysis and remodelling.

Yield tables did not accurately reflect current harvesting systems, particularly STS systems that were intended to promote more active regeneration.

Elements of the growth model (particularly basal area increment) were found to be functioning inappropriately for some plots and required re-evaluation.

#### 2.6.4 Limitations in yield scheduling

FRAMES was not responsive to dynamic variation in the source of logs to specific customers and resulting variation in harvesting and haul costs, as only average costs for a Price Zone were used. It did not respond to the relative economics of source and timing of specific delivery to specific locations, and so did not guide the process of scheduling the harvesting to improve overall economic outcomes. A functional delivered cost model was required.

FRAMES as developed was suitable only as a strategic modelling tool and had limited relevance at tactical level. At that time, insufficient data were available for FRAMES to accurately produce estimates of harvestable volume at a tactical scale. Specifically, a stratification based on Price Zone still retained considerable variability in the structure, condition and growth potential of stands of trees within each Price Zone. This has meant that while volume estimates for a Price Zone in aggregate were reasonable, volume estimates for individual compartments or groups of compartments were highly variable even within a single Price Zone. The fact that FRAMES outputs were not widely used by the Regions for tactical planning purposes created a gap between planning short-term (1-5 years) and longer term (15 years +) wood flows. This knowledge of where logs will be supplied over the medium term (5 – 15 years) is a critical part of the planning process that was lacking in FCNSW's systems at that point.

No systematic process was in place to reconcile FRAMES predictions for harvestable volume and actual harvested volume, making validation and on-going improvement difficult.

# 3 FRAMES improvements since 2009

## 3.1 GIS and Area

### 3.1.1 LiDAR for DTM, boundaries, roads, tracks, stream modelling, planning of harvesting

LiDAR was developed in the early 1960s, shortly after the invention of the laser, and combined the focused imaging of laser with the ability to calculate distances by measuring the time for the signal to return.

For forestry and terrain mapping, capture of LiDAR data involves the firing of thousands of light pulses per second from an instrument in an aircraft in a relatively narrow vertical beam towards the earth and detecting either the full waveform or multiple returns per pulse, plus return pulse intensity. Initial pulse intensity of at least 2 emitted pulses per $m^2$ is desirable for effective forestry use. GPS data for aircraft positioning (X, Y and Z co-ordinates) are supplemented by an inertial navigation system that adjusts for pitch, yaw and roll, as well as ground control points for improved accuracy. If the location of the LiDAR instrument is known accurately, the points at which a pulse strikes a surface such as the ground and leaves at the top of the trees can be determined with great accuracy.

LiDAR is used in this way to produce a range of outputs of considerable benefit to forestry. One key output is an accurate digital terrain model (DTM), which is a digital representation of the ground surface. LiDAR-derived DTMs are far more accurate than topographic maps developed from API, particularly under canopy, and are far more flexible in their capacity for modelling. DTMs can be used to depict or derive accurate slope, slope classes, stream locations, stream buffers, old road and track locations, accessibility, contours, and shaded relief maps that show terrain attributes.

A DTM, together with a LiDAR-derived layer showing the vegetation canopy (specifically, a digital surface model or DSM), can assist in accurate definition of both tenure and compartment boundaries. Such boundaries often follow geographic features that are more easily recognisable and mappable with a DTM, or are associated with significant changes in tree cover that can be mapped from a DSM.

A DTM can also be used to define stream location and stream class. Accurate stream identification is critical to modelling the impact of stream buffers on net harvestable area. Catchment size, rainfall data and data on surface runoff can be used to model stream location, size, permanence and order. Stream order has been defined in NSW using the Strahler stream classification system, where topographic streams identified from API are given an 'order' according to the number of additional tributaries associated with each waterway. This system provides a measure of system complexity and therefore the potential for fish habitat to be present. Wider buffers are applied to higher order streams and more stringent harvesting and road/track crossing restrictions are applied compared to lower order streams. As LiDAR progressively became available across coastal forest areas, FCNSW investigated alternative ways to model stream networks. Initially the D8 drainage modelling using ESRI ArcGIS was trialled, using a minimum stream area threshold of 0.5 ha. Subsequent investigations identified GeoNet (Passalacqua *et al* 2010[1], 2012[2]) as the most flexible, accurate and appropriate stream modelling option. GeoNet streams have now been incorporated into the FCNSW corporate streams feature class.

The use of a DTM for surface definition, stream location and stream classification significantly improves the accuracy of slope classification, stream buffer definition and delineation of inaccessible areas, all of which contribute to defining the net mapped area. Any improvement to the net harvestable area calculation directly impacts on the accuracy of predicted harvestable volume.

In addition to the benefits of improved area definition, the LiDAR derived DTM, DSM and CHM benefit forest planners by:

- Enabling the specification of more appropriate survey intensity for meeting Threatened Species Licence conditions, since survey intensity is linked to net harvestable area
- Improving the planned location of snig tracks to access harvestable logs, by highlighting slope limitations, rock outcrops, old road/snig tracks and mapped exclusion areas that cannot be effectively crossed
- Identifying the location of tall and dense stands of trees within the mapped net harvestable area for closer field review, and of small or sparse stands of trees for more cursory field review or even excluding from potential harvest. This knowledge also assists in decisions about the economics of developing access to specific areas via roads or snig tracks.

The benefits of LiDAR for improvements in FRAMES inventory are addressed in section 3.2.1.

### 3.1.2 Event Management System

In 2011, FCNSW implemented an Event Management system to record the spatial extent and timing of harvesting events, known from 2013 as Forest Records and Events Database (FRED). This is a GIS-based system for recording, among other things, harvest plans and the results of harvesting operations at the compartment level, providing a spatially explicit compartment history. FRED has also been linked to the FCNSW sales system (Scion), so that volumes actually harvested can be matched to the spatial location of the harvesting event.

FRED provides a crucial link between FRAMES predictions and results of actual harvesting operations. However, it has rarely been used in this way due to the lack of accuracy of FRAMES predictions at tactical level. This has discouraged users from providing effective feedback on how FRAMES is performing. Nonetheless, the mapped harvested areas and associated harvested volumes by log grade that are stored in FRED can be:

- Cross-checked against FRAMES predictions of net harvestable area for that harvesting location.

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[1] Passalacqua *et al* (2010) Testing space-scale methodologies for automatic geomorphic feature extraction from lidar in a complex mountainous landscape, *Water Resources Research* vol 46

[2] Passalacqua *et al* (2012) Automatic geomorphic feature extraction from lidar in flat and engineered landscapes, *Water Resources Research* vol 48

- Used to identify inventory plots that should be remeasured because a harvesting event has occurred.
- Used to review the performance of various components of FRAMES involved in the conversion of inventory assessment of standing trees to actual harvested volumes by log grade.
- Used to check on the accuracy of specifications used in defining the silvicultural treatment used in the harvesting operation.
- Used to assess the performance of FRAMES at tactical level, once the improvements in FRAMES set out in section 5.1 are implemented.

Improvements in mobile technology is enabling FCNSW to more accurately record and map the extent of harvesting. As of 2016, several harvesting machines have been using the internally developed FCMapRT app to store and download harvest area extents. This is resulting in more accurate harvesting area mapping compared with the traditional post-harvest mapping techniques, which were based on estimation of harvest areas. FCNSW is in the process of integrating these GPS derived harvest areas into the FRED database.

FRED will play an increasingly key role in the continuous improvement process for FRAMES. Providing feedback between FRAMES predictions, tactical plans and actual harvesting operations (see section 5.2), as well as helping to ensure that the underlying database for FRAMES predictions of the future supply of logs accurately takes into account the harvesting history of the forest estate.

### 3.1.3 Net Harvest Area Modifier improvements

Net Harvest Area Modifiers (NHAMs) reduce the net mapped area to account for unmapped areas that are excluded from harvesting, such as steep areas not previously mapped, areas that are inaccessible because of localised rock outcrops or topographic isolation, proximity to exclusion boundaries (the practical effect of which is to create a 'buffer-on-buffer'), unmapped drainage lines and poor stream network mapping.

Since the original NHAMs were developed for FRAMES, there have been changes in harvesting practice. Harvesting is now largely mechanised rather than manual, which has altered the parameters of what would be considered accessible and economically viable for harvesting. Mechanisation may increase the ability to harvest adjacent to exclusion boundaries through greater control over the direction of falling, but conversely may have limitations in steeper areas. Mechanisation may also increase the effectiveness of dealing with localised obstacles and adverse conditions. Interpretation of drainage line issues has also changed, as have regulatory requirements relating to buffers. These changes have made the original NHAMs less representative of current harvesting practices. Consequently, a project was undertaken in 2011 to update the NHAMs for all coastal forests.

A full report on this project can be found on the Forestry Corporation web site.

The NHMA project used interpretation of new and existing aerial photography to define current harvesting exclusion areas and to identify the reasons for their exclusion. These boundaries were digitised and formed the basis of spatial models to generate new NHAMs.

For the study area, the reduction in net mapped area arising from the unmapped harvesting exclusions modelled by NHAMs changed as follows:

- A reduction from 25% of net mapped area to 20% in North East Region, due primarily to improved mechanised harvesting
- A reduction from 25% of net mapped area to 10% in Central Region, due to both improved mechanised harvesting and modifications to treatment in the field of stream buffers

- An increase from 21% of net mapped area to 23% in the South Coast and Tumbarumba sub-regions of Southern Region, due primarily to harvesting now including significantly steeper areas than were harvested at the time of development of the original NHAM
- An increase from 21% of net mapped area to 30% in the Eden sub-region of Southern Region due to harvesting of steeper areas.

Application of NHAMs within the GIS requires development of models that express the relationship between the eligible harvest area and the area actually harvested as a proportion of area available for harvest. The proportion of area harvested is a function of slope, distance to hard (i.e. mapped and clearly identified) boundaries and forest productivity classes. These proportions are then applied to the net mapped area via 5 m x 5 m grid cells, calculating firstly the proportion of grid cell area harvested and then the modified area of that grid cell (proportion harvested x 0.0025 ha). For example, if the attributes of a particular cell were modelled to indicate that the proportion of harvesting for that particular grid cell was 70%, then the area nominally available for harvesting within that grid cell within the Net Mapped Area would be reset at 70% of 0.0025 ha or 0.0018 ha.

The impact of the new NHAMs at Region/sub-region level is summarised below in Table 1.

| Region/Sub-region | Gross Area (ha) | Area available for harvesting after mapped exclusions (ha) | Area available for harvesting after mapped exclusions and NHAM (ha) | Area reduction due to NHAM (%) |
|---|---|---|---|---|
| **North East** | 454,980 | 256,609 | 206,620 | 19.5% |
| **Central** | 409,005 | 228,352 | 203,311 | 11.0% |
| **Eden** | 167,043 | 124,678 | 92,231 | 26.0% |
| **Tumbarumba** | 65,072 | 48,326 | 39,407 | 18.5% |
| **South Coast** | 203,331 | 141,540 | 102,813 | 27.4% |
| **Overall** | **1,299,431** | **799,505** | **644,382** | **19.4%** |

Table 1: area reductions applied by sub region.

The original NHAM for the former North East and Central Regions (now North Coast) was 27%. This project produced new NHAMs for North East of 19.5% and for Central of 11.0%. The most likely reasons for the reduction in NHAM were:

- Improved mapping layers
- Improved control through the use of mechanised harvesting
- Improved in-forest tools for better boundary location
- 2003 Integrated Forestry Operations Approval (IFOA) Amendment No 2 that modified restrictions on harvesting adjacent to buffer zones
- In the case of Central Region, more focused efforts on maximising the economic returns from harvesting through improved supervision and tighter field control of harvesting operations.

The project results for both the North East and Central regions were consistent with expectations.

The original NHAM for Southern CRA Region was 21%. This project produced new NHAMs for South Coast of 27.4%, and for Tumbarumba of 18.5%. Tumbarumba was expected to have lower NHAM area reductions than the South Coast because it is generally flatter and less dissected. The fact that the area reduction due to NHAM across South Coast was higher (at 27.4%) than the area reduction for the study compartments (at 23%) indicates that the factors that contribute to NHAM were more prevalent across the sub-region than in the compartments selected for the project. NHAMs arising from this project were considered more representative of the area than was the case for the original NHAM project.

The new NHAM for Eden across all compartments was 26.0%, somewhat lower than the 30% for the compartments selected for the project. It was considered that compartments harvested over the last four years may have been representative of current harvesting operations but may not have represented the variety of compartments to be harvested in the future. The new NHAM was included in the 2011/12 yield review for Eden. However, as future harvesting operations transition from multi-aged forests into thinning of regrowth stands, FCNSW will review the NHAMs so that they are applicable to the different silviculture practices applied in the forests with a regrowth age structure.

Since the above-mentioned NHAM study was undertaken, new NHAMs have been applied to LiDAR-based DTMs for around 70% of the North Coast where complete LiDAR DTMs are available. Application of NHAMs to all LiDAR DTMs will occur in due course.

A further review of NHAMs will be required incorporate harvest data collected by the GPS installed in harvesting equipment and improved modelling of stream networks using LiDAR data. Harvest area data based on GPS tracking will enable harvest operations to be modelled with higher accuracy than is currently possible. From 2016, FCNSW will progressively implement GPS-defined harvesting areas and analyse them in relation to the broader data eg physical boundaries such as drainage lines and steep slopes. This will enable FCNSW to better understand why particular areas were not harvested and in turn strengthen NHAM relationships.

#### *3.1.3.1 Additional NHA impacts not included in the NHA modifier*

**Threatened Ecological Communities (TECs)**
TECs are listed by the NSW Scientific Committee and are protected under the *Threatened Species Conservation Act*. They are not included under the current coastal Integrated Forestry Operations Approval (IFOA) as they did not exist (were not described or listed) at the time of the license being designed, so any deliberate disturbance within them is considered 'Harm or Pick' under the Act and exposes FCNSW to prosecution with penalties of up to $1million. Across NSW there are approximately 90 listed TECs.

TECs are described vegetation communities, which are sometimes cryptic and vague. TECs are not mapped. This lack of clarity around definitions and absence of mapping of TECs results in a significant risk for FCNSW in relation to potential prosecution and has an unknown effect on timber supply. With this in mind, the NSW government has undertaken a mapping process during 2015 and 2016 to identify and map 18 of the most prominent TECs. As at September 2016, this mapping project is close to completion. These maps will provide the first opportunity for FCNSW to incorporate TECs (and a possible new buffering requirement) as spatial layers in FRAMES. To date there has been no allowance for TECs. Early draft maps show that the NHA impact on the South Coast is likely to be around 1,500 hectares. On the North Coast the impact is likely to be between a reduction in NHA of between 10,000 and 20,000 hectares depending on the buffering requirements.

**Bell Miner Associated Dieback (BMAD)**
Significant areas of forest estate across NSW are affected by BMAD, which is a complex condition that causes the death of hardwood trees. Severe cases can see hardwood trees die out on a large scale and effectively be replaced by mesic forest species that are not susceptible to BMAD.

The extent of affected forest is unknown. A mapping project is underway in northern NSW to determine the spread of BMAD and its severity. There are known substantial areas in northern NSW, particularly in Supply Zone 1 in and around the border ranges region. While the extent is not mapped, and therefore the effect on timber availability in the future unknown, the FRAMES modelling process can account for BMAD to a certain extent where inventory plots occur in affected stands. However, it is not clear if this is a reasonable representation of the potential future impacts of BMAD. Further work is warranted in examining this issue. BMAD mapping data may be incorporated into the FRAMES system in 2016/17 once appropriate simulation assumptions for future harvesting, growth and yield have been determined.

### 3.1.4 Strike Rate Modifier improvements

The purpose of the Strike Rate Modifier (SRM) is to capture the impact of reductions in Net Harvestable Area associated primarily with flora and fauna prescriptions of the Threatened Species Licence (also known as 'Type C' protective measures). These harvest area reductions are not formally mapped and are not able to be identified at an estate level but are detected during pre-harvest planning and surveys. SRMs were calculated from a review of previous harvest plans and events as a percentage reduction in NHA and applied across a Region.

A range of changes in practices had impacted on the accuracy of the SRM since its specification in the RFA negotiations:

- The formal mapping of owl habitat as well as ridge and headwater protection zones removed approximately 50% from the overall Strike Rate Modifier in 2005, and consequently the SRM for the former North East and Central Regions was reduced from the RFA figure of 6.71% to 3.4%.
- Species and habitat related area exclusions in the South Coast and Tumut Management Area parts of Southern Region were largely mapped over recent years further reducing SRM rates.

A study in 2011 determined that the SRM for North East Region should be set at 4% and the SRM for Central Region at 2.1%. The average of these SRMs is consistent with the SRM of 3.4% specified in 2005. The SRM for South Coast and Tumut Management Area parts of Southern Region was set at 0%.

The full report of the 2011 SRM study can be found on the Forestry Corporation web site.

### 3.1.5 Small polygons and isolated areas

The Net Mapped Area database has been reviewed to identify small polygons (i.e. GIS mapped areas) in the GIS database that are classified as harvestable forest but will not be harvested because they are small and isolated from harvestable areas and hence cannot be practically accessed.

Polygons of less than 0.2 ha were grouped into classes based on whether it would be practical to cross an exclusion zone to access the area for harvesting. For example, it was determined that it would not be practical to cross a first order drainage buffer to access a polygon area of less than 0.2 ha. For isolated areas between 0.2 ha and 2 ha, harvesting was not practical if a 30 m buffer needed to be crossed or the polygon was more than 30 m from a road. For isolated areas between 2 ha and 5 ha, the corresponding buffer width and distance to road was 50 m. All polygons of more than 5 ha were considered available for harvesting, regardless of the degree of isolation.

Analyses to date have identified reductions of 0.6% in Net Mapped Area across a Region arising from this process.

### 3.1.6 Consolidation of databases

The final improvement to GIS and area improvements has been the consolidation of all relevant spatial data into the GIS. A single database has been prepared that subdivides the entire forest estate into the minimum sized polygons within a consistent set of attributes. The attributes comprise:

- Compartment Number
- State Forest Number

- Management Area ID
- Price Zone
- Yield Association (see section 3.2.1)
- SSQ class (see section 3.2.1)
- Slope in 5° classes
- Most recent harvest event details
- Forest Management Zone exclusion status
- Net Harvest Area modifier.

This consolidated database simplifies the process of extracting areas with specific parameters from the overall forest estate.

## 3.2 Inventory

### 3.2.1 LiDAR for improved forest stratification

As noted in section 3.1.1, LiDAR can be used to generate Digital Terrain Models (DTMs), Digital Surface Models (DSMs) and Canopy Height Models (CHMs). These models, together with additional data gathered by the LiDAR detector, can be used to stratify the forest estate into units that are far more homogeneous in terms of harvestable sawlog volume than the previously used Price Zone stratification. This stratification both significantly reduces the variability in estimates of harvestable volume per hectare and improves the spatial accuracy of volume per hectare estimates from the Growth and Yield Simulator.

### 3.2.2 History of LiDAR usage for resource assessment by FCNSW

LiDAR data was first made available to FCNSW in 2003 (from the Murray Darling Basin Authority) as part of a whole of Government project that primarily collected LiDAR for accurate ground elevation and flood modelling purposes. Basic canopy height information was also extracted, however only 'first' and 'last' returns were captured at approximately 1.5 points (returns) per square metre (see image below).

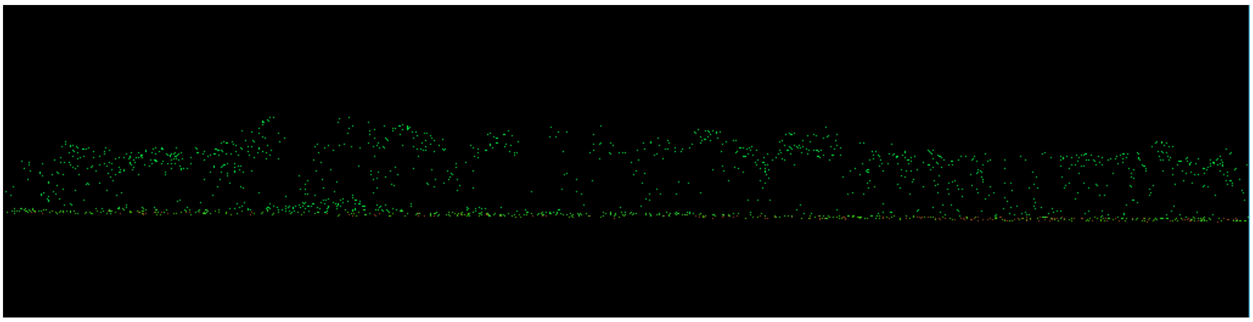


**Figure 5: 2003 LiDAR data**

In 2007, the NSW Land Property and Management Agency (now Land and Property Information (LPI) started making LiDAR data, captured for mapping projects, available to Government departments under a Memorandum of Understanding. Project areas ranged in size and location. With hardware and software improvements, capture rates increased to approximately 5 returns per square metre (see image below). Where available, FCNSW sought to use this data for ground feature and canopy height mapping.

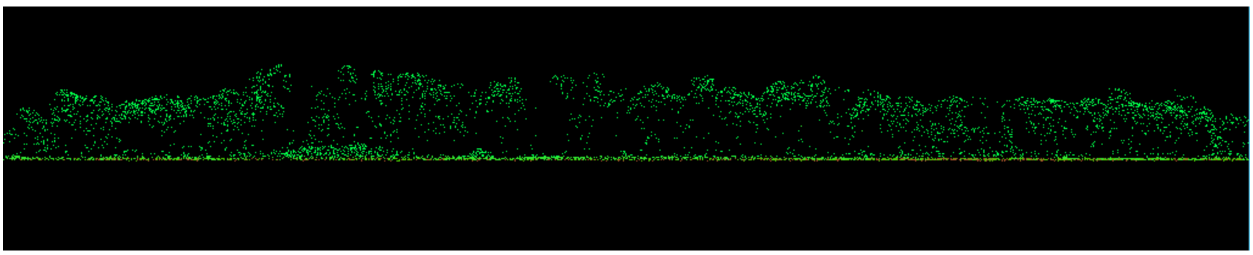


**Figure 6: 2007 LiDAR data**

Starting in 2009, FCNSW commenced its own LiDAR capture program with the intention of filling gaps in the LPI data on the North Coast, South Coast and Eden. Improved sensors enabled the program to capture approximately 14 returns per square metre (costing approximately $1.75 per hectare) (see image below). The data was primarily sourced for accurate landscape mapping purposes (drainage systems, roads, forest extent and height etc).

In 2011, the canopy height and density data was used to produce the first structural index (also known as SSQ) spatial layer for native forests as surrogate for volume mapping. These models have proved invaluable for operational (harvest) planning. In 2012, as part of the URS North Coast Resource Review, Native Forest Strategic Inventory (NFSI) data was correlated with structural index mapping to provide sub-compartment volume stratification (section 3.2.3).

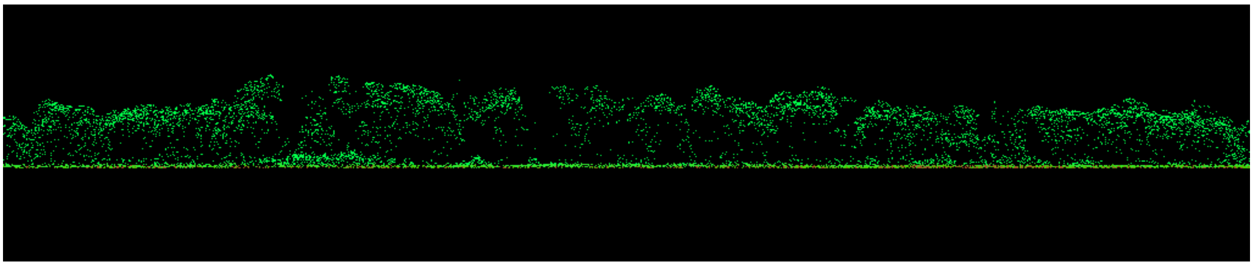


**Figure 7: 2011 LiDAR data**

In 2014, FCNSW undertook its first full LiDAR integrated resource assessment in the Eden Management Area. LiDAR data was sourced from a mix of LPI and FCNSW captures (with between 5 and 10 returns per square metre). Three hundred and fifty inventory plots, which were accurately located using differential GPS, were measured with a sampling schema designed to ensure the full range of canopy features were sampled. The schema was designed to also be backwardly compatible with traditional FRAMES analysis processes. With assistance from DPI statisticians, experimental analysis with the Plot Imputation method (section 3.2.4) was completed in 2015. The results of this analysis have been incorporated in a prototype spatial estate model in 2016. Comparison with the traditional analysis approach, and with field data, where available, is being completed. Further experimentation with plot imputation has occurred, yielding better predictor and response variables. This is resulting in improved correlations and reduced model error levels.

In 2015, FCNSW captured LiDAR for Bathurst and Bombala softwood plantations and the River Red Gum State forest and Western Land Leases (WLL) areas at approximately 28 returns per square metre (costing $1.45 to $1.75/ha) (see image below). Coincident 12.5cm resolution aerial photography was captured with the LiDAR data. This data is being incorporated into plot imputation assessments (refer 3.2.4). In 2016, 100,000 ha of mid-North Coast forests was captured to this new standard. Ground based inventory plot measurement is scheduled to be completed by June 2017.

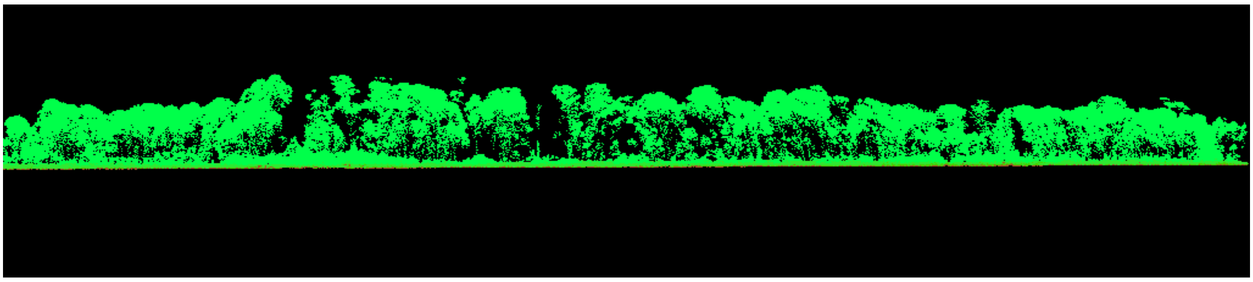


**Figure 8: 2015 LiDAR data**

### 3.2.3 LiDAR derived stratification system for the North Coast

The time since last measurement for plots in the inventory database for the North Coast ranges from 1 to 20 years. Many of the older inventory plots have not been precisely located using GPS. As a result, there is a need to replace existing inventory plots within LiDAR areas. This significantly limits the ability to undertake LiDAR derived analyses. Value adding to the North Coast assessment has been achieved by stratification of the resource into LiDAR-based structure classes.

Under the original Price Zone stratification, FRAMES projected growth in plots individually, because there was no structural classification for either aggregating plots or assigning the plot data to specific areas in the landscape. All plots within a Price Zone were then aggregated to produce yields per hectare over time, but these yields could not be identified spatially. This was a key reason why FRAMES worked reasonably well strategically but was highly variable at tactical scale.
With stratification using LiDAR-based structure class (and other layers such as Yield Association), plot information for specific structure classes can be extracted, aggregated and grown forward using yield curves that more accurately represent the response of specific forest stands to specific silviculture than the previous aggregating approach. Furthermore, the resulting yield information is allocated spatially rather than averaged across a Price Zone. The combined effect of these two changes is to dramatically increase the extent to which strategic assessment of log volume is more consistent with assessment at tactical scale.

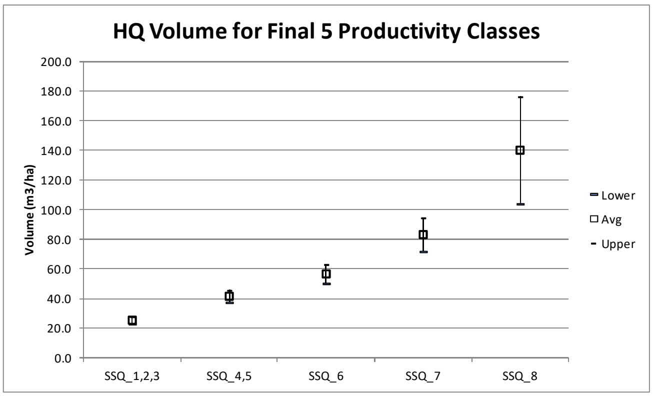
LiDAR has been used to generate a GIS layer called SSQ (sum of squared Canopy Height Model values). This evolved from experimentation and field verification which determined that squaring height values provides an effective weighting for the taller (more mature) stands. This classification was also found to relate well with structural, occupancy and volume features. SSQ values range from 0 (no trees present) through to 3,000,000 (very dense tall forests). For visualisation and field use, the SSQ values were grouped into 8 Structural Index classes. The SSQ grouping values are summarised below.

| Structural Index Classes | SSQ Range |
|---|---|
| **SSQ_0** | NoLidar |
| **SSQ_1** | 0-299,999 |
| **SSQ_2** | 300,000-399,999 |
| **SSQ_3** | 400,000-799,999 |
| **SSQ_4** | 800,000-999,999 |
| **SSQ_5** | 1,000,000-1,199,999 |
| **SSQ_6** | 1,200,000-1,499,999 |
| **SSQ_7** | 1,500,000-2,000,000 |
| **SSQ_8** | 2,000,000+ |

Table 2: Classification of Structure Indices.

An investigation of the relationship between SSQ and volume was undertaken by attributing each strategic inventory plot with SSQ value for the recorded locality in which it was measured. Although regression analysis would be the most effective method to quantify the relationship between these two scalar variables, it was not introduced at this stage. There was also a concern that the relationship may have been compromised as many plots had estimated (rather than GPS measured) location details. As a result, analysis of the plot level volume relationships to the broader SSQ classes was considered more appropriate.

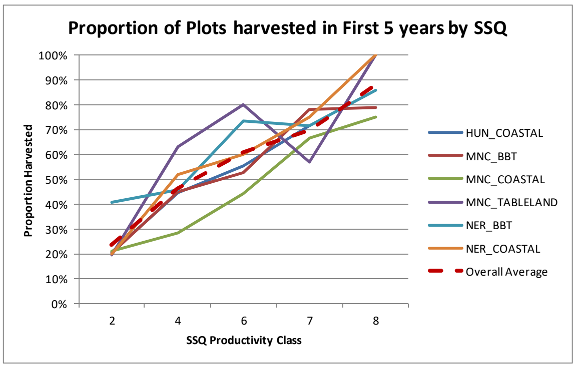
SSQ class was plotted against FRAMES-predicted harvestable HQ sawlog volume which had been determined from inventory plot data. The correlation was strong, indicating that SSQ class provides a good basis for stratification, where HQ sawlog volume is the variable of interest. Prior to any consideration of location or stratification, five SSQ groupings were identified as being both significantly different and well correlated to FRAMES-predicted harvestable HQ sawlog volume per hectare.




| Analysis_Grp | No.Plots | HQSawlog | CI | Lower | Avg | Upper |
|---|---|---|---|---|---|---|
| SSQ_1,2,3 | 482 | 25.3 | ± 10% | 22.8 | 25.3 | 27.7 |
| SSQ_4,5 | 361 | 41.5 | ± 10% | 37.3 | 41.5 | 45.6 |
| SSQ_6 | 159 | 56.6 | ± 11% | 50.1 | 56.6 | 63.0 |
| SSQ_7 | 105 | 83.1 | ± 14% | 71.7 | 83.1 | 94.5 |
| SSQ_8 | 36 | 140.1 | ± 26% | 103.9 | 140.1 | 176.2 |

Figure 9 : Variation in HQ volume for LiDAR derived productivity classes.

A strong correlation was also found between SSQ classes and the proportion of inventory plots that FRAMES predicted would be harvested in the first five years of a simulation. As expected, the higher the SSQ class number (and hence, implicitly, the higher the capacity of the area represented by the SSQ class to produce harvestable HQ sawlogs), the more likely it was that inventory plots would be harvested early in the FRAMES simulation.




| Sub_Region | SSQ Class - Proportion of plots harvested in 1st 5 years | | | | |
|---|---|---|---|---|---|
| | 2 | 4 | 6 | 7 | 8 |
| HUN_COASTAL | 21% | 45% | 56% | 71% | |
| MNC_BBT | 20% | 45% | 53% | 78% | 79% |
| MNC_COASTAL | 21% | 28% | 44% | 67% | 75% |
| MNC_TABLELAND | 20% | 63% | 80% | 57% | 100% |
| NER_BBT | 41% | 46% | 74% | 71% | 86% |
| NER_COASTAL | 20% | 52% | 60% | 75% | 100% |
| **Overall Average** | **24%** | **47%** | **61%** | **70%** | **88%** |

Note: The anomalous result for SSQ 7 for the Tableland grouping in this chart reflects the preponderance of commercially unattractive species in this stratum, which FRAMES does not select for harvesting.

Figure 10: Proportion of inventory plots harvested in the first 5 years by SSQ class.

The utility of SSQ for stratification was refined by examining the differences between probable limits of error (PLEs) in stratifications that combined SSQ classes, Yield Associations and geographic zones. In some cases, the strata had to be simplified because too few inventory plots were available within a combination of stratum components to produce a meaningful estimate of HQ sawlog volume. This shortcoming can be rectified in the future, if it is considered advantageous, by targeting new inventory plots in under-represented strata.

SSQ classes for the North Coast were re-defined as:

- SSQ0 - no LiDAR coverage
- SSQ2 - combination of SSQ1, SSQ2 and SSQ3
- SSQ4 - combination of SSQ4 and SSQ5
- SSQ7 - combination of SSQ6, SSQ7 and SSQ8.

Yield Association Groups on the North Coast up to 2012 comprised the following:

- Moist Blackbutt
- Moist coastal eucalypts (comprising original yield associations of Flooded gum, Brushbox and moist coastal eucalypt)
- Semi-moist and taller dry eucalypts (comprising original yield associations of semi-moist and taller dry eucalypts and moist Spotted gum)
- Dry Blackbutt and Spotted gum (comprising original yield associations of Blackbutt - dry and Spotted gum - dry)
- Dry sclerophyll
- Moist Tableland eucalypts
- Dry Tableland eucalypts (comprising original yield associations of Tableland eucalypts - dry and Tableland stringybarks).

For the purposes of the LiDAR-based stratification, these Yield Associations were revised into new Yield Association Groups (YAGs) to more accurately reflect significant differences in HQ sawlogs and associated PLEs:

- Moist Blackbutt (YAG 11)
- Moist coastal eucalypts (YAG 12)
- Other semi moist and dry sclerophyll types (YAG 25, from YAG 13 + YAG 15)
- Dry Blackbutt (YAG 19)
- Dry Spotted gum (YAG 24)
- Combined Tableland types (YAG 26, from YAG 16 + YAG 17)

These Yield Associations were further tagged as BBT (some HQ sawlog Blackbutt volume) or OTH (other than BBT).

Strata were developed by targeting PLEs of ≤20% for stand BA and of ≤45%, for volume of HQ sawlogs and preferably a minimum of 10 inventory plots per stratum, while ensuring appropriate groupings of similar species and broad geographic zone.

The stratification being used for North Coast modelling as at January 2015 are shown in table 3 (below)

| Region | Yield Association Group | SSQ Class | BBT/OTH |
|---|---|---|---|
| North East | Moist Blackbutt | 4 | BBT |
| North East | Moist Blackbutt | 7 | BBT |
| North East | Moist coastal eucalypts | 2 | BBT |
| North East | Moist coastal eucalypts | 4 | BBT |
| North East | Moist coastal eucalypts | 7 | BBT |
| North East | Dry Blackbutt | 2 | BBT |
| North East | Dry Blackbutt | 4 | BBT |
| North East | Dry Blackbutt | 7 | BBT |
| North East | Dry Spotted gum | 2 | BBT |
| North East | Dry Spotted gum | 4 | BBT |
| North East | Dry Spotted gum | 7 | BBT |
| North East | Other semi moist and dry sclerophyll types | 2 | BBT |
| North East | Other semi moist and dry sclerophyll types | 4 | BBT |
| North East | Moist coastal eucalypts | 7 | OTH |
| North East | Dry Spotted gum | 2 | OTH |
| North East | Dry Spotted gum | 4 | OTH |
| North East | Other semi moist and dry sclerophyll types | 2 | OTH |

| | | | |
|---|---|---|---|
| North East | Other semi moist and dry sclerophyll types | 4 | OTH |
| North East | Combined Tableland types | 4 | OTH |
| North East | Combined Tableland types | 7 | OTH |
| Central | Moist Blackbutt | 2 | BBT |
| Central | Moist Blackbutt | 4 | BBT |
| Central | Moist Blackbutt | 7 | BBT |
| Central | Moist coastal eucalypts | 2 | BBT |
| Central | Moist coastal eucalypts | 4 | BBT |
| Central | Moist coastal eucalypts | 7 | BBT |
| Central | Dry Blackbutt | 2 | BBT |
| Central | Dry Blackbutt | 4 | BBT |
| Central | Dry Blackbutt | 7 | BBT |
| Central | Dry Spotted gum | 2 | BBT |
| Central | Dry Spotted gum | 4 | BBT |
| Central | Other semi moist and dry sclerophyll types | 2 | BBT |
| Central | Other semi moist and dry sclerophyll types | 4 | BBT |
| Central | Other semi moist and dry sclerophyll types | 7 | BBT |
| Central | Moist coastal eucalypts | 4 | OTH |
| Central | Other semi moist and dry sclerophyll types | 2 | OTH |
| Central | Other semi moist and dry sclerophyll types | 4 | OTH |
| Central | Combined Tableland types | 2 | OTH |
| Central | Combined Tableland types | 4 | OTH |
| Central | Combined Tableland types | 7 | OTH |

Table 3: Strata used for the 2015 North Coast resource modelling project

LiDAR-based stratification has proved to be a valuable addition to North Coast FRAMES modelling. Refinements to the approach are planned for some areas, notably those localities are not scheduled for LiDAR capture and plot imputation analysis (section 3.2.4) in the foreseeable future. Experience gained from the previous work has indicated that improvements can be made to LiDAR-based stratification relationship through a more localised focus on species groups and SSQ aggregation.

As at 2016, this approach has not been implemented to other analysis regions for several reasons:

- LiDAR data is not yet available across the entire forest estate
- Investigation is continuing to determine the best-performing LiDAR stratification for inventory purposes.
- LiDAR capture intensities have increased with time (refer to section 3.2.2) and so analyses that encompass multiple capture years have proved challenging.
- A major research and development effort has been placed into developing a Plot Imputation approach described below.

### 3.2.4 LiDAR plot imputation derived resource assessments

While the original FRAMES design provided for the output of strategic level resource data, there is an opportunity to use LiDAR plot imputation assessments in FRAMES to provide more spatially explicit information that can support tactical and operational planning. With the use of LiDAR, it is now possible to identify the stand structure and locate the high, medium and low volume stands to assist planning which areas of the resource should be harvested and when.

Plot imputation assessments have been successfully applied in plantations in New Zealand and Canada. FCNSW is currently investigating the application of this approach to be utilised in native forests. Since January 2015, FCNSW has been working on prototypes of plot imputation analysis for Eden (using 2013 LiDAR data) and the River Red Gum forests (using 2015 LiDAR data).

Plot imputation correlates LiDAR metrics with training data derived from measured, and accurately located, inventory plots.

By dividing the estate into pixels (grid cells) which approximate the size of inventory plots, the relationship between LiDAR metrics and plot parameters can be used to allocate the closest matching plot to each pixel. This process is described as assigning the 'nearest neighbour' (refer to image below). By interrogating the inventory plot metrics represented across a selection of pixels, detailed stand information (eg basal area, volume and stocking) can be estimated. Future estimates of volume can be obtained by projecting plot-based estimates using yield tables assigned to each grid cell or pixel. Yield tables can be averaged across an 'area of interest' eg a compartment, enabling the current average standing volume to be determined and how this will change over time.

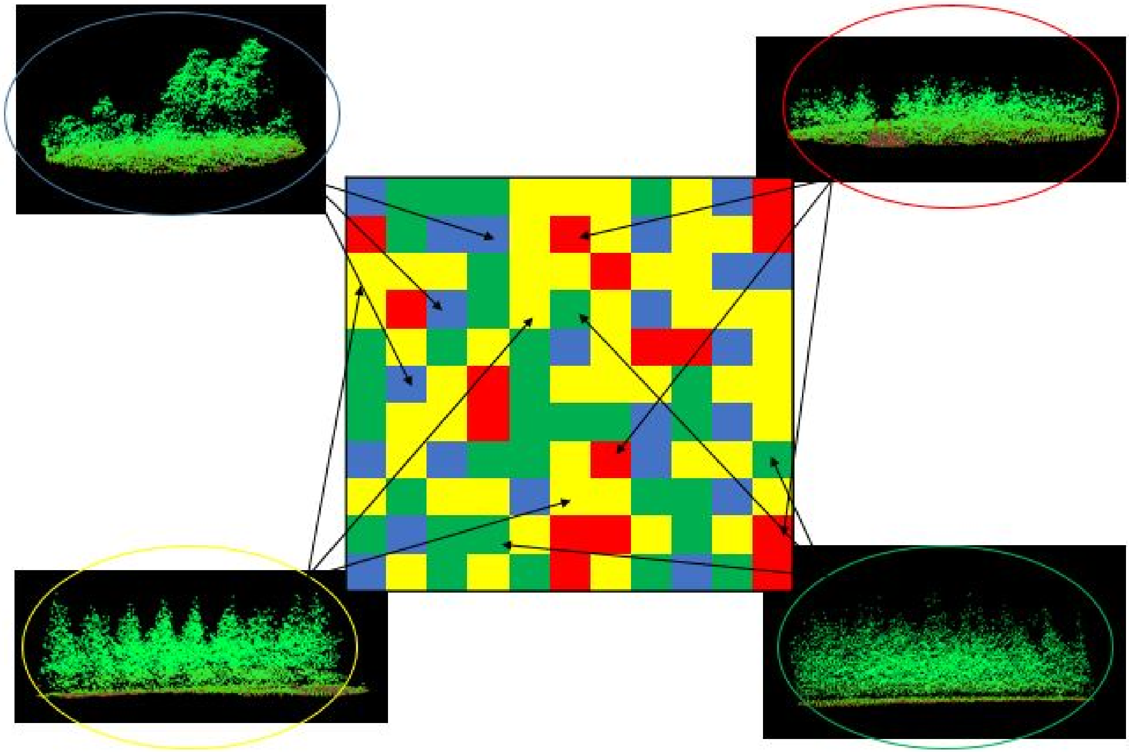


Figure 11: Example LiDAR plot imputation resource assessment

FCNSW has undertaken a comparison of errors associated with the nearest neighbour (NN) imputation method have been prepared for both Eden and River Red Gum forest areas.

A review of the initial imputation runs for Eden included a comparison between the errors associated with a conventional inventory and plot imputation grid-based estimates for equivalent "areas of interest". The results shown below in Table 4 demonstrate 23%, 35% and 32% improvement (reduction in RMSE% - Root Mean Square % error) for per ha Total Standing Volume (TSV), HQ volume and HQ Large volumes respectively from an imputation-based inventory compared to conventional inventory.

| | RMSE% Conventional | RMSE% Imputation | Ratio (improvement) |
|---|---|---|---|
| MTH | 7.7 | 4.4 | 1.76 |
| TSV_ha | 19.2 | 15.6 | 1.23 |
| SPH | 22.6 | 8.8 | 2.57 |
| BA_HA | 13.5 | 12.4 | 1.09 |
| BA_ha_R | 31.8 | 31.9 | 1.00 |
| HQ_ha | 49.5 | 36.6 | 1.35 |
| HQL_ha | 57.4 | 43.6 | 1.32 |

Table 4: Comparison of error rate between conventional and imputation based inventories.

Because of the complexities of the imputation process, further work is needed to express improvements in the reliability of the population estimate in terms equivalent to sampling error (or PLE) as reported for the traditional random sampling processes.

High level summaries are also available from Red Gum imputation project. A summary has been prepared of estate-level comparisons of mean volume estimates from simple random sampling, regression and plot imputation. The results (see figure 12 below) showed that the kNN (imputation) estimate of mean volume was not significantly different from simple random sampling, but the error was much less.

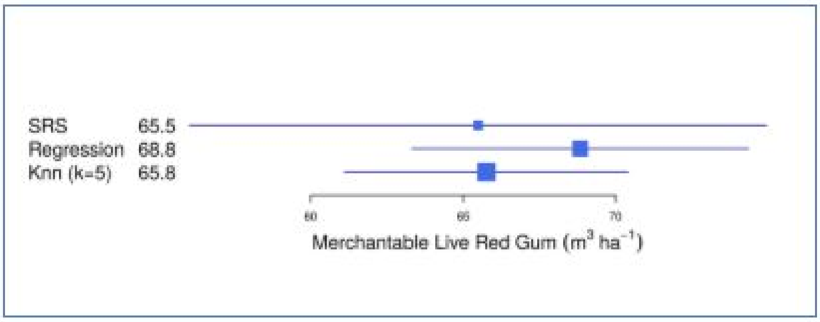



Figure 12: Comparison of volume estimates from conventional and imputation based inventories in Red Gum forests.

In addition to the improved precision of LiDAR-based estimates, the advantages of plot imputation estimates are:

- High spatial resolution of outputs and ability to produce tactical and operational scale outputs
- Applicability at sub-population levels
- Ability to generate estimates where no plots are present
- Can be used to produce estimates for all products, not just those used to build a regression model.

Challenges remain in how to identify species and merchantability within the highly variable native forest resource using plot imputation results. However, it should be noted that this information is equally difficult to determine from conventional inventory and assessment processes. Use of supplementary data sources such as physiological and topographic models and sales records may assist in strengthening these prediction features.

FCNSW is in the process of identifying the most appropriate approach to collect additional field verification data to support this work.

**Future of Stratification**
Given the large resource area and high cost of LiDAR capture, future analysis will incorporate a mosaic of stratification and assessment methods. For example, the next North Coast review will potentially include plot imputation analysis over the recently captured price zones near Wauchope; regression-derived stratification will be applied for price zones near Grafton and Casino, which have updated inventory but older LiDAR; and the 2012 stratification will be used for remaining areas.
Each of these analyses will deliver differing qualities of resource estimates, which will be reflected the estate model that combines them. Tactical level projections will be able to be generated for come Price Zones, while others will be limited to the more conventional strategic level reports.

### 3.2.5 Inventory plot measurement

Remeasurement of inventory plots is targeted at not less than once every 10 years or after a harvesting event, whichever occurs first. In the south of the state (South Coast, Eden and Tumbarumba) the inventory remeasurement program is largely up to date. However, the inventory plot remeasurement process is behind schedule on the North Coast, with 767 plots requiring remeasurement in mid-2016 (38% of the active North Coast plots). As 50% of North Coast plots were measured in 2003, a full remeasurement program was considered too expensive to implement as a single inventory and a staged program has been planned to smooth the measurement program into the future. The first stage of this program has been undertaken in 2016 with 431 plots remeasured in areas north and west of Coffs Harbour. The second stage of the program will target plot remeasurements in areas between Coffs Harbour and Taree to the south. This program, planned for 2017, will reduce the backlog to 19% of the active North Coast plots. In addition, a review of the Native Forest Inventory Framework will be undertaken to ensure that future plot measurements are compatible with imputation modelling.

Detailed inventory attribution improvements that cater for harvesting and new silviculture requirements have been implemented:

(a) The extent of any harvesting events that have occurred after 2005 is spatially defined in FRED and labelled with:
- Year completed
- Silviculture applied (AGS, Thin, STS Light, STS Moderate, STS Regen)
- The number and average size of gaps created, on AGS tracts.

(b) All strategic inventory plots that fall into post-2005 harvested tracts are tagged with a detailed post-harvest condition code.

(c) YTGen has replaced Cruiser as the plot analysis technology.

(d) Trees in the plots with DBHOB <30 cm are estimated and tallied into 5cm diameter classes.

(e) Consistency between mapped actual harvest area in FRED, identification of inventory plots requiring post-harvesting re-measurement and geo-referencing of inventory plot locations has been enhanced.

The inventory procedures are documented in the Corporations *Native Forest Strategic Inventory contractors manual* and the *Species and Quality Assessment Manual.* Both these documents have been reviewed and updated in 2016.

The previous inventory design focused a significant amount of effort on smaller trees. These trees do not contribute to the strategically important early wood supply modelling periods. There is also a high degree of uncertainty associated with tree quality for small trees. The minimum tree diameter measured was increased from 10cm to 30cm, reducing the 'on-plot' measurement effort by approximately 70%. This refinement was estimated to save approximately 30-40% of on-plot measurement times and around 15% of total plot measurement costs. To maintain compatibility, smaller trees have their diameter estimated rather than measured.

In more recent times a simplified approach to stem cruising has been adopted, similar to the earlier MARVL approach. Review of the detailed stem cruising approach revealed that it was being applied in a less consistent manner due to the complexity of the procedure, widely varying form of native species and impacts of unseen internal defects.

### 3.2.6 Inventory data processing

YTGEN was introduced for processing of inventory plot data in 2012. It is an improvement over the previous Cruiser system, providing the capacity to implement a log cutting strategy based on the centre diameter (CDUB) of a log, rather than small end diameter (SEDUB) as used in Cruiser. This enables the accurate prediction of log volumes by sales system grades. Specification of logs via CDUB also enhances the ability of FRAMES to model growth of logs by log grade, which is undertaken for the 15-year period following an inventory plot measurement. YTGen has the additional advantage of being backwardly compatible with both MARVL and Cruiser, which means that old plot data can be recalculated if necessary.

YTGen processes inventory data and creates a database that reports detailed metrics for the logs that can be generated. These metrics include product grade, log volume, large end, small end and centre diameters. Processing in YTGen includes new minimum log length specifications, consistent with current practices and developed for improved efficiency of haulage and log processing in mills.

YTGen uses a very different methodology to calculate log volumes than either of its two predecessors. As a consequence, the recovery factors that are used to modify predicted log volumes by log grade have required a major revision (see section 3.3.5).

## 3.3 Yield Simulation

### 3.3.1 Pre-treatment of inventory data

For modelling purposes, inventory plots measured after 2009 identified in FRED as being in areas harvested, but which have not been remeasured, are deemed to have been disturbed by harvesting operations. A simulated harvesting is applied to these plots in FRAMES before inclusion of that inventory data in future growth and yield prediction. On the North Coast, plots identified in FRED as being in areas harvested in the period 2002 to 2009, but which had not been remeasured, were assumed not to have been disturbed in a harvesting event and are retained in the database without having a simulated harvesting applied to them. Inventory plots measured from 2013 onwards include a data record indicating whether a harvesting event has occurred in or near the plot. This assists subsequent reconciliation analyses.

Regeneration harvesting is carried out under the STS definition within the IFOAs, where 40% (45% South Coast) of the standing basal area (BA) may be removed within a specified tract. To allow for suitable conditions for productive Blackbutt regeneration and to ensure that the harvest area meets the requirements of the STS definition, specific areas are set aside as unharvested ‘offsets’. This allows for removal of more than 40% of BA on those areas where harvesting is targeted. This is in keeping with the general description of NSW selective harvesting as described in FCNSW silviculture manual.

> *“since eucalypt forests do not fulfil the criteria for successful application of classical single tree selection, a modified selection system is used where an uneven removal, heavier in some areas and lighter in others is applied across a harvesting tract.”*

Regeneration harvesting (STS Regen) harvesting thus conforms to the overall specifications of STS silviculture under the IFOA, which specifies that the BA of trees selected for logging should not exceed a specified percentage of the BA of all trees existing immediately prior to logging, within the net harvestable area of the tract. The specified percentage is 40% in the former North East and Central Regions (now North Coast) and 45% in the former Southern Region (now South Coast).

With STS Regen, the trees that are harvested are concentrated within part of the harvestable area. Only seed trees, hollow-bearing, habitat recruitment and feed trees are retained in the actual harvest area. The remainder of the harvestable area is retained as a BA offset. The size of this is such that the combined BA of trees in the offset plus seed and habitat trees is not less than 60% of the pre-harvesting BA. The intent of STS Regen is to provide for effective, vigorous and extensive regeneration in the area harvested. This will significantly enhance future HQ sawlog production compared to more traditional STS silviculture.

Inventory plots and associated harvested areas to which STS Regen silviculture has been applied are now processed separately from areas of light and medium intensity selective harvesting. This is because STS Regen produces more even-aged regeneration, effectively replacing a mature even aged forest. Consequently, future growth and yield from STS Regen areas is modelled via a simpler age-based model for growth and yield. As at June 2015, approximately 10,000 hectares of mapped regeneration areas following STS Regen harvesting are modelled in this way.

AGS harvesting operations were phased out in favour of STS Regen. The practical application of AGS under the IFOA led to small gaps that were difficult to regenerate and created substantial additional site disturbance. Because its significantly higher cost and complexity in practice, and poor regeneration outcomes being observed (especially in the important taller and moister Blackbutt types), AGS is unlikely to be practiced in the foreseeable future. Consequently, areas treated with AGS in the past are simulated for other silviculture types in the revised FRAMES model.

Analysis of HQ sawlog volume predictions in FRAMES indicated that changes were required to Yield Association Groups to more accurately reflect differences in HQ sawlog volume production. These changes to YAGs were described earlier in section 3.2.1.

### 3.3.2 Growth modelling improvements

Growth modelling in FRAMES uses BA increment as the underlying driver for growth, and then calculates log and product volumes from BA, height and taper. FRAMES originally used an individual tree BA growth model for the first 30 years of the simulation, and then switched to a stand BA growth model from that point for the remainder of the 100-year simulation. A period of 30 years was considered the maximum period over which realistic individual tree BA growth should be modelled.

Examination of predicted volume growth suggested that the stand BA growth model was not performing as expected.

| **Analysis of Harvesting Events - STS Moderate Silviculture** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **No. of Harvest Events Achieved in 100 Yrs** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | None |
| **Resulting Return Time (yrs)** | 100 | 50 | 33 | 25 | 20 | 17 | 14 | 13 | 11 | 10 | |
| **Area weighted Proportion of Plots** | 81.0% | 56.4% | 31.2% | 14.4% | 5.6% | 2.3% | 1.0% | 0.3% | 0.2% | 0.1% | 19.0% |
| **Area Treated (ha's)** | 279,570 | 194,377 | 107,628 | 49,688 | 19,375 | 7,924 | 3,555 | 1,180 | 630 | 301 | 65,370 |

Table 5: Proportion of plots being harvested in a 100 year simulation.

This analysis showed that 19% of plots (representing over 65,000 hectares of net harvestable area on the North Coast) never triggered a harvesting event, while nearly 45% only triggered one harvesting event.

A detailed review indicated that a significant number of plots (around 11% for both the North and South Coasts, shown graphically for the South in the figure below) had a measured BA exceeding the modelled maximum for the site. It was also found that BA growth was being unrealistically constrained in plots that have reached or are nearing their modelled maximum. Redevelopment of the stand BA growth model was considered impractical. As an alternative, the individual tree BA model was allowed to run for the full 100-

year simulation. Concern that the individual tree model would not be sufficiently constrained over that time frame proved groundless, because stand level parameters in the individual tree BA growth model sufficiently constrain stand BA growth such that the model continues to work within reasonable bounds across a range of stand conditions and extended time periods.

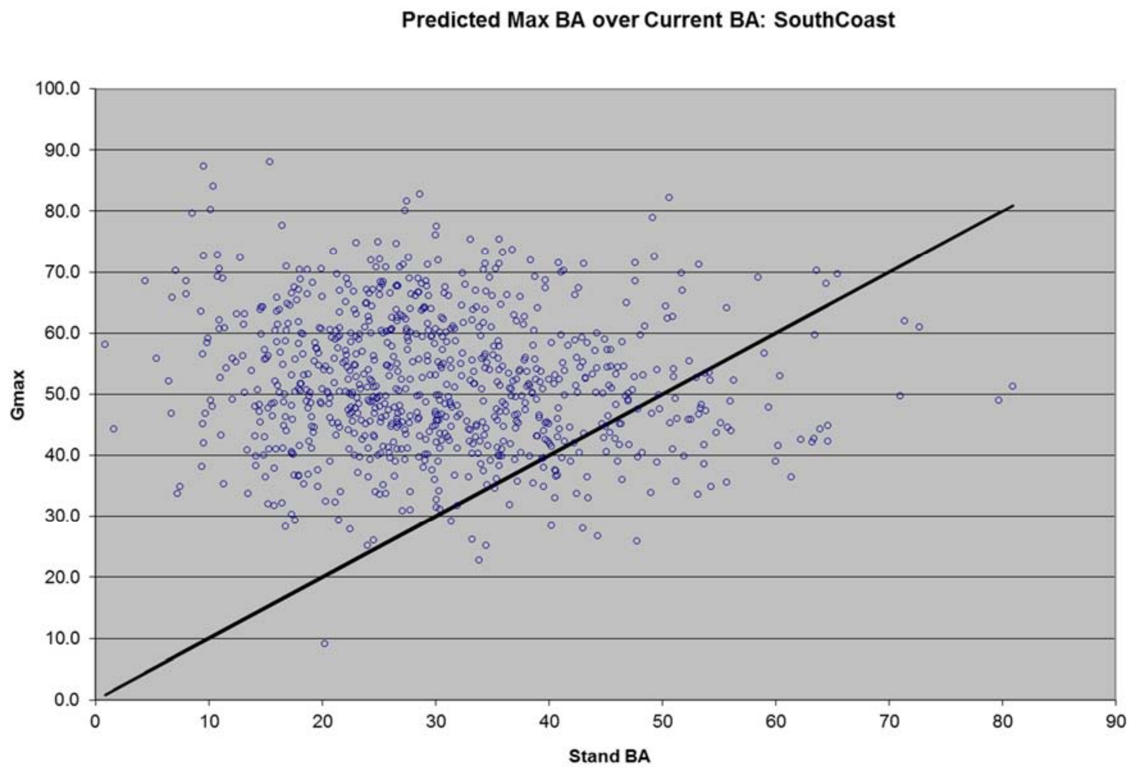



Figure showing BA Model maximum projected BA – points to the right of the line represent plots with higher measured BA than the modelled maximum.

### 3.3.3 Simulator improvements

The use of YTGen permits growth of individual trees to be undertaken by projecting individual logs by log grade, as determined by YTGen from inventory data. This contrasts with the earlier process in FRAMES, where whole tree growth was converted to log volumes by grade using TPPs (see section 2.4.5). This results in considerable loss of detail in estimating production of logs by grade. The current approach significantly improves the prediction of volume by log grades. The process of growing logs forward by log grade is considered appropriate for 15 years, after which the variability in volume by log grade is considered too high. From that point forward, log volumes by grade are determined using revised TPPs.

Application of these volumes by log grade has been partitioned into "Easy Access" (on slopes up ≤ 20° and areas ≥ 50 m from a riparian buffer) and "Difficult to Access" (slope > 20° and/or < 50 m from a riparian buffer), when specifying viable harvest threshold volumes for different silvicultural treatments.

Modelling of STS Regen in the Yield Simulator has been significantly revised:

- The number of years between an STS Regen harvest and recruitment of regeneration has been linked to YAG (see section 3.2.1), to reflect the fact that the establishment and growth of regeneration to 10cm DBHOB varies between species groupings).
- The species mix of HQ sawlog volume from STS Regen operations has been used to provide an estimated species mix for regeneration arising after STS Regen harvesting operations.
- The minimum period that must elapse after an STS harvesting operation before another harvesting operation can occur at the same site is five years. In practice, harvesting operations in the BA offset

and seed tree components of an STS Regen operation are expected to occur between 6 and 15 years after the first STS Regen harvesting operation. This is difficult to model in FRAMES directly. As an approximation, FRAMES calculates the total harvestable volume from the tract and apportions this yield at user specified intervals.

- As mentioned in section 3.3.1, regeneration after an STS Regen harvesting operation is more akin to plantation establishment and growth than to the scattered and slow-growing regeneration arising from conventional STS harvesting. The same model structure as is currently used to predict future log volumes from hardwood plantations has been implemented to apply to regeneration rising from localities already treated with STS Regen harvesting operations.

Further refinements that have been incorporated in the growth and yield simulation process include:

- Habitat/seed tree retention modelling has been coded into the simulator which has enabled more flexibility to include a range of tree size and quality selection options.
- Post-harvest regeneration recruitment modelling has been enhanced to be sensitive to stand density after harvest.
- Localised tree size and merchantability requirements have been incorporated (informed from historic sales date).
- Improvements to tree selection algorithms for STS and thinning scenarios.
- A more localised focus on product level volumes and recovery has been incorporated.
- Improvements to silvicultural treatment methods that are linked to stand structure (number of HQ trees present) enabling growth on younger more vigorous stands to be optimised to capitalise on future HQ growth.

### 3.3.4 Tree Product Proportionment models (TPPs)

FRAMES uses inventory data for prediction of log grade for the first 15 years of the simulation (see Section 2.4.5), and then uses Timber Product Proportionment models (TPPs) for log grade prediction from year 16 onwards. The switch from Cruiser to YTGen for calculation of log volume by grade meant that new TPPs needed to be developed. This is demonstrated in the comparison depicted below, in which the proportion of total stem volume (TSV) by tree DBHOB is compared for HQ35 logs from Cruiser with HQ40 logs from YTGen (HQ35 logs from Cruiser are used because the “35” represents SEDUB, which approximates the “40” for CDUB from YTGen). The previous FRAMES model (HQ35 TPP 2004) is also shown.

Separate TPPs were developed for “H” trees and “L” trees (see section 2.4.5) and for different log grades within each “H” or “L” tree based on products and size. The final 2010 TPP model for “H” trees is shown on the following page. The kink in the TPP model for trees above 850 mm DBHOB in figure 14 (below) has been artificially imposed. Inventory data shows that trees of this DBHOB and above are significantly more likely to be downgraded to waste rather than meeting higher log grade specifications.

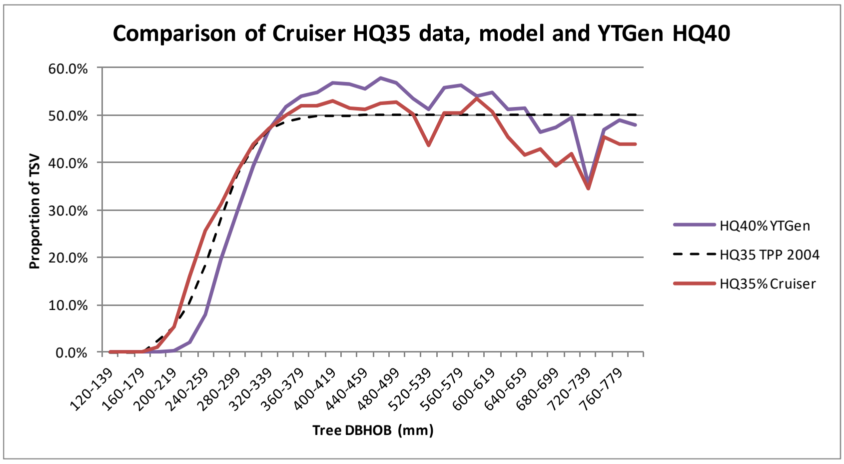



Figure 13: Comparison of TPP models from Cruiser and YTGen

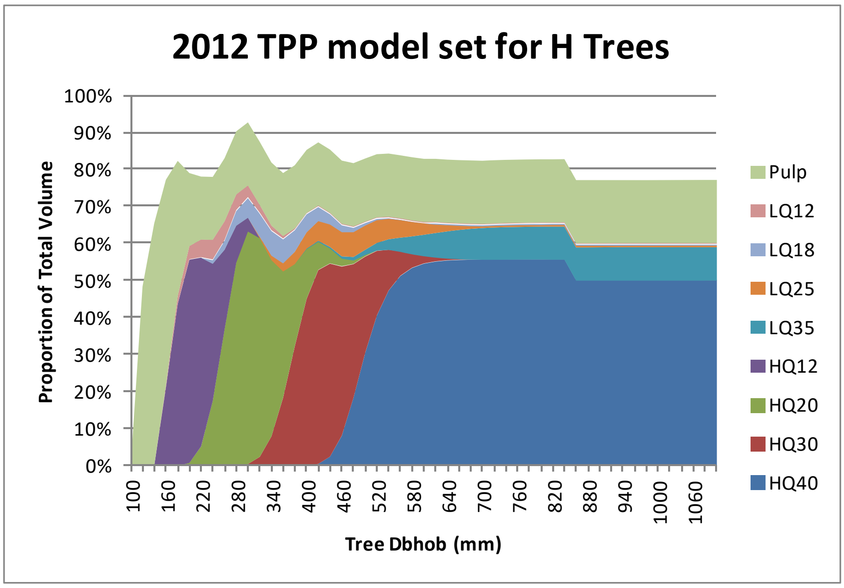



Figure 14: Graphical representation of the 2012 TPP models used for trees graded as 'H'.

Analyses have shown that the new TPP models perform reasonably well across the North Coast. However, they appear to under-predict sawlog volumes in some HQ classes in local areas dominated by Blackbutt and over-predict HQ sawlog volumes in poorer site quality areas. To address this issue, separate TPPs have been developed for Blackbutt, one for high site quality Moist Blackbutt (YAG 11) and one for the lower site quality Dry Blackbutt (YAG 25). Resolution of this issue for other species is not considered critical as TPPs are used for prediction of log volumes by grade typically from 15 years into the future. Nonetheless, future analyses will target the improvement to TPPs using relationships with stand height measures and Yield Association Groups.

### 3.3.5 Recovery and leakage factors

First stage sawlog volume estimates by grade from FRAMES represent a "best case" scenario (see section 2.4.6) and do not take account of issues such as:

- Unseen internal defect that is apparent after felling the tree
- Harvesting damage
- Incorrect or conservative log grading.

The first two of these volume write-downs are addressed in FRAMES via recovery factors and the third via leakage factors.

As YTGen more accurately projects HQ sawlog products (utilising log centre diameter and therefore better matching the sales process), the relationship between predicted and recovered product needed to be revisited. The North Coast log recovery studies arising from MARVL-based assessments in 2000 and Cruiser-based assessments in 2007 were re-analysed in 2012. Log volumes by grade were recalculated for both "pre" (standing) and "post" (on ground) logs using YTGen. As the MARVL assessed tree list was significantly larger, that data was stratified by species group. The smaller Cruiser dataset was separated into desirable and less desirable species.

The newer YTGen based analysis reduced the HQL volumes predicted in logs and consequently lowered the recovery factors required. The new modifiers are presented in the table below. In summary:

- For MARVL plots, the overall write-down of HQ40 sawlog volume was reduced from 30% to 25%. The volume associated with the 25% write-down was reallocated to HQ30 (15%), LQ (15%) and Pulp (70%).
- For Cruiser plots of more desirable species, the write-down of HQ40 sawlog volume was reduced from 30% to 4% (this reduction included correction of a calculation error found in the earlier recovery factor). Pulp recovery was also lower than predicted, resulting in a 44% write-down. The volumes associated these write-downs were reallocated to HQ30 (10%), LQ (50%) and Waste (40%).
- For Cruiser plots of less desirable species, the write-down of HQ40 sawlog volume was reduced from 55% to 39%. HQ30 sawlogs required a write-down of 20%. The volumes associated these write-downs were reallocated to LQ (70%) and Waste (30%).
- Recovery factor calculations were performed for HQ40, HQ30, LQ and Pulp logs from trees classed as "H", "L", "P" and "W" respectively (see section 2.4.5).

In 2010, a study was undertaken to compare log grading of harvested logs by the best log grader on the North Coast with log grading for the same logs by routine local log graders. The limited data available suggested a leakage write-down of between 5% and 20% for HQ products. Consequently, a 10% leakage write-down has been applied.

Recovery and leakage factors were combined into total volume write-downs. This was undertaken as follows:

- A leakage factor of 10% was added to the recovery factor for HQ40.
- Of the 10% leakage from HQ40, some is graded as HQ30 and some as LQ. In addition, some HQ30 leaks into LQ. The net leakage for HQ30 is estimated at 4%.
- The remaining leakage from HQ40 and HQ30 is reallocated predominantly to LQ grade, while ensuring that total log volume from a stem equals the sum of volumes from each log grade.

Calculations were undertaken separately for unique combinations of inventory data source, tree class and whether the tree was classed as "desirable" or "less desirable".

Combined recovery and leakage factors for North Coast species are presented in Table 6 below.

| Measure Source | NC Species Group | Group Id | HQ40 Recovery Write-down | Recovery + Leakage Adjustment |
|---|---|---|---|---|
| MARVL | Blackbutt Group | 1 | -4% | -14% |
| MARVL | Spotted Gum Group | 2 | -19% | -29% |
| MARVL | Brushbox | 3 | -33% | -43% |
| MARVL | Tallowwood | 4 | -3% | -13% |
| MARVL | Blue Gum | 5 | -6% | -16% |
| MARVL | Ironbarks | 6 | -1% | -11% |
| MARVL | Red Woods | 7 | -10% | -20% |
| MARVL | Stringy Barks | 8 | -7% | -17% |
| MARVL | New England Group | 9 | -31% | -41% |
| MARVL | Poor durables | 10 | -21% | -31% |
| Cruiser | Desirable Species | - | -4% | -14% |
| Cruiser | Other Species | - | -39% | -49% |

Table 6: Recovery modifiers applied to North Coast species for the 2012 URS Review.

In 2015, a new approach to recovery modelling was introduced that incorporates the stronger relationship between predicted and actual volumes (with $r^2$ values between 0.7 and 0.9), rather than recovered percentages ($r^2 = 0.09$).

This approach incorporates a two-stage analysis. Stage one extracts the binomial trends (true/false) for trees that do not produce the predicted timber quality. This relationship is used to condition the predictions at a whole tree level.

Stage two explores the predicted and actual out-turn for those trees that do produce the predicted quality. Figure 15 below demonstrates the relationship between predicted high quality volume (H_Pre) and actual (H_Post) for 180 trees sampled in Eden. Figure 16 shows the same data modelled using the traditional proportions approach.

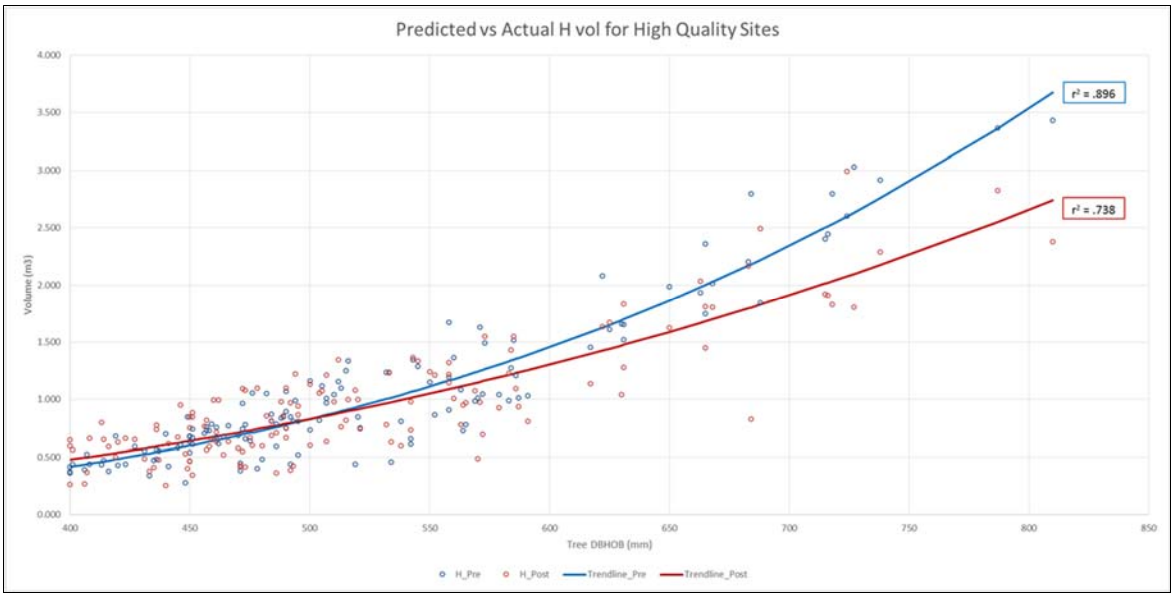



Figure 15. Comparison of predicted vs actual 'H' volume for high quality sites in the Eden study area.

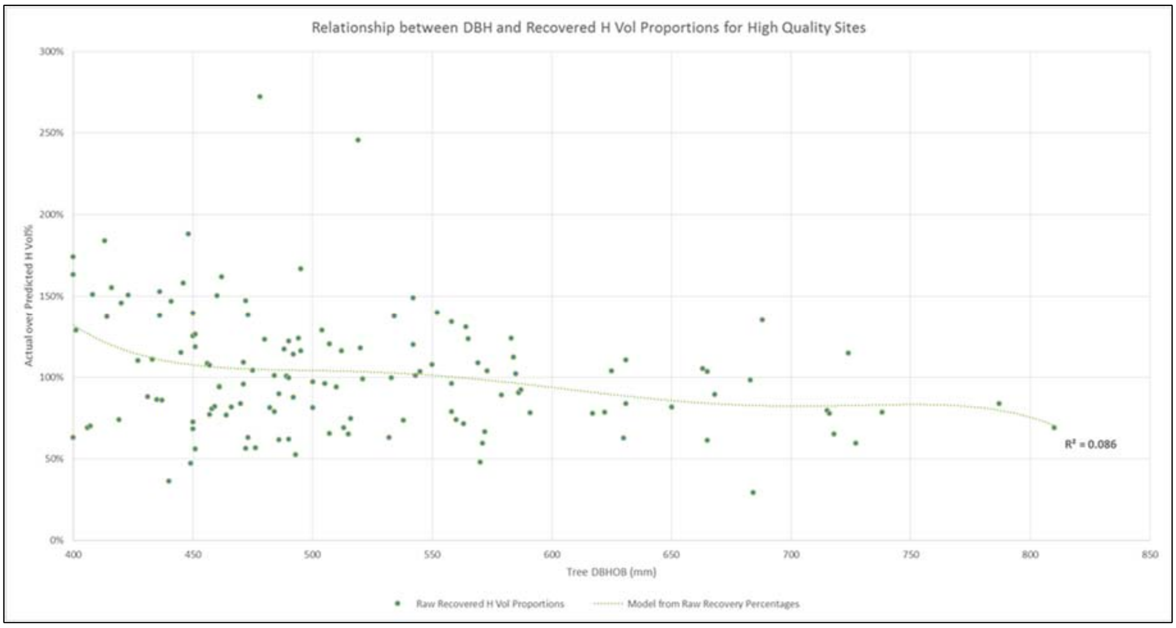



Figure 16. Comparison of predicted vs actual 'H' volume as a function of DBHOB for high quality sites in the Eden study area using traditional recovery proportions.

As at July 2016, this two-stage modelling approach has been implemented for the Eden analysis region and preliminary analysis has been completed for incorporation of the North Coast data. Other localities will be analysed with this approach as required.

### 3.3.6 Utilisation data capture

In 2016, a new tree utilisation sampling project was introduced to incorporate field capture of log product information collected by harvesting contractors as part of daily operations. This information will be used to develop a species x size x locality database of product recovery from actual harvest data which will provide more comprehensive information than that available from specific recovery study trials.

Key features of this procedure include:

- FCNSW technicians will undertake pre-harvest mark-up to: identify one sample tree per hectare; measure DBHOB; assign a whole tree quality code (high, low or pulp); and paint these details onto the tree stem. The sampling intensity equates to approximately 1 tree per day in typical production operations. All sample trees will have a recorded GPS location so that the intensity of sample trees per hectare, across any specific part of the estate, is known.
- Tree felling operators will transfer the DBH and quality details onto the butt of the tree after it is cut down.
- The sample stems will be segregated on the log landing, where the operator will record the species, DBH and quality details along with length and diameter of all products produced. Information will be captured using hand-held log tracking devices. While some bias may occur in the early stages of implementation, this is expected to reduce as operators become familiar with the process. On-site audits of this process will be undertaken by Harvesting Coordinators.
- Product utilisation data captured on the hand-held devices will be automatically transferred to the Scion sales database for collation and analysis

Trials of the new system are currently being undertaken. If successful, it is expected that this procedure will significantly improve knowledge of tree size and species related utilisation trends, at both strategic and local levels. Further, this utilisation information will be continually captured to provide the current state of product utilisation and better reflect markets and contractor practices. This will provide more reliable estimates of product utilisation than current modelled recovery factors.

### 3.4 Yield Scheduling

As part of FRAMES, Woodstock is used as an optimisation model which utilises linear programming, an objective function and a suite of constraints.

The early Woodstock models in FRAMES were set up to maximise NPV based on average harvesting, haul and stumpage costs for Price Zone. Constraints included: volume of HQ harvested; supply by area; maximum and minimum supply volumes in each period; and permitted variation in harvested volume from one period to the next.

The problem with formulating the yield scheduling model in this way was that harvesting schedules could not respond dynamically to changes in the source and destination of specific parcels of logs. There was no capacity in the formulation to ensure that areas were harvested in a way that ensured that the logs supplied to mills were drawn from the most cost-effective location when balanced across supply regions and over time.

A new formulation has been developed for North Coast modelling that has the following characteristics:

- The objective function seeks to maximise mill door log prices less harvest and haulage costs.
- A set of nominal mill sites was developed, each representing the approximate volume-weighted supply point within a sub-region. The nominal mill sites for the North Coast are: Port of Brisbane; Kyogle; Grafton; Thora; Kempsey; Herons Creek; Bulahdelah; and Tea Gardens. Nominal haulage cost to these sites from each Price Zone were calculated.
- Targets were set for: all HQ sawlogs; all HQ Blackbutt; and HQ40 Blackbutt.
- Targets were set for supply of HQ logs to Boral Timbers, addressing species, supply zone and mill site requirements.
- Constraints on supply of specific species and grades of logs were set for specific locations.
- Separate constraints were applied for different time periods, to address Wood Supply Agreement (WSA) periods and conditions for some processors, and to allow for a step down in supply at the expiry of the WSA period.
- Target constraints on the variation in supply of species and log grades were imposed to smooth out supply over time.
- Constraints were imposed on the maximum and/or minimum volumes to be harvested by Price Zone, to ensure that the spread of harvesting operations was balanced and not concentrated in the closer and more easily accessible areas in the earlier periods of the schedule. If allowed to occur, this type of concentration of harvesting can lead to significant increases in harvesting and haulage costs over time, as the closer areas would have already been harvested and the more distant and expensive harvest areas would dominate future harvesting.

The revised Woodstock formulation significantly improves the utility of FRAMES:

- There is a much tighter link between log supply planning and the practical and economic realities of management of log supply over time, area, species and between customers.
- Together with improved FRAMES capacity in predicting harvestable volumes at the compartment or group of compartments level, the closer link with practical planning increases the confidence of field staff in the performance of FRAMES and builds commitment towards both reliance on FRAMES and a continuous improvement process.

- There is a clearer demonstration to management of the capacity of the forest estate to meet highly constrained supply conditions over time, leading to earlier warning of supply issues and capacity to implement moderating scenarios.

Further development of estate modelling has occurred in 2016 with the creation of a prototype spatial model for the Eden Management Area. This model utilises the Plot Imputation analysis results which have enabled yield tables to be reported at the sub compartment level.

Features of the Eden tactical Wood Supply model include:

- Harvest units consisting of the unique combinations of stand age (grouped up to 10-year origin year intervals) and thinning state within compartment.
- Yield association and site quality data is incorporated spatially.
- A range of thinning and reset options are available for each harvest unit.
- A "Type II" model that allows stand metrics such as stocking, basal area and volume to contribute to dynamic silvicultural decision making. This represents a significant improvement in modelling of silvicultural options over the traditional approach where these were coded directly into the simulator.

Production of spatially referenced yield tables enable the scheduling outputs to be exported to GIS for visualisation and field verification. Testing and evaluation of the Eden model is scheduled from late 2016. Experience gained from this exercise will be incorporated into the next update for the North Coast, and beyond that, other regions where imputation or LiDAR-based stratification of the resource is planned.

### 3.5 Summary of FRAMES Improvements

The focus of FRAMES development over the period 2009 to 2016 has been to improve the capacity of FRAMES to provide estimates of harvestable volume at a tactical level.

The key components of the progressive improvement in FRAMES during this time are:

- The increasing use of air-borne LiDAR technology to derive an accurate digital terrain model (DTM). This is used to derive accurate slope, slope classes, stream locations, stream buffers, old road and track locations and similar terrain attributes.
- Accurate GeoNet modelling of stream location using LiDAR has improved delineation of stream buffers resulting in an improved definition of net harvestable area.
- Increased application of mobile technology is enabling FCNSW to more accurately record and map the extent of harvesting. As of 2016, several harvesting machines have been using the internally developed FCMapRT app to capture harvest area extents. This will result in more accurate harvesting area mapping compared with the traditional post-harvest mapping techniques which are based on estimating harvest areas.
- Development of a spatially accurate LiDAR-derived stratification provides more precise estimates of harvestable volume by grade and yield association at the compartment or harvest unit level.
- Updated inventory that improves current and future sawlog availability estimates and more accurately models current silvicultural systems.
- LiDAR plot imputation assessments in FRAMES are being developed to provide more spatially explicit information to support tactical and operational planning. With the use of LiDAR, it is now possible to identify the stand structure and locate the high, medium and low volume stands. This will assist with planning which areas of the resource should be harvested and when.
- Enhanced spatial analysis tools and a comprehensive database to more accurately identify areas available for harvesting.

- Updated modifiers that improve the conversion of theoretically available volume by log grade into volumes by log grade that are sold.
- Improved scheduling of harvesting activities to account for economic factors and wood supply requirements and constraints.

# 4 Reconciliation Reporting

The Auditor General's Performance Audit "Sustaining Native Forest Operations: Forests NSW" of April 2009 included an action item (Recommendation 5), requiring (the then) Forests NSW to "*compare harvest results against its yield estimates over five year periods as a means of testing the accuracy of estimates*" and "*report the results annually starting June 2010*".

The first report addressing this requirement and covering the reconciliation of actual harvested volumes versus harvestable volumes predicted by FRAMES for the period July 2005 to June 2010 for the RFA areas within the former North East and Central Regions plus the Southern Regional Forest Agreement (RFA) region was prepared and submitted in 2011 (see the 2011 report on the Forestry Corporation web site). Preparation of this report highlighted the difficulties of undertaking such a reconciliation when FRAMES does not estimate harvestable volume by grade at tactical level. The reconciliation for this report was undertaken by Analysis Groups, which were combinations of Region, broad geographic zone, yield associations (Blackbutt-rich or otherwise), and silvicultural treatment.

An updated FRAMES Reconciliation was completed in 2013 (see the 2013 report on the Forestry Corporation web site). A 2015 reconciliation is scheduled for publishing in 2017.

Accurate delineation of harvested areas is essential for ease of reconciliation and to ensure that strategic and tactical projections are based on an accurate representation of available area. FCNSW is currently improving the mapping of harvest extent using LiDAR and GPS harvest tracking data. This will lead to improvements in reconciliation processes.

# 5 Where to from here?

## 5.1 Tactical planning

Up to 2015, resource assessment has been at a strategic level. With the availability of LiDAR to provide stratification, regression modelling and plot imputation products, the key focus of FRAMES development work from 2015 has been to shift modelling to a tactical level. The intended outcome is an annualised 15-year tactical wood supply plan, within a strategic wood supply framework, that reports yields and harvesting activity at the compartment or group of compartments scale.

The steps to achieve this outcome are:

1. Update LiDAR attributes where harvesting has occurred after the LiDAR data acquisition.
2. Utilise plot imputation (where available) to create harvest unit level yield tables and use LiDAR-derived volume stratification elsewhere to create improved yield projections.
3. Investigate whether data resolution is suitable for deriving annualised outputs.
4. Incorporate updated hardwood plantation yield tables where applicable (new growth models, LiDAR stratification, refined wood supply).
5. Modify the Woodstock model to:
   - Accommodate spatially defined harvest units
   - Be consistent with the strategic model outputs
   - To incorporate operational requirements such as wet weather areas and ecology surveys
6. Develop a suite of reports including: areas treated; harvest yields per hectare; and species mixes to provide readily usable analysis of wood supply outcomes at a spatial level.

7. Reconcile predicted yields per hectare at compartment or group of compartments level with regional field based tactical assessments and recent harvest results. Refine models where reconciliation differences require changes to silvicultural or harvesting assumptions.
8. Compare and contrast modelled wood supply with regional plans, refine models accordingly and develop a formal tactical plan in consultation with Regions.
9. Submit tactical plan for formal approval, implementation, variation management and ongoing monitoring.
10. Update the strategic wood supply model to consider variations identified in tactical planning processes.

## 5.2 Future reconciliation reporting

As well as being a regulatory requirement for external review (see section 4), reconciliation between FRAMES estimates, tactical plans and actual sales improves the utility of and confidence in FRAMES as an effective management tool for resource modelling.

The development of a 15-year tactical plan will provide a key link between the strategic data that underpins wood supply to each region and short term (three to five year) tactical planning. This in turn will underpin the formal 12-month Plan of Operations (documented harvest schedules provided to customers).

The Forest Records and Events Database (FRED) enables the extent and yield of harvest operations to be recorded and maintained in a structured and consistent way. Incorporation of GPS-enabled harvest tracking data will significantly improve the resolution of data available for reconciliation. Data from FRED will be extracted every two years at a minimum, to facilitate comparison of actual yield with model forecasts.

A key benefit of this linked approach is providing direct feedback to FRAMES for both strategic and tactical modelling processes. Multiple sources of feedback will facilitate model refinements ranging from improved consistency and defensibility of the WSA supply capacity, to features such as localised silvicultural or market conditions that have not previously been able to be considered.

The framework to formalise the inter-relationships between these processes is set out in the diagram below. To meet appropriate governance standards, the maximum 'formal' review cycle for these analysis regions is five years.

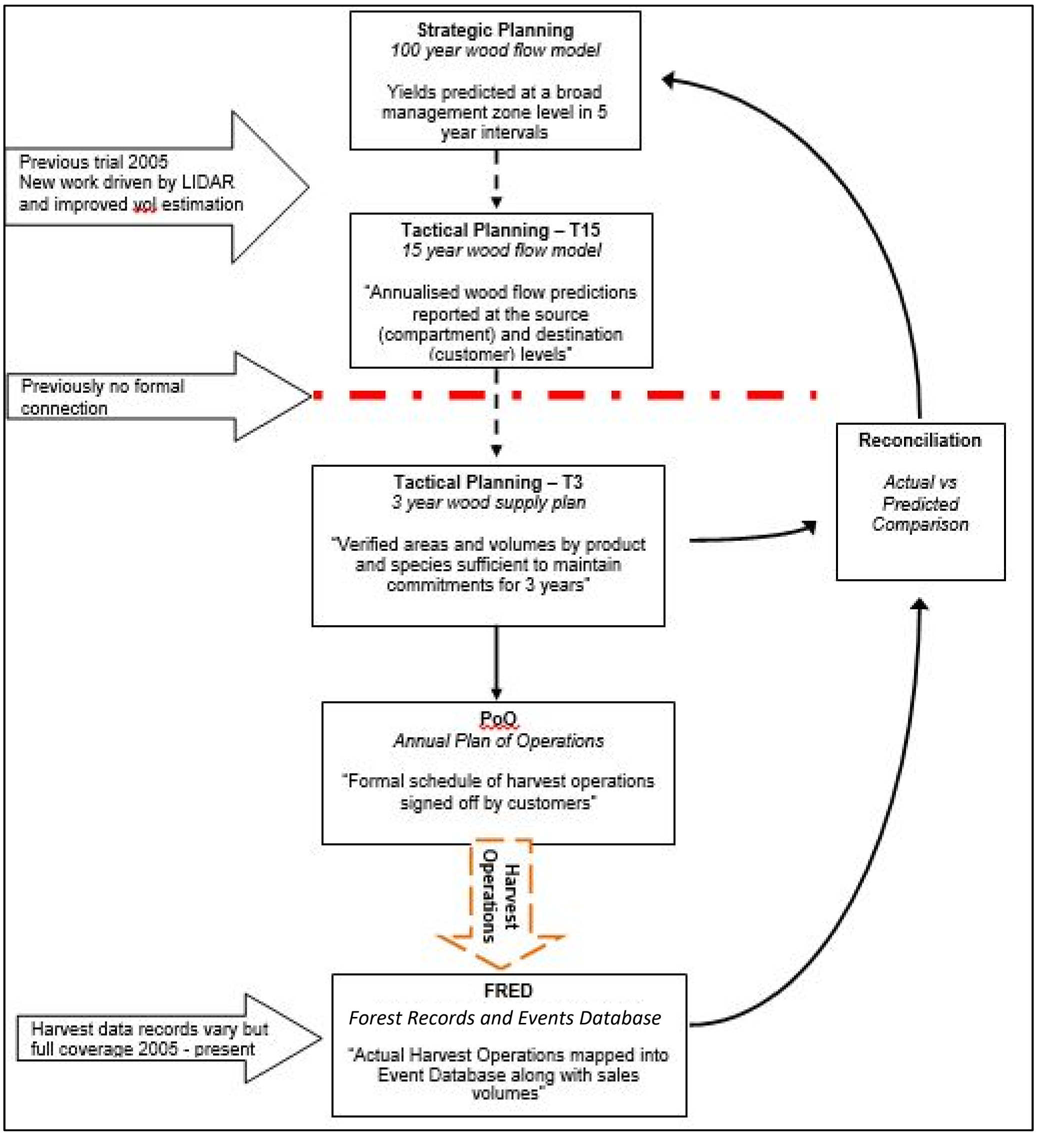



Figure 16. Hardwoods Timber Resource Planning Cycle

## 5.3 Improved integration between LiDAR and yield prediction

FCNSW now has some experience with LiDAR derived plot imputation methods for the generation of yield tables for volume projection. As the cost and analysis times have increased because of the complexities of this analysis, a hierarchical approach will be taken from 2016 to utilise the best available data:

1. High resolution plot imputation where available (section 3.2.4).
2. LiDAR derived stratification (section 3.2.3).
3. Conventional stratified sampling where neither of the first two data sources are available.

These analyses will be integrated into spatial Woodstock models (section 3.4) enabling tactical model formulations that can be exported to GIS for visualisation and field verification.

Challenges remain in how to identify species and merchantability within the highly variable native forest resource using plot imputation results. However, it should be noted that this information is equally difficult to determine from conventional inventory and assessment processes.

Overall, the benefit of incorporating spatially explicit approaches such as stratification and eventually LiDAR-based plot imputation, is that this will bridge the current gap between strategic level forecasts and tactical planning. This will provide many benefits, most notably adding value to operational planning and adding a new dimension of feedback to model performance. The challenge for the business is in coping with the increased volume and complexity of resource information, the increased body of analysis that is required in processing the models, and completing, contrasting and comparing the outcomes with traditional strategic models that underpin current planning.