



Yield Simulator

Upper North East and Lower North East Regions

A project undertaken as part of the NSW Comprehensive Regional Assessments

May 2000



YIELD SIMULATOR

**UPPER NORTH EAST AND LOWER
NORTH EAST REGIONS**

State Forests of NSW

A project undertaken for
the Joint Commonwealth NSW Regional Forest Agreement Steering Committee
as part of the
NSW Comprehensive Regional Assessments
Project number NA14/FRA

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ISBN 1 74029 054 2

This project has been jointly funded by the New South Wales and Commonwealth Governments and managed through the Resource and Conservation Division, Department of Urban Affairs and Planning, and the Forests Taskforce, Department of the Prime Minister and Cabinet

The project has been overseen and the methodology has been developed through the FRAMES Technical Committee which includes representatives from the New South Wales and Commonwealth Governments and stakeholder groups.

The development and implementation of the Yield Simulator project was undertaken by staff of Forest Resources Branch, Forest Policy and Resources Division, State Forests of NSW.

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PROJECT SUMMARY

This report describes a project undertaken as part of the comprehensive regional assessments of forests in New South Wales. The comprehensive regional assessments (CRAs) provide the scientific basis on which the State and Commonwealth Governments will sign regional forest agreements (RFAs) for major forest areas of New South Wales. These agreements will determine the future of these forests, providing a balance between conservation and ecologically sustainable use of forest resources.

This project is one of four modules of the Forest Resource and Management Evaluation System (FRAMES), which was the tool used in CRA/RFA negotiations to calculate sustainable wood flows over time.

Project objective/s

The FRAMES Yield Simulator was developed to provide a computerised system that would predict future growth and timber yields for native forest areas. The system uses quantitative inventory data (from the strategic inventory) as the primary input to the simulation process. The system was also designed to incorporate and be responsive to a range of silvicultural prescriptions and management strategies.

Methods

The simulator project involved the combination of field based harvesting studies and computer software programming. The primary tasks included in the development are:

1. Net harvest area modifiers (determining the physical impediments to harvesting not already captured in GIS data);
2. Tree availability modifiers (determining the level of damage and mortality caused by harvesting events);
3. Tree defect modifiers (determining the difference between standing tree quality and actual harvested log quality);
4. Standardised silvicultural prescriptions (defining the parameters used to model the silvicultural options used in forest management);
5. Computer software development (developing a system to apply the models and prescriptions to data captured in the strategic inventory project - NA04/FRA, summarising the results in a form useable by the strategic scheduling project – NA54/FRA).

Models developed from the above were combined with the Biometrics models (NA13/FRA) to produce the Yield Simulator System.

Key results and products

The Yield Simulator provides estimates of future timber volumes from strategic inventory data in response to a range of silvicultural prescriptions and management strategies. The Yield Simulator incorporates many user-defined variables, which can be used to model a large number of silvicultural and management options, and assess the impact of those options on environmental values over time. Once an acceptable mix of future yield options is obtained for each stratum of the forest, the yield estimates are then combined with area calculations to produce sustainable wood flow projections over time in the Strategic Yield Scheduler.

1. OBJECTIVE

The Yield Simulator was developed to provide a computerised system that would predict future growth and timber yields for native forest areas based on user defined silvicultural prescriptions and management strategies. The system uses quantitative inventory data (from the strategic inventory) as the primary input to the simulation process.

2. SCOPE OF WORK

The Yield Simulator has been developed in Microsoft EXCEL 97. The model has been designed with Visual Basic program code and the system uses the Excel work sheets for inputs (tree data, look-up tables), output data storage, and reporting.

The systems development took approximately 18 months to complete for the UNE and LNE CRA Regions. The project involved the use of three field inventory crews, three professional foresters and additional assistance from district and regional staff. Modifications and the incorporation of localised modifiers will require continued development to cater for the Southern CRA Region.

In writing the final report the authors found that the project does not easily fit into the pre-defined CRA Project Reporting structure. To cater for this difficulty a certain amount of repetition is introduced to the inputs and methods chapters. This facilitates ease of reference to specific subprojects and processes that are incorporated into the Yield Simulator.

The studies and development work that have formed the Yield Simulator have been combined into the first coordinated and standardised approach to growth and yield modelling to be undertaken for a broad spectrum of native eucalypt forests in NSW. To ensure the ongoing relevance and reliability of the system, the processes and outputs are being integrated into State Forests Native Forest Management Information System. The methodologies that have been employed for field studies are also being incorporated into ongoing field management practices.

3. MODELLING APPROACH

The methodology adopted to determine woodflow sustainability in NSW' mixed Eucalypt forests can be divided into four primary components:

1. Measurement (inventory) of the forest resource at a given point in time (FRAMES strategic inventory process);
2. Prediction of future growth and yield for the inventory (yield simulator);
3. Determine the net harvestable area for the resource (FRAMES Net Harvest Area Project); and
4. Combining the yields from the inventory with harvestable area estimates into a woodflow sustainability model (strategic Yield Scheduler).

These processes are presented graphically in Figure 3.1.

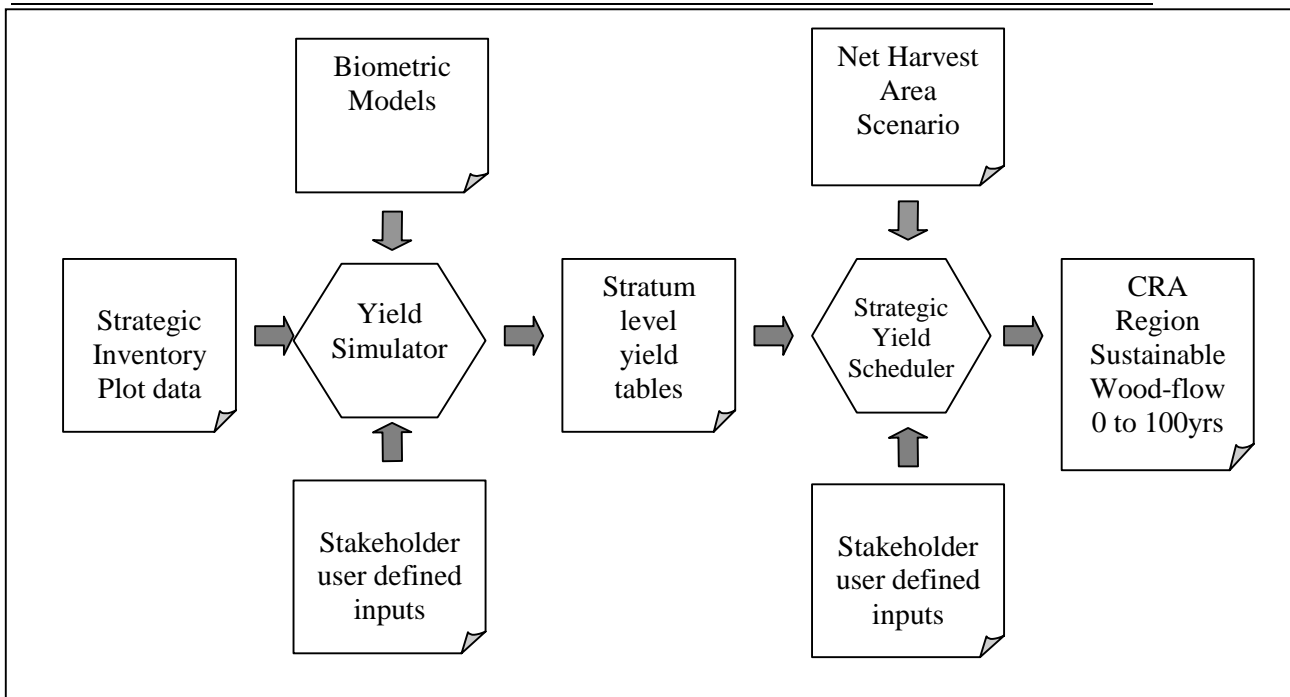
The Yield Simulator provides the link between tree and stand data collected in field inventories and the woodflow sustainability analysis in the Strategic Yield Scheduler. The simulator was designed to provide a reproducible prediction of growth and yield for an inventory stratum, based on user defined silvicultural and management inputs. During the Regional Forest Agreement negotiations, in an iterative process, stakeholders were able to modify these inputs and gain an appreciation of the impact these amendments would have on the yield tables for each inventory stratum.

The Regional Forest Agreement negotiations required the development of a yield modelling system that would be responsive to the needs of a wide range of stakeholder groups. The incorporation of key user defined inputs was therefore a major consideration in the development of a flexible management planning tool. The system was structured so that the modelling assumptions could be clearly identified by the user and the sensitivity of the results to the assumptions easily tested.

The data provided by the Strategic Inventory forms the primary input into the Yield Simulator. To cater for the enormous variation encountered in tree size and frequency distributions in inventory strata, the simulator was designed to model growth at the plot level and on the individual trees present within each plot. Estimates of the plot structure in future years are driven directly by the growth characteristics of the individual trees present and the harvesting strategy selected by the user. The growth process itself is influenced by the dynamics of individual tree diameter increment as well as tree mortality and recruitment. These processes interact on an annual basis throughout the simulation period. The annual growth for each tree within each inventory plot is simulated until the tree either dies from natural mortality, is harvested when it attains suitable timber product specifications, or until the 100 year planning horizon is reached.

This tree level modelling methodology overcomes a potential weakness of stand based modelling (as used in the Interim Assessment Process) where broad assumptions had to be made about the structural classification of strata and how stand structure changes with successive harvesting over time.

FIGURE 3.1: LINKAGE BETWEEN THE YIELD SIMULATOR AND THE STRATEGIC YIELD SCHEDULER



The Yield Simulator’s primary output is the “Yield Table” which reports the expected per hectare timber yields when managed according to defined silvicultural harvesting prescriptions. Because of the long modelling horizon (100 years) and the strategic nature of the woodflow determination process, the simulator reports yield information in five yearly intervals.

A yield table represents temporal estimates of future yields of volume by broad quality class. The yields are tabulated in cubic metres per hectare over time for uneven aged native forests. Yield tables are one of the primary inputs to the yield scheduling process, which are discussed separately in the FRAMES Strategic Yield Scheduler report.

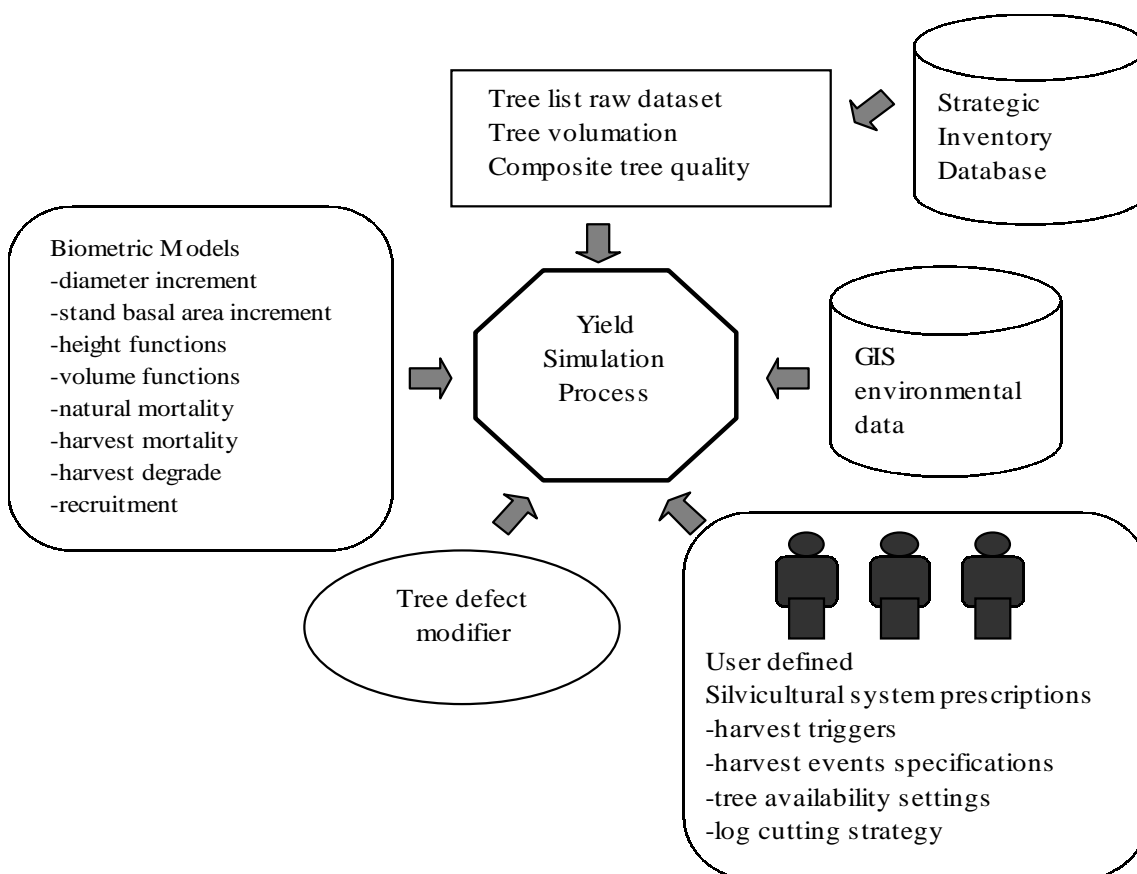
4. KEY INPUTS

The key inputs into the Yield Simulator project are:

1. Strategic Inventory data;
2. GIS environmental data for strategic inventory plot locations;
3. Biometric models for volumation, growth, mortality and recruitment;
4. Tree defect modifiers;
5. Silvicultural prescriptions; and
6. Net harvest area modifier data.

The relationships between these inputs (except net harvest area modifiers) are presented in Figure 4.1. When the Yield Simulator project proposal was written, it included a Net Harvest Area Modifier sub-project. While the net area study was undertaken as part of the Yield Simulator development, the modifications to harvestable area are incorporated as inputs to the Net Harvest Area Query program. Section 5.1 details the net area modifier study results.

FIGURE 4.1: KEY INPUTS TO THE YIELD SIMULATOR



4.1 STRATEGIC INVENTORY DATA

The FRAMES Strategic Inventory provides the primary data source for the FRAMES Yield Simulator. The two key inputs derived from the inventory plots are:

4.1.1 Tree List

The tree list contains the raw plot data imported into the Yield Simulator as EXCEL tables. The raw dataset for UNE and LNE regions has 1,719 inventory plots containing over 74,000 tree observations. The plot data contains the following attributes used in the simulation process.

Plot-level variables:

- Stratum identifier
- Plot number
- Site height
- Distance to filter strip (measured if ≤ 50 m)
- Environmental Variables (see Section 4.4)

Tree level variables:

- Tree number
- Species code
- Diameter at breast height over bark (DBHOB)
- Dominance class
- Crown quality class
- Hollow status
- Logging impediment status
- Composite tree quality code

All tree level variables except the composite tree quality code are directly assessed/measured in the field and are defined in the “Strategic Inventory Field Manual”. The composite tree quality class is a derived variable calculated from the detailed MARVL format tree descriptions recorded in the field. The full tree description cannot be used for temporal modelling because features like branches, scars, stem sweep, lumps and bumps will change with tree growth.

The composite quality code provides a ‘whole of tree’ quality classification. The derivation of this code is summarised in Table 4.1. The method for calculating volumes using this methodology is described in the following section.

TABLE 4.1: RULES FOR COMPOSITE TREE QUALITY ALLOCATION

Tree Quality Class	Classification Rules
H	At least 5 metres of high quality wood (class A) in one contiguous section of the tree.
L	Not capable of being classified as H but has at least 3.6 metres of combined high quality wood and low quality wood (class A, B) in one contiguous section of the tree.
P	Not capable of being classified as L but has at least 3.6 metres of combined high quality wood, low quality wood and pulpwood (class A, B, P) in one contiguous section of the tree.
W	Not capable of being classified as P.

4.1.2 Tree volumation proportionment tables

In order to extract the full value from the detailed tree quality descriptions recorded in the strategic inventory, detailed analysis was performed with the MARVL inventory system software. The analysis was required to provide accurate assessments of the merchantability of trees in the inventory data. This key strategic inventory output categorised trees based on yield association groups, composite tree quality classes and tree diameter (dbh). The analysis used the product determination methodology described in the Strategic Inventory Final Report and MARVL Documentation.

The output of this analysis was a series of tables that could be used by the yield simulator for determining the proportions of each timber quality category contained in a tree (based on its current size, composite quality classification and the yield association group with which it is associated). A sample of the table is presented in Table 4.2.

TABLE 4.2: TREE VOLUME PROPORTIONMENT TABLE EXAMPLE FOR HIGH QUALITY MOIST BLACKBUTT

COMPOSITE QUALITY	DBHOB CLASS (mm)	PROPORTION OF LARGE HIGH VALUE	PROPORTION OF SMALL HIGH VALUE	PROPORTION OF LOW VALUE	PROPORTION OF PULP	PROPORTION OF WASTE
H	100-150	0.0000	0.0000	0.0000	0.0000	1.0000
H	150-200	0.0000	0.0000	0.0000	0.3939	0.6061
H	200-250	0.0000	0.0000	0.0000	0.8351	0.1649
H	250-300	0.0000	0.2824	0.0000	0.5881	0.1295
H	300-350	0.0000	0.5934	0.0000	0.2821	0.1245
H	350-400	0.0000	0.6537	0.0034	0.2101	0.1328
H	400-450	0.0668	0.5315	0.0209	0.2238	0.1571
H	450-500	0.2928	0.2537	0.0795	0.2310	0.1429
H	500-550	0.4226	0.1448	0.0974	0.2194	0.1158
H	550-600	0.3920	0.0173	0.1826	0.2219	0.1861
H	600-650	0.4119	0.0128	0.2011	0.1980	0.1762
H	650-700	0.4744	0.0000	0.1856	0.1796	0.1603
H	700-1000	0.4597	0.0025	0.1778	0.2063	0.1538
H	1000+	0.4870	0.0000	0.1186	0.2180	0.1764

4.2 GIS ENVIRONMENTAL DATA

The biometric models use a combination of tree and stand variables as well as environmental parameters such as rainfall, temperature, slope, soil depth, soil fertility, topographic position, solar radiation and Prescott moisture index. The values for these environmental variables are obtained from GIS spatial layers. Inventory plot locations are intersected with these layers and a point coverage is created with the environmental variable values for each plot.

4.3 BIOMETRIC MODELS

A brief overview is provided on each of the Biometric Models used in the Yield Simulator. For more information refer to the Biometric Models Project Final Report (February 2000) for details on model forms and development methodologies.

4.3.1 Height functions

The height prediction model predicts tree heights initially and then after diameter increment simulations in the Yield Simulator. The height prediction model was developed from the large strategic inventory dataset, based on the relationship between tree species, diameter (dbhob) and tree height.

4.3.2 Volume functions

Volume functions are used to predict the total volume for each tree modelled in the simulator. The equations predict the underbark stem volume for a tree using the species, dbhob and height variables.

4.3.3 Diameter increment models

Diameter Increment Models are used to predict the growth in tree diameter (dbhob) over time. A total of 52 tree level diameter models (for 13 broad species groups) were developed for the UNE & LNE CRA Regions. These models predict the diameter increment for a wide range of environmental, tree and plot variables, and represent the best available functions for northern NSW.

Tree dominance was identified as a significant variable in predicting diameter increment, although dominance is difficult to predict beyond 20 years or after the first harvest event. Two sets of diameter increment models were developed, models including the tree dominance variable were used for the prediction of diameter growth for all plots until a simulated harvesting event was triggered or for a maximum of 20 years. Diameter growth simulated after a harvest event or after 20 years of simulation was based on a diameter increment model without the dominance variable.

The lack of soil variables for inventory plots below the Hunter River in LNE CRA Region required the development of an additional set of models that could be applied without soil information.

4.3.4 Stand basal area models

Stand basal area growth models were used after 30 years of simulation to condition the combined growth of individual trees. If after 30 years the sum of individual tree basal area growth exceeds the predicted total basal area increment, then the tree diameter increments were proportionately redistributed back to a level that equals the predicted stand growth. Conditioning of long term growth patterns was used to ensure unusual stand conditions or tree combinations did not cause unexpectedly high growth rates.

4.3.5 Recruitment model

The recruitment model is split into two parts, a function that predicts the probability of recruitment occurring and a second function that predicts the number of recruits likely to occur. The combined model is applied annually within the growth module to determine the amount of regenerated 'ingrowth' of new trees into the 10cm–15cm DBHOB size class. The recruitment model was developed from permanent growth plot data and is based on the relationship between recruitment and stand structure (the number of stems in diameter class <30cm).

Trees recruited to a stand need to have species, timber quality and dominance information allocated. This is done with a monte-carlo simulation methodology where the attributes are linked to proportions found in the original stratum. The distributions of these variables are calculated in the simulation initialisation routine. This methodology assumes that the inventory plots retain similar species and quality distributions over the simulation period.

In addition to the modelling of natural regeneration, the Yield Simulator also provides for manual recruitment over-ride. This option reflects the routine practice of enrichment planting in some forest types in UNE and LNE regions.

4.3.6 Natural mortality model

The tree mortality function was derived to model the natural death of trees from non-catastrophic natural events (ie. tree maturation, suppression, competition, pests and diseases). This function reflects the natural thinning processes within a stand based on the evidence obtained from PGP data. Analysis of the PGP data indicated that over 75% of natural stand mortality occurs in the smaller diameter classes (<18cm dbhob), therefore, the larger the tree, the greater the probability of survival. Without this function the inventory plots would develop abnormally high stocking rates (stems per hectare).

4.3.7 Harvest mortality model

This model predicts the likelihood that a tree will be unintentionally destroyed during a simulated harvesting operation. The probability that a given tree, within a given quality class, will be destroyed during harvesting is a function of tree diameter, total stand basal area, intensity of harvesting (ratio of harvested basal area to total basal area) and topographic slope of the location.

In the harvest mortality model, trees were grouped into three tree quality classes to express the relationship between merchantable value of a tree and the probability that an individual tree will be destroyed during harvesting (the general trend shows large high quality trees have the lowest probability of harvest mortality).

4.3.8 Harvest degrade model

Harvesting and other silvicultural treatments cause some damage to trees remaining in the residual stand and resulting in a downgrade in merchantable value (degrade). This model determines the probability that a tree will not be degraded (ie. downgraded in log quality) during a simulated harvesting. The probability of harvest degrade is a function of tree quality class, overtopping basal area, tree size (dbhob) and topographic slope of the inventory plot. The probability that a tree will not be degraded during harvesting was modelled rather than predicting the probability of degrade, particularly for high quality trees because there was not enough data to fit logistic functions.

4.4 TREE DEFECT MODIFIERS

The tree defect modifier study was undertaken to determine the differences between predicted product volume estimates and actual harvested product volumes. The predicted volumes are from the Strategic Inventory MARVL volumation and these are compared with the actual harvested product volumes as recorded by State Forests log sales system (FORSALE). This difference is termed 'regrade' and is expressed as a percentage of the volume estimates. The regrade occurs when tree product volume estimates made by an inventory crew differ from the actual log products cut by the logging crew.

Variations in the estimation of product volumes by inventory methods are often due to hidden internal wood defects not detectable in a standing tree. Defects can result from a range of factors: deterioration associated with age; injury from damage agents such as insects, fire, wind and harvesting events; and fungal infections associated with insect borers or branch occlusion processes. Defects reduce processing efficiency and the desirable properties and value of the final wood products to varying extents. Often these defects are not identified until the tree is felled, the logs are cut, and internal defects can be seen in cross-section. Defect assessment is by a standardised log grading method which compares defect measures to an agreed industry standard. These standards are called Compulsory Utilisation Schedules and are used to grade logs into a range of products based on species, diameter, length and maximum allowable internal and external defects. Appendix 1 describes the tree defect modifier study methodology.

4.5 SILVICULTURAL PRESCRIPTIONS

The yields predicted by the Yield Simulator are closely linked to the silvicultural strategy adopted. Silviculture involves the manipulation of forest stands to achieve a desired forest structure and composition. This may be done for a range of objectives such as inducing successful regeneration of a new forest crop, achieving adequate or enhanced growth potential of existing trees, improving forest health and vigour, regulating and maximising production of specific timber products or maintaining ecological diversity within a forest. Because different stakeholders vary in their opinion of what constitutes a desired outcome, it was necessary to build flexibility in silviculture selection into the Yield Simulator.

The silvicultural options provided in the Yield Simulator were developed with the assistance of an expert panel of State Forests field foresters. The panel included internal staff with recognised expertise in forest silviculture and harvest planning. Members of the ESFM and FRAMES Technical Committees were also consulted separately. In a series of workshops this panel reviewed silvicultural management practices employed within the UNE/LNE Regions and considered the terms of reference of the RFA process. The panel delineated two basic management options that are required including:

“Group Selection” which imposes a clear spatial pattern to harvest events, and
 “Single Tree Selection” which focuses on tree features rather than spatial patterns.

With these two silvicultural tools, stakeholders are able to quantify the impact of the key forest management mechanisms and explore the impacts of options that range from low intensity sawlog only harvesting through to intensive practices with full pulp market availability.

Having outlined the silvicultural framework required the panel then identified the quantitative forest features required to represent silviculture within the simulation environment. This process addressed the classification of stand maturity, the objectives of harvesting and finally the constraints required to limit harvesting activity.

The stand parameter inputs identified as providing the most appropriate mechanisms to trigger, prioritise and constrain simulated harvest events are summarised below. Detailed descriptions are provided in Section 5.3.

4.5.1 Single tree selection silvicultural input types

When should a harvesting event occur?

- Minimum high quality volume per hectare required to trigger a harvest event
- Minimum diameter of logs that can contribute to the high quality volume threshold
- Minimum harvest return time in years

How intensive will the harvesting event be?

- Maximum percentage of basal area to be removed
- Minimum standing basal area to be retained
- Maximum low quality and pulpwood threshold volume to be removed per hectare
- Maximum percentage of high, low, pulp and waste trees to be removed in 20cm diameter classes

Which trees should not be available for harvesting?

- Retention of trees with a physical or logistical impediment to harvesting
- Retention of trees with a filter strip prescription impediment to harvesting
- Retention of trees likely to contain suitable wildlife hollows

What are the log product specifications (log cutting strategy)?

- Selection of strategy from a combination of minimum log length for high quality large logs and either small end or centre high quality large diameter.

What kind of tree regeneration do we expect?

- dominance classification (i.e. dominant, co-dominant, subdominant & suppressed)
- species determination
- timber quality classification
- How much time does regeneration take to reach the recruitment size (10-15cm)
- Minimum regeneration stocking threshold required before manual planting is triggered
- Minimum stocking level to be attained through manual planting

4.5.2 Group selection silvicultural input types

When should a harvesting event occur?

- Minimum high quality volume per hectare required to trigger a harvest event
- Minimum diameter of logs that can contribute to the high quality volume threshold
- Specific return time between gapping events (in years)
- Allow or bypass pre-gapping whole-stand first and/or second thinning
- Allow or bypass “on-gap” first and/or second thinning
- Minimum standing volume and basal area per hectare required to trigger a first or second thinning event

How intensive will the harvesting event be?

- Percentage of net area removed in each gapping event
- Specify the size (diameter) of individual gaps
- Number of gapping events required to harvest the net area
- Specific return time between gapping events (in years)

Which trees should not be available for harvesting?

- Retention of trees with a physical or logistical impediment to harvesting
- Retention of trees with a filter strip prescription impediment to harvesting
- Retention of trees likely to contain suitable wildlife hollows
- Retention of a proportion of the net area for habitat trees and gap dynamics limitations

What are the log product specifications (log cutting strategy)?

- Selection of strategy from a combination of minimum log length for high quality large logs and either small end or centre high quality large diameter.

What kind of tree regeneration do we expect?

- How much recruitment (trees/ha) will populate the gaps
- dominance classification (i.e. dominant, co-dominant, subdominant & suppressed)
- species determination
- timber quality classification
- How much structural improvement (the proportional increase of co-dominant trees) is expected as a result of gap size
- How much time does regeneration take to reach the recruitment size (5-10cm)

4.5.3 Determination of silvicultural input values

Having outlined the list of parameters required to simulate silvicultural systems, default input values were required to be assigned to each stand variable used. The State Forests Silvicultural panel reviewed data from actual harvest events to complete this process. As a range of intensities are presented in the system, the panel needed to review field practices and determine specifications that ensure both biologically successful and environmentally acceptable implementation. Refinement was added by providing separate input parameters for different species/site quality groups. The combinations used are summarised in Table 4.3.

TABLE 4.3: YIELD ASSOCIATION GROUPS USED IN THE YIELD SIMULATOR

Full Association Description	Code Reference
Moist Blackbutt	Moist BBT
Moist Coastal Eucalypts	MCE
Semi Moist and Taller Dry Eucalypts	Semi Moist+Taller Dry
Moist Tableland Eucalypts	Moist Tablelands
Dry Eucalypts Types	All Dry Types

4.6 NET HARVEST AREA MODIFIER

The net harvestable area as calculated from mapped exclusions differs from the net harvestable area mapped from actual harvesting events. The area modifier attempts to express this difference as a proportion (%) of an area that will be harvested based on the geo-spatial features present.

The inputs to the analysis were created by unioning the GIS datasets listed below. The resulting combined dataset is structured to allow the calculation of a modifier equation that correlates geo-spatial and environmental variables with presence/absence of harvesting.

- a) Soil regolith
- b) Rainfall erosivity isopleth
- c) Slope
- d) Yield Association Code
- e) Distance to nearest filter strip buffer boundary¹
- f) Locality code (CRA Region, SF Name, SF No., Compartment No.)
- g) PMP Code
- h) Forest type Code
- i) Wood Resources Inaccessibility Class
- j) Harvesting Study Code (from API work)

Distance to filter strip boundary for the study compartments was measured from the actual drainage mapped from the aerial photographs. When the study results were translated to the entire CRA region, the modifier equation used modelled drainage. This was necessary as neither LIC drainage or actual drainage was available for the entire CRA regions.

¹ For the UNE/LNE study compartments, filter strips were generated using a standardised 20metre buffer on each side of the API observed drainage features.

5. METHODS AND RESULTS

The Yield Simulator subprojects are briefly outlined below. Detailed reports are appended. The methodologies for the development of the Strategic Inventory database and the Biometric Models are provided separately in their relevant final reports both dated August 1999.

5.1 NET HARVEST AREA MODIFIER SUB-PROJECT

This project involved the detailed analysis of recently harvested compartments in order to understand and develop land use models that incorporate the key physical factors that limit harvesting in native forest areas. The following paragraphs summarise the methodology employed and the key results of the study. A full project report is included in Appendix 2.

Aerial photographs of 59 recently harvested compartments were analysed in order to determine the full spatial extent of harvesting. Unlogged areas were analysed in detail to determine the reasons why harvesting did not occur. This information was digitised to a GIS polygon cover with the objective of determining relationships between the absence of harvesting and stored GIS features. The list of features that were used in the modelling exercise is included in the analysis dataset described in Section 4.6.

The aerial photography was captured at 1:15,000 scale, with harvest area information being recorded to the ½ hectare level off the photos. The standardised list of harvest study codes that were used to classify all polygons delineated from the interpretation work is listed in Table 5.1. As areas that were not harvested potentially had more than one reason for exclusion, all assessed reason codes were tagged to the polygons.

TABLE 5.1: POLYGON CODES USED IN THE FRAMES NET AREA STUDY

Net Area Study Polygon Type	Code Used in GIS
Harvested Areas	H
PMP Exclusion	P
Rainforest (non-harvestable forest types)	R
Steep	S
Rock and/or Inaccessible	I
Old Growth	O
Flora Protection	F
Fauna Protection (Animals)	A
Filter Strip Extensions (Creeks)	C
Pre-merchantable (Tiddlers)	T
Unmerchantable	U
Harvesting Logistics	L
Supervisor Error	E
Unsure – no reason	?

A summary of the findings from the study is presented in Table 5.2. The terminology adopted to present the results is described below.

Gross Area: Gross area is defined as the total area within the fifty-nine study compartments that had full stereo photo coverage, was given a meaningful harvesting code (ie. Not including slithers which were apparent as a result of overlaying separate GIS layers) and was identified as Native Forest Estate and not Eucalypt plantation².

Net Mapped Area (NMA): Net Mapped Area is the remaining component of the gross area after polygons with following characteristics have been removed:

- polygon slithers with an area less than 0.1 m²,
- slope > 30°,
- within 20 metre buffer of “API mapped” drainage features,
- areas categorised as physically or economically inaccessible (WRS Class 3),
- areas categorised as non-harvestable in State Forests Preferred Management Priority (PMP) System,
- areas with unproductive forest types (based on State Forests Research Note 17 forest typing).

The Net Mapped Area defines the mapped or theoretical area available for harvesting based on available GIS information.

Net Loggable Area (NLA): The Net Loggable Area is a step down from the NMA based on information found in the harvest planning, actual harvesting or post-harvest API process that precluded harvesting from occurring. The NLA excludes polygons with the following features:

- Eucalypt plantation (Forest Type 218H),
- Areas marked during the harvesting event as being within a non-harvestable PMP classification (P),
- Rainforest [R],
- Old Growth (O),
- Flora or Fauna protection reserves (F,A),
- Pre-merchantable and Unmerchantable forest (T,U),
- Areas unable to be harvested because of logistical reasons (L),
- Areas not logged due to supervisor error (E),
- Areas where no harvesting occurred and which had no clear reason for non-harvesting (?).

TABLE 5.2: SUMMARY OF ANALYSIS OF 59 HARVESTED COMPARTMENTS

Land Classification	Area (ha's)	Percentage
Gross Area of Study Compartments – GA	11,257	100%
Net Mapped Area – NMA	6,501	58% (b/a)
Net Harvestable Area – NHA	4,326	38% (c/a)
Net Logged Area – NLA	3,244	75% (d/c)
Area Logged Outside NHA	138	4% (e/d)
Net harvestable area not harvested	1,082	25% (c-d/c)
Areas not logged in NLA primarily due to filter strip protection	581	53% (g/f)

² As identified by the Forest Type Code 218H (refer Forestry Commission NSW, Research note 17).

The analysis shows that State Forests planning tools and pre-harvest field inspections identified 6700 ha's that would not be harvested (60% of the gross area of the study compartments). However harvesting was only able to access 3,245 hectares, leaving a further 1300 theoretically harvestable hectares still unlogged. The factors restricting harvesting from those areas are physical limitations including unmapped rock or inaccessibility (harvest study code I), steep areas (harvest study code S) and filter strip extensions (harvest study code C).

The net area modifier analysis draws on relationships between the presence of harvesting within the net loggable area and five GIS modelled features (slope, regolith, erosivity, forest height and distance to filter strip). The analysis was completed after the logging and feature data were converted to a 25 metre grid surface. The grid surface linked the binomial (presence/absence of harvesting) variable to each GIS feature. The modifier variable was calculated as the ratio of net harvested area to net loggable area for each feature set combination.

Regression analysis was used to create a statistically valid model representation of the trends. The final model selected took the form: The Predicted Modifier = $(\text{sine}(\text{prop}))^2$ where:

$$\text{prop} = 0.557359 + 0.153338 * \text{soil1} - 0.249989 * \text{soil2} + 0.493694 * \text{rain2} + 0.469514 * \text{rain3} + 0.477297 * \text{slope1} + 0.336660 * \text{slope2} + 0.096938 * \text{slope3} - 0.095263 * \text{ya1} - 0.418808 * \text{dist1} - 0.191666 * \text{dist2} - 0.069234 * \text{dist3}$$

This model was based on 249 observations and had the following fit statistics: $R^2=0.68$; Mean bias=-0.0046; and RMSE=0.210. The variables presented and analysis technique are described in more detail in the Net Area Modifier project report is included as Appendix 2.

A second model was subsequently required which represented a scenario of allowing trees to fall in the filter strip extension areas ("buffer on buffer" areas). This scenario was created by copying the original analysis dataset and converting any harvest study polygon with a single code "C" to a code "H" (areas not harvested purely because of their proximity to filter strips were assumed to be harvested).

The New Model also took the form: The Predicted Modifier = $(\text{sine}(\text{prop}))^2$ where:

$$\text{prop} = -0.166102 + 0.682980 * \text{soil1} + 0.313405 * \text{soil2} + 0.552480 * \text{soil3} + 0.506652 * \text{rain2} + 0.586655 * \text{rain3} + 0.554068 * \text{slope1} + 0.397549 * \text{slope2} + 0.169486 * \text{slope3}$$

The second model had the following fit statistics: $R^2=0.73$; Mean bias=-0.0040; and RMSE=0.186. This model was fitted using 255 observations.

It is important to note that areas excluded from the net loggable area were clipped from the analysis dataset and therefore did not influence (or bias) the modifier model. Only physical features (I,S,C) were present to influence the area modifier analysis.

In summary the net area study showed that only 74.99% of the study area that was mapped in the Net Loggable Area was harvested. In the scenario where filter strip extensions (ie areas that were not harvested because of the risk of trees falling into the actual filter strip) were assumed to be harvested the proportion of net loggable area that would be accessed increased to 88.41%. The "real" impact of slope accounts for the majority of unlogged areas within the NHA (the differences between actual slope and GIS modelled slope less than 30 degrees).

The milestone for this project was the modifier equations presented above. To apply the models into the FRAMES System, 25 metre grid surfaces were created for the full spatial extent of the UNE and LNE CRA regions. These grid surfaces held the attribute data required for the model (GIS modelled slope, soil regolith class, rainfall erosivity class, forest height category and distance to filter strip boundary). A net area modifier value was then calculated for each grid cell. The resulting values which ranged between zero and one represent the proportion of the grid cell likely to be accessed in a harvest event. The “modified” area of a grid cell is calculated by multiplying the area of the cell by the proportion factor. This equation is demonstrated below.

25 by 25 metre Grid Cell Area (ha's)	Modifier Value	Modified Area (ha's)
0.0625	1	0.0625
0.0625	.75	.046875
0.0625	.42	.02625
0.0625	0	0

To calculate the modified net area of a polygon, the modified grid cell areas within the polygon are summed together ie:

$$\text{Modified Polygon Area Estimate} = \sum (\text{Grid Cell Modified Area's})$$

Note that if a grid cell (or a polygon) is already excluded from harvesting due to other mapped reasons, for example rainforest, slope > 30°, drainage filter strip, then the modified area estimate is ignored and the net harvestable area remains as zero. The modifier information is only applied to cells/polygons that are inside the net harvest area.

The CRA final report for the “Application of protective measures and forest practices into a quantitative database” provides a useful reference on how the full range of GIS coverage's and the net harvest area modifier model are integrated into an automated area reporting system within FRAMES.

5.2 TREE DEFECT MODIFIER SUB PROJECT

Tree defect modifier analysis (also known as timber quality verification study) was undertaken as a sub-project of the Yield Simulator development to calibrate the Strategic Inventory estimates of high quality large sawlogs assessed from standing trees. Key factors that required adjustment and that could not be measured in the strategic inventory include:

- a) Unseen internal defect;
- b) Differences between the volumation methodologies of the inventory and State Forests Sales System;
- c) Utilisation constraints.

Tree defect and utilisation features that are addressed by the study include hollowed pipe, dry rot, closed and open gum veins, gum pockets, lumps along stem, spiralled grain, pin-hole gum veins, wood staining, sweep, scars and branches.

The defect modifier inventory calibration was completed by analysing the differences between the inventory product volume estimates of a sample of standing trees and the actual “on truck” product volumes of those same trees after harvesting. The defect assessment was carried out across a range of yield associations, structure classes and Management Areas. The sample trees were chosen in selected compartments during licensed harvesting operations underway from June to October 1997. The defect modifier study incorporated results of measurements of over 700 trees. The full sub-project report is included as Appendix 1.

The MARVL inventory system was used as the basis for visually assessing stem quality of standing trees in the Strategic Inventory (Refer to the Strategic Inventory Final Report, July 1999, for a full description of the MARVL inventory system). The defect study followed trees assessed by MARVL through the harvesting process. The study team tracked the trees as they were serviced into products, graded and measured using the standardised log measurement method as set out in State Forests' Hardwood Log Measurement manual. Details of cut log lengths, large end, small end and centre diameters and defect core were recorded for trees at the log dump.

The pre-harvest data was processed by the MARVL Version 3 system in the same way as the Strategic Inventory plots were analysed. The post-harvest log data was volumated using the State Forest log sales system software (FORSALE). A comparison of results enabled the determination of correction factors that reflect the differences between the two techniques.

The difference between the MARVL product volume estimates and actual FORSALE product volume is termed 'regrade'. Where the volume regrade was found to be significant (the two means were found to be significantly different the 95% confidence level) the correction factors (modifiers) were applied. Data was sampled for the study across six yield associations. A summary of the results is presented in Table 5.3.

TABLE 5.3: SUMMARY OF TREE DEFECT MODIFIER DATA FOR LARGE HIGH VALUE LOGS

Yield Association Group	No of sample trees	Sum of MARVL volume (m ³)	Sum of FORSALE volume (m ³)	Actual (FORSALE) as a % of MARVL	Significant at 95% level	Final Modifier
1. Moist Blackbutt	29	76.53	58.35	76.2	Yes	76.2
2. Moist coastal Eucalypts	106	247.83	207.33	83.7	Yes	83.7
3. Semi-moist and taller dry Eucalypts #1	77	99.75	108.43	108.7	No	100
4. Dry Blackbutt and Spotted Gum	194	254.06	167.43	65.9	Yes	65.9
5. Dry sclerophyll Types #2	0					65.9
6. Moist tableland Eucalypts	118	196.9	104.46	53.1	Yes	53.1
7. Dry tableland Eucalypts	49	72.97	30.69	42.2	Yes	42.2
Combined Summary	622	1021	707	69.3		

Note:

#1 Because of non-significance no modifier was used for this Yield Association Group.

#2 Because no data was sampled results for Dry BBT and Spotted Gum were adopted.

The results identify that on average the FORSALE log merchandising system records only 70% of the large high value volume estimated by the MARVL inventory system. The differences vary between yield association types, ranging from a low of only 42% in the dry tableland types up to just over 100% in the semi-moist and taller dry eucalypt types. The second extreme was encountered in a yield association where the field assessors were tending to visually downgrade the standing trees which were in fact able to cut high quality logs at the log dump.

Although the defect study recorded information about all products assessed and harvested, the results were not possible to extrapolate for the non-HQ sawlogs. This was primarily due to the following factors:

1. Access to markets for alternative timber products (high quality smalls, low quality salvage logs, pulp etc) is varied and inconsistent. Some operations did not have certain product markets so would cut all non-sawlogs to salvage timber. Others were sometimes forced to waste timber that could be sold in other areas.
2. Although HQ small log and salvage markets did exist for some of the localities, we found that the product specifications varied. This meant that it was not possible to compare results in a meaningful way.

The defect modifiers calculated in this project were integrated into the Yield Simulator volumation process. Any raw estimate of high quality large volume was adjusted down by the proportion calculated for trees in that yield association group. The high quality large volume downgrade was automatically re-apportioned with 50% going to the low quality timber category and 50% going to pulpwood.

5.3 SILVICULTURAL PRESCRIPTIONS

An outline of the silvicultural prescription requirements of State Forests is well summarised in the ESFM project report #4 – Descriptions of silvicultural systems. Norm Hawkes, June 1998.

“ The selection of an appropriate silvicultural system which uses harvesting ... [is aimed at]... inducing the successful regeneration of a new forest crop or achieving adequate or enhanced growth potential, health and vigour, or ecological structural diversity within the treated stand. The selection of a silvicultural system or treatment depends on consideration of the following factors:

- *objective of management of the stand*
- *present stand conditions*
- *required future condition*
- *seed-bed requirements*
- *seed-source requirements*
- *site-specific environmental constraints*
- *rotation age*
- *cutting cycle phase and length*
- *available timber and/ or timber products*
- [environmental constraints]
- [presence or markets within economic distance]

Based on this paper, there are 7 silvicultural options identified which impact on the forest structure and composition, and determine future wood yields:

- spacing (non-commercial thinning)
- commercial thinning
- single tree selection
- group selection
- shelter-wood system
- alternate coupe harvesting
- clearfell (intensive harvesting)

The final suite of silvicultural options provided in the Yield Simulator was developed with the assistance of an expert panel of State Forests’ field foresters. The panel included internal staff with recognised expertise in forest silviculture and harvest planning. Members of the ESFM and FRAMES Technical Committees were also consulted. In a series of workshops this panel reviewed silvicultural management practices employed within the UNE/LNE Regions and considered the terms of reference of the RFA process. The panel identified that there are two basic silvicultural options that can be used to provide the required outcomes.

Single Tree Selection (STS)

This is a silvicultural system involving the periodic selective harvesting of individual or small clusters of commercially mature trees. Single tree selection silviculture is applied to stands where the wood productive condition of the stand is maintained from the management of a mixed structure. Harvesting removes trees that have achieved an economic maturity that is not likely to be exceeded by additional net increment at the next harvest return. Harvesting also removes trees that promote growth onto other retained trees in the immediate vicinity.

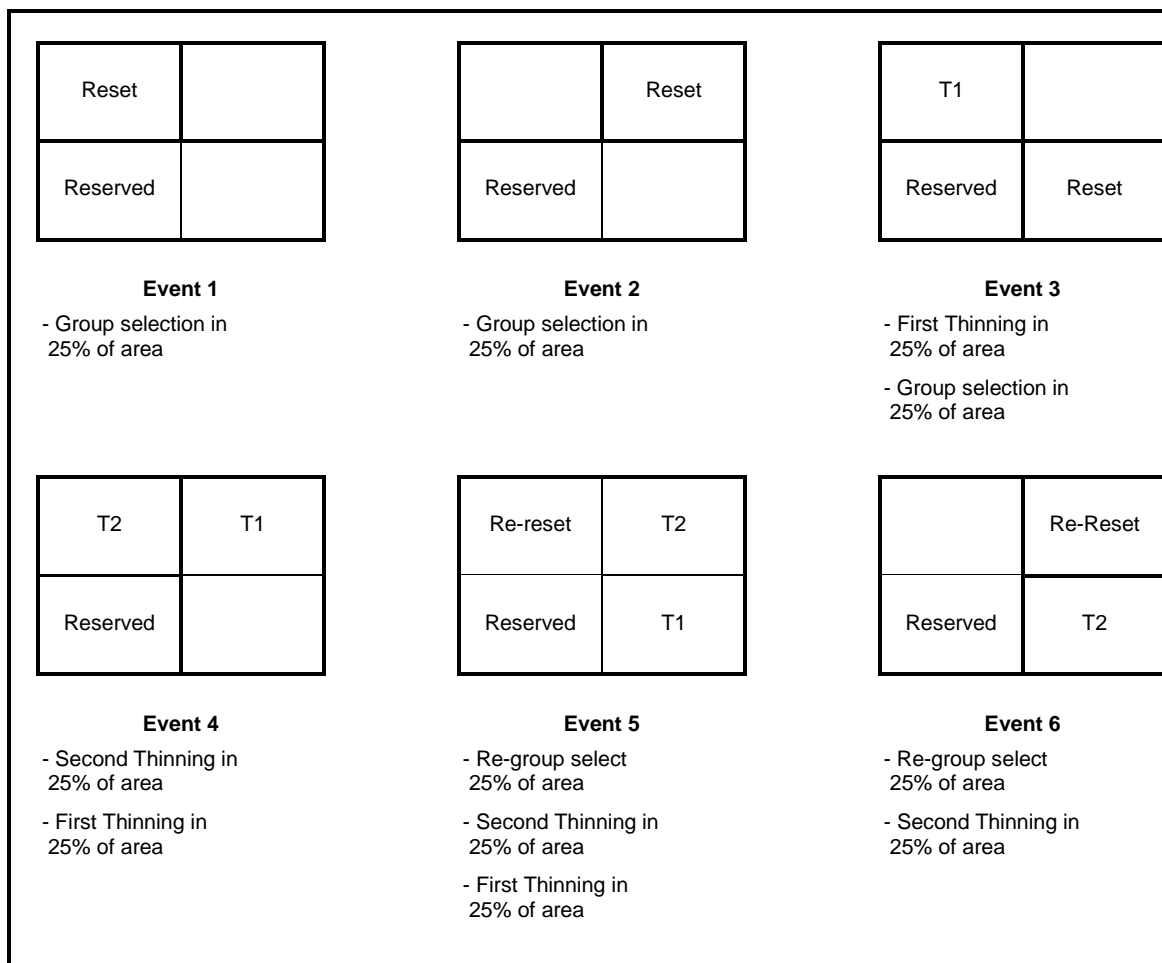
Australian Group Selection (AGS)

Group selection is a harvesting system where a management unit is progressively harvested as small clusters of even aged groups of trees in a staggered sequence over time. Group selection silviculture is applied to stands where the wood productive condition of the stand is maintained or enhanced from the management of small randomly located groups of trees. This silviculture employs harvesting rules that set a spatial pattern to tree removal and retention. Within spatially harvested groups, harvesting periodically thins the stand by removing trees from below until removal of the final crop trees and subsequent re-establishment of the group.

Group selection is initiated through the harvesting of mature elements of a stand into fully cleared gaps. Ideally the gaps are circular with diameters ranging from 40 to 100 metres (Florence – Ecology and silviculture of Eucalypt Forests, 1996). After a given period of years the compartments are revisited and adjacent gaps (not necessarily immediately adjacent, but within the same area) will be created. At each return visit for a management unit, the previously formed gaps (older regenerated trees) are evaluated in terms of their suitability for thinning to promote growth on the larger better form trees and remove smaller less desirable trees. These gaps are then thinned if required. Eventually over many decades, once the sequence of gaps has been established across the whole area, the initial gaps will have reached a point of maturity when they will be reset again and the whole cutting cycle will be repeated. The result of this silvicultural system is an uneven aged forest comprised of even aged small gaps.

An example of the cycle of harvesting events that could occur in group selection management is diagrammatically presented in Figure 5.1. Although in reality the harvested gaps would be randomly distributed through the harvest area, for visualisation purposes in this example, they have been “squeezed” together to represent a single block.

FIGURE 5.1. DIAGRAMMATIC REPRESENTATION OF THE CHRONOLOGICAL SEQUENCE OF HARVESTING EVENTS IN GROUP SELECTION



Having outlined the silvicultural framework to be used the State Forests panel then identified the quantitative forest features required to represent silviculture within the simulation environment. This process addressed the classification of stand maturity, the objectives of harvesting and finally the constraints required to constrain harvesting activity.

The stand parameter inputs identified as providing the most appropriate mechanisms to trigger, prioritise and constrain simulated harvest events are described below.

The parameters are divided into the following categories:

- Harvest triggers;
- Harvesting events;
- Tree availability;
- Log cutting strategy; and
- Regeneration recruitment

5.3.1 Harvesting triggers

Harvest trigger variables are present to specify when the stand is classified as mature and ready for harvest. This mechanism involves the simulated growth of each inventory plot until it meets the merchantability/maturity conditions that trigger a harvest event (i.e. can satisfy the minimum and maximum constraints).

Single Tree Selection

A STS harvest event will be triggered if the following parameters are met:

- *Minimum HQ large volume for harvest*
This parameter specifies the minimum harvestable large high quality volume that must be present to justify a harvest event.
- *Minimum Diameter for HQ large volume for harvest*
Specifies the minimum diameter (at breast height) for the large high quality trees that can be used in the calculation of HQ large volume.
- *Minimum retained Basal Area*
Specifies the minimum stand basal area that must be retained in the harvest event. The large high quality volume must therefore be available in trees where the basal exceeds the minimum specified here.
- *Minimum harvest return time*
Specifies the minimum number of years that must elapse in the simulation environment between any two STS harvest events.

Australian Group Selection

An AGS gapping event will be triggered if the following parameters are met:

- *Minimum HQ large volume for reset*
Specifies the minimum harvestable large high quality volume that must be present for the initial reset operation.
- *Minimum Diameter for HQ large volume for reset*
Specifies the minimum diameter (at breast height) for the trees that can be used in the calculation of 'High Quality large volume'.
- *Return time between two gapping events*
Specifies the number of years that must elapse between reset gapping events.

Thinning options are available as part of the suite of tools available within the AGS silviculture system. These include whole of stand thinning events (1st and or 2nd thinning) undertaken before gapping is initiated (available for even aged regrowth stand structures), and “on gap” thinning operations. The on gap thinning events are available for the regrowth that is modelled to grow on the gaps after the reset operation has occurred. The thinning operations are triggered if the following parameters are met:

- *Allow or Bypass any first thinning (T1) operation*
True/False flag that switches on or off the program loop that allows first thinning events to proceed.
- *T1 Retained Basal Area*
Specifies the minimum total basal area that must be retained in the first thinning event that occurs in gapped areas. The retained stand consists of the largest high quality trees present.
- *T1 Volume Required*
Specifies the minimum volume required to trigger the first thinning event. The volume is made up of any products except waste.

- *Allow or Bypass any second thinning (T2) operation*
True/False flag that switches on or off the program loop that allows second thinning events to proceed.
- *T2 Retained Basal Area*
Specifies the minimum total basal area that must be retained in the second thinning event that occurs in gapped areas. The retained stand consists of the largest high quality trees present.
- *T2 Volume Required*
Specifies the minimum volume required to trigger the second thinning event. The volume is made up of any products except waste.
- *Minimum HQ large volume for re-reset*
Specifies the minimum harvestable large high quality volume that must be present to trigger the resetting or re-gapping operation on already gapped areas.
- *Min Diameter for HQ large volume for reset*
Specifies the minimum diameter (at breast height) for the trees that can be used in the calculation of high quality large volume for the next and subsequent reset operations in gapped areas.

For AGS, it may also be desirable to undertake stand level thinning of even aged regrowth areas before gapping operations are commenced. By default even aged small regrowth areas, referred to as E1 stands (strata 1-4), are permitted to have first and second stand level thinning (T1 and T2). Large regrowth areas, referred to as E2 stands (strata 5-10), are assumed to have had no thinning and are permitted to have a delayed first thinning (DT1) only. The following thinning controls allow the user to specify these thinning prescriptions.

- *E1 - T1 Retained BA/ E1- T2 Retained BA*
Specifies the minimum basal area that must be retained in pre-gapping thinning events for E1 structure classes.
- *E1 - T1 Volume required / E1 - T2 Volume Required*
Specifies the minimum volume required to trigger a thinning harvesting event in E1 structure class. The volume is made up of any products except waste.
- *E2 - DT1 Retained BA*
Specifies the minimum basal area that must be retained in the pre-gap delayed first thinning operation in E2 structure stands.
- *E2 - DT1 Volume Required*
Specifies the minimum volume that must be present in E2 structure stands to trigger a delayed first thinning event. The volume is made up of any products except waste.

5.3.2 Harvesting events

Once a harvest event is triggered the simulator then removes a number of the trees randomly selected according to the constraints and targets imposed.

Single Tree Selection

The options available for defining the STS harvesting event are based on stand basal area, product class volume, diameter class, hollow presence and logging impediment parameters.

- *Remove no more than ()% of basal area*
Single Tree Selection silviculture can be modelled for three harvest intensities: light, moderate and heavy. Rules are applied to limit the proportion of the original stand basal area that is removed for each of these intensities. These proportions can be modified by the user, however the default settings are:

Light	Remove no more than 20% of the standing basal area
Moderate	Remove no more than 30% of the standing basal area
Heavy	Remove no more than 40% of the standing basal area

These harvest intensities ensure that number of trees harvested is constrained by a maximum level of stand basal area that can be removed at any one harvest event.

- *Do not cut LQ, Pulp trees if LQ, Pulp volume is greater than ()*
This parameter allows the user to specify an upper limit for the number of non-high quality trees that are to be harvested. The variable is used to stop harvesting of non-HQ trees in the harvest simulation if the event has already yielded the specified limit of combined low quality and pulp volume. A maximum harvest volume for low quality products is set to ensure that unmanageable volumes of low quality products are not produced. If market opportunities existed for low value products it is unlikely that STS would be the preferred silviculture system to adopt.
- *Maximum percentages removed by diameter class*
The maximum percentages table (see Table 5.4) enables the user to specify harvest removal proportions for different tree qualities and size classes. Each cell in the table represents the proportion of trees in that quality/diameter class that are targeted for removal in a harvest event. The overall harvesting process is prioritised in the order from the cell referenced with (a) though to (p). A simulated harvest event continues removing trees in this order until the proportions are achieved or the stand level constraints are met.

TABLE 5.4: EXAMPLE OF MAXIMUM PERCENTAGES REMOVED BY DIAMETER CLASS

Dry Yield Associations				
Tree Quality	Maximum Percentages Removed by Diameter Class			
Type	10-30cm	30-50cm	50-70cm	70cm+
High Quality	0% (d)	20% (c)	80% (b)	80% (a)
Low Quality	0% (h)	80% (g)	80% (f)	80% (e)
Pulpwood	0% (l)	0% (k)	0% (j)	0% (i)
Waste	0% (p)	0% (o)	0% (n)	0% (m)

In this example it is assumed that pulpwood and waste are not deliberately harvested in Single Tree Selection (STS) although some pulpwood and waste products will arise as a by-product when harvesting for higher value products.

Australian Group Selection

Under Australian Group Selection, the simulation algorithm creates a separate gapping group (cohort) for each gapping event specified. The algorithm is initiated by growing each plot forward until the first reset harvest trigger criteria is met. A harvest event is triggered at that point with the yield that is generated being simulated by applying the proportion of area harvested to the total standing volume present. This first set of gaps simulated now represent Gapping Cohort 1. The harvesting event then triggers the simulator to model even-aged regrowth management on the gaps created. A temporary yield table is created for the even-aged management that occurs on the gaps (first thinning, second thinning and re-resetting). The yields in the temporary table are applied to the cohort on a cyclic basis, until the end of the simulation is reached.

To simulate Cohort 2, the original plot data is grown on from the first gapping event until the specified gapping return time. The second reset harvest is then simulated with the yields being calculated in the same way as for cohort 1 (including the “on-gap” even-aged regrowth yields that can be applied from the temporary yield table calculated when cohort 1 was initiated). The yields for cohort 3 are calculated by growing the original plot data further through time until the gapping return time is reached again. Each un-gapped cohort will be progressively grown one return time interval longer than the previous. The following simple matrix illustrates how a hypothetical plot might be treated if divided into 6 gapping events (ie. 6 cohorts).

Gap	Simulation Period										
Cohort	0	1	2	3	4	5	6	7	8	9	10
1	reset			T1		T2		re-reset			T1
2		reset			T1		T2		re-reset		
3			reset			T1		T2		re-reset	
4				reset			T1		T2		re-reset
5					reset			T1		T2	
6						reset			T1		T2

The matrix shows that the reset for each cohort is dependent on when the first cohort is capable of being harvested. The T1, T2 and re-reset operations following creation of gaps by reset will follow the same pattern. This results in a working circle of groups of different relative maturity.

The harvest events that follow a stand “reset” by gapping may comprise two thinning operations before another “reset”. These thinning operations are not group selection but "thinning from below" for T1 and from "below and beside" for T2. Thinning from below selects the smallest, least dominant and lower composite quality class codes to be removed. The selection of trees within a particular diameter / dominance / quality class is conducted on a random basis, rather than selectively picking the best to worst. Minimum residual basal areas ensure retention of adequate growing stock. There is no explicit specification for high quality in residual BA because the thinning operation targets lower quality trees, leaving predominantly higher quality trees remaining. All plots of the same yield association (regardless of initial structure class) following reset are no longer classified by structure class, and follow the same standard silvicultural regime of T1, T2, reset operations. The user has the option to switch off (by-pass) thinning events.

The yield per hectare (and period) for each strata is calculated by summing the extracted timber volumes for the cohorts (adjusted for the relative proportion of area in each cohort), adding these to obtain the volume from each plot, and then summing all the plots to provide a strata total yield. Strata total yield is then divided by the number of plots in the strata to derive the overall yield per hectare. The annual yield data is kept as cumulative totals by period.

To model the AGS process the following parameters are quantified for light, moderate and heavy harvest intensities:

- *Gap Size (m)*
Specifies the gap diameters assumed to represent light (40m), moderate (70m) and heavy (100m) harvest intensities.
- *Proportion of net area gapped in a harvest event*
Specifies the percentage of net harvestable area to be gapped in each harvesting reset event
- *Proportion of net area retained from harvesting*
Specifies the percentage of the harvestable area that will be reserved from harvesting operations (never logged) throughout the AGS harvest cycle. This reservation caters for gap dynamics and habitat tree retention requirements.
- *Number of gapping events (ie. no. of groups)*
Specifies the number of return time periods needed to complete the AGS gapping cycle.
- *Gapping event return time (yrs)*
Specifies the number of years that must elapse between gapping events.

An example of a typical AGS prescription for the three harvesting intensities is outlined in Table 5.5.

TABLE 5.5: PREFERRED GROUP SELECTION PRESCRIPTION INPUTS

Variable	Harvesting Intensity		
	Light	Moderate	Intensive
Gap size (m)	40	70	100
Proportion of net area gapped in a harvest event	15%	22.5%	22.5%
Proportion of net area not harvested (retained area)	10%	10%	10%
Number of gapping events (i.e. no. of groups)	6	4	4
Harvest event return time (years)	10	7	5

In light group selection for instance, 15% of the area would be gapped in the first harvest event, then 10 years subsequently another 15% would be gapped. It would take 6 gapping events, or 90 years, before the 90% of the net harvest area is gapped. The retained 10% is not subjected to thinning or reset operations. Under light group selection the forest area is represented by 6 cohorts and 10% of the area retained. The proportion of area left unharvested reflects the fact that, in any gapping sequence, the simple geometry of gaps, retention of advance growth, habitat trees and so on, all combine to leave a proportion of the intended harvest area unharvested over the gapping cycle.

5.3.3 Tree availability control

This control enables the user to make trees unavailable for harvest selection if they have certain tree hollow or logging impediment attributes.

- *retention of trees with an impediment to harvesting*
Each tree in the original Strategic Inventory database contains a logging impediment field indicating whether the tree would be unavailable for harvest due to either a physical impediment or a filters strip retention prescription. This field was coded as follows:

Logging Impediment = 0	(No impediment to logging)
Logging Impediment = 1	(Physical impediment to logging)
Logging Impediment = 2	(Filter strip impediment)

The user can select those impediments that are to be used to exclude trees from the harvest selection process.

- *retention of trees containing wildlife hollows*

Trees in the original Strategic Inventory database also contain a ‘hollows’ field indicating the evidence of suitable wildlife hollows and coded as follows:

Hollows = 0	(No hollows present)
Hollows = 1	(Evidence of hollows present)
Hollows = 2	(More evidence of hollows present)

The user has the option of removing a tree from the harvest selection process based on its hollow status. Hollow status is only present in the original inventory tree list and is not modelled for new trees entering the simulation process.

5.3.4 Log cutting strategy options

The log cutting strategy option allows the user to select alternative high quality product volumation methodologies for use in the simulation process. Each strategy reflects variation in the small end or centre diameter and log length specifications to be used. The five options are summarised in Table 5.6. Each strategy has been developed using the MARVL inventory analysis system (as described in the FRAMES Strategic Inventory Project) and has the format described in Section 4.1.2 (tree volume proportionment tables).

TABLE 5.6: LOG CUTTING STRATEGY OPTIONS

Option	Description
1	34cm sed, 3.6m min length. High Quality Large sawlogs were cut with a SED of 34cm, and a minimum length of 3.6 metres.
2	34cm sed, 2.4m min length High Quality Large sawlogs were cut with a SED of 34cm, and a minimum length of 2.4 metres.
3	25cm sed, 3.6m min length High Quality Large sawlogs were cut with a SED of 25cm, and a minimum length of 3.6 metres.
4	25cm sed, 2.4m min length High Quality Large sawlogs were cut with a SED of 25cm, and a minimum length of 2.4 metres.
6	Revised Standard Cutting Strategy - 40cm cdub, 2.4m min length High Quality Large sawlogs were cut with varied SED and length constraints to reflect 40cm centre diameter under bark, and a minimum length constraint of 2.4 metres. Large high value class Minimum SED (mm) Minimum length (m)
	1 390 2.4
	2 380 3.6
	3 370 5.0
	4 360 7.0
	5 350 9.0
	6 340 11.0

5.3.5 Regeneration recruitment

Recruitment refers to the tree regeneration that enters the simulation environment during the simulation process. The recruitment model (see also Section 4.3.5) is used to predict the occurrence and frequency of natural recruitment trees into the 10 cm DBHOB size. When trees enter the plot population they are randomly allocated a diameter between 10cm and 15cm. However, the dominance class, species and timber quality information that is required for recruitment is determined separately in the following silvicultural prescriptions user defined variables.

- *Proportion of recruitment by dominance class*
Specifies the dominance characteristics of recruitment trees. The default settings in the simulator represent the proportion of trees by dominance class in the current stratum. The proportions of each dominance class may be varied as long as the new proportions total 100%. Note that dominance is a key variable used to model diameter increment in the first 20 years of simulation.
- *Proportion of recruitment by species and quality class*
Specifies the species and timber quality characteristics of recruitment trees. The default settings represent the proportion of trees by species and quality code in the current stratum. These default settings are calculated when the data initialisation routine is run. The user can adjust these proportions if they consider the default mix is unrepresentative.
- *Manual Recruitment Over-ride*
If the number of trees per hectare remains unacceptably low within the given lag time after a harvest event then a manual recruitment "boost" can be triggered. This process simulates routine manual enrichment planting of seedlings after harvesting to maintain site utilisation. The process of selecting the characteristics of individual trees is the same as used in continuous natural recruitment. The following parameters are used to set the manual recruitment prescriptions:
 - *Lag period for harvest to manual recruitment >10cm*
Sets the amount of time required for the planted regeneration to grow into the 10-15cm diameter range.
 - *Trigger stocking level for manual recruitment*
Sets the stocking level (trees per hectare >10cm dbhob) which triggers the manual recruitment routine. Any stand with a stocking less than or equal to the level specified after the lag period has elapsed following a harvest event will trigger the manual recruitment routine.
 - *Stocking Level of Manual Recruitment*
Defines the total number of stems per hectare expected to exist in the stand after manual recruitment. This figure includes both the existing trees and those manually added.

Recruitment processes are modelled differently for STS and AGS systems. In STS prescriptions the recruitment model (see Biometric Models Project) is used to predict both the natural background ingrowth and the accelerated recruitment of new trees following harvesting events.

In AGS prescriptions, recruitment is modelled on the assumption that gap creation produces significantly different conditions for regeneration through the creation of large canopy openings (30 to 100m in diameter). After a gap has been reset, it is assumed that its species composition and density resembles that of an "E1" small even-age regrowth forest. Only trees ≤ 30 cm DBHOB in E1 stands contribute to the recruitment profiles. The environmental variables for the plot are used for the regenerating gaps.

The parameters that differ from STS continuous recruitment are:

- *Number of trees to be recruited per hectare*
Specifies the number of new trees per hectare (stocking) that will populate the reset gap. The default stocking density used to recruit new gaps is based on the average small regrowth (e1) stocking levels for that yield association. The user also has the option of manually altering this number.
- *Lag period for recruitment to reach between 5-10cm*
The time taken for the recruitment trees to be recognised (enter the 5-10cm dbhob range) in the plot varies according to the growth rates of yield association.
- *Species composition and tree quality*
Specifies the species and tree quality class distributions to be assigned to the new recruitment. The composition is determined by assessing trees <30cm DBHOB in the pre-existing E1 structure class of the specific yield association.
- *Assignment factor to adjust the percentage of co-dominants*
Specifies the dominance category distribution to be assigned to the recruitment. The default dominance distribution is determined from the inventory data for the original small regrowth structure class. After a reset operation, the dominance distribution of regrowth in a gap is intended to follow this basic pattern with modifications based on the size of the gaps created (the larger the gap the greater the proportion of co-dominant to sub-dominant trees due to decreased edge effect). The simulator models provides for increasing co-dominance recruitment proportions with increasing gap size:
 - A 40 metre gap size = 20% co-dominance boost
 - A 70 metre gap size = 40% co-dominance boost
 - A 100 metre gap size = 60% co-dominance boost

5.4 COMPUTER SOFTWARE SYSTEMS DEVELOPMENT

The Yield Simulator systems development took approximately 18 months to complete for the UNE and LNE CRA Regions. The application was developed with the Visual Basic programming language using Microsoft EXCEL 97 for data input and output storage/reporting. The Visual Basic code runs the whole simulation process, reading the input data into dynamic arrays, modelling the stand dynamics on an annual basis and reporting yield and stand condition data to formatted output tables.

The FRAMES Technical Committee was responsible for overseeing the system development and their input has contributed to the design and functionality. Internal resource assessment specialists programmed the system. The structure and system environment has permitted the team to improve and upgrade software components as new models or structural refinements are required.

5.5 YIELD SIMULATION PROCESS

This section details the simulation information flow logic used within the Yield Simulator.

5.5.1 Overview

The yield simulator is a computer model that forms part of the Forest Resource and Management Evaluation System. The primary function of the simulator is to generate yield tables that provide information on the future growth and harvested timber yields for native forest areas. The yield tables report the growth and yield information separately for each Strategic Inventory stratum (all data is reported at the “per hectare” level). The yield tables are referred to as “State Databases” and are exported to the FRAMES Yield Scheduler for forest estate sustainability modelling.

The yield simulation process utilises the combination of user-specified inputs and monte-carlo based modelling techniques. The strategic inventory plot and tree level database provides the source and starting point for modelling. The growth of each tree in each plot is annually simulated using a combination of tree and stand level increment functions, mortality and recruitment models.

The simulator incorporates the modelling of two silvicultural harvesting regimes (Australian Group Selection and Single Tree Selection). Within each regime a range of harvesting intensities are also analysed (light, moderate, heavy intensity). Each regime and intensity option is modelled sequentially for the specified simulation length. The user can edit the parameters that influence the silvicultural processes and the harvesting intensity.

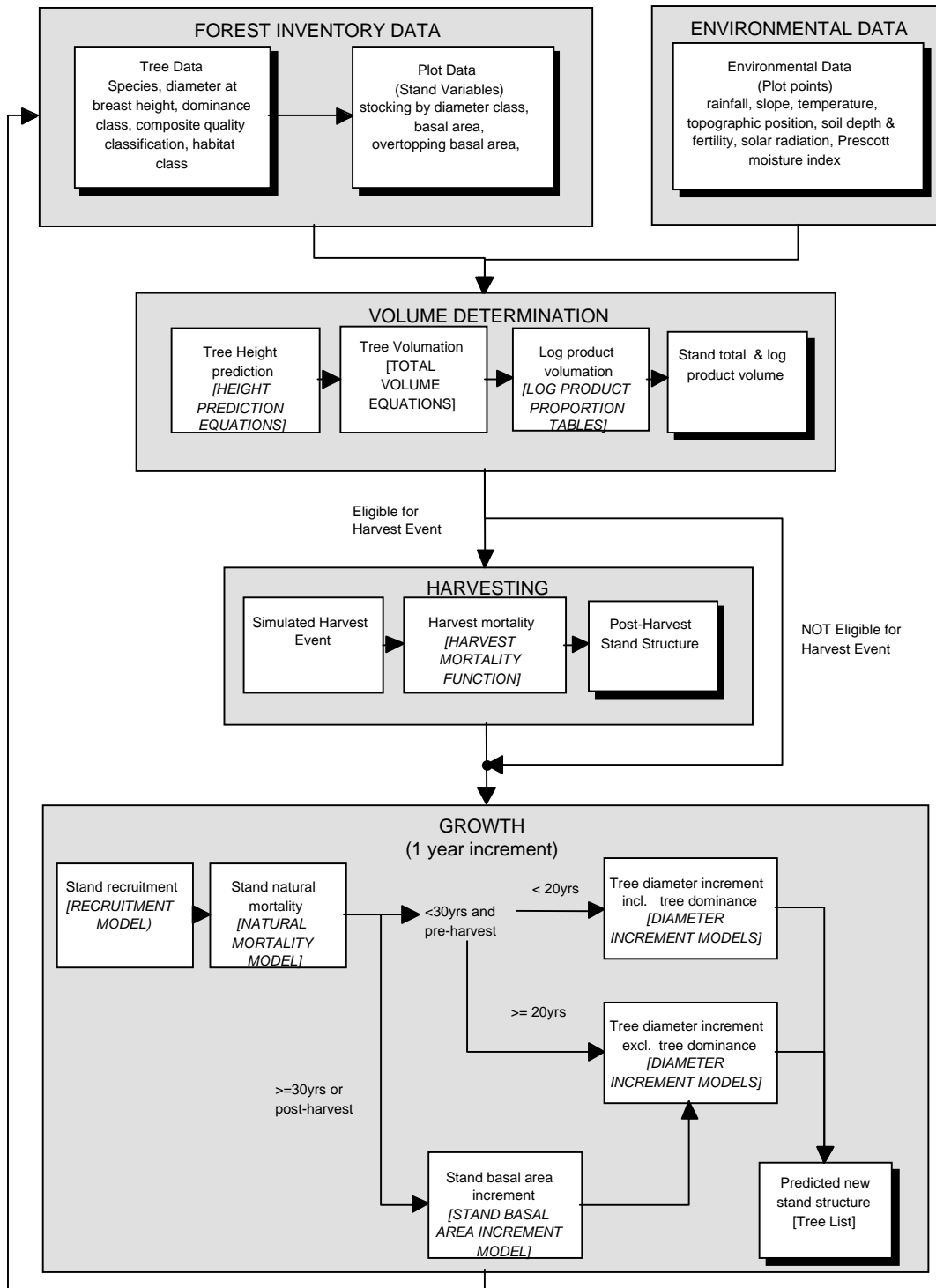
The system models each plot independently in the simulation environment (each plot only contributes yield when it is capable of doing so). This methodology caters extremely well for the dynamics of native forest stratum, allowing the localised plot level maturity to be reflected in the yield tables that are produced. The system also maintains individual trees in the simulation environment, growing them forward year by year using the tree, stand and environmental variables.

Each plot is evaluated on an annual cycle as to its suitability for harvesting. This is done by comparing the plot parameters (volume of different log grades, basal area, and stocking etc) against the specified threshold harvesting inputs (see Section 5.3). If these harvest criteria are met the simulator will remove trees from the plots according to the user defined harvesting prescriptions. Following harvesting, the model simulates tree recruitment, incremental growth and mortality of the retained trees in a plot. This sequence of events is repeated each year of the simulation period defined by the user.

Given the relatively slow growth rates of uneven-aged native eucalypt forests, and the strategic nature of the FRAMES modelling, a planning horizon of 100 years has been incorporated within the simulator. These factors also allow yield reporting to be combined to five yearly periods without sacrificing data integrity. This system structure provides a dataset suitable for representing the resource dynamics in long term strategic level yield scheduling models.

Figure 5.2 provides an overview of the information flow processes incorporated into the yield simulator.

FIGURE 5.2: OVERVIEW OF SIMULATION METHODOLOGY



5.5.2 Growth processes in detail

The sequence of growth processes undertaken in Version 4d is described in Table 5.8. The table describes distinct processes, reflecting the modular design of the system. For example, process 2 in the table refers to determining recruitment. The recruitment sub-process is described in more specific detail in Table 5.9 (processes 2.1-2.9).

A summary of the variables referenced in these descriptions is provided in Table 5.7.

TABLE 5.7: VARIABLE NAMES REFERENCED IN GROWTH PROCESS DESCRIPTIONS

Variable Name	Description
Wt	No. of trees per hectare represented by the current tree record
Dbh	Diameter at breast height of current tree record
SDI1	Stand Density Index One
SPH	Number of trees per hectare (in the plot)
BA	Basal Area (in the plot)
BA_T	Modelled Basal Area Growth (one year)
Pres_ind	Prescott Index calculated as follows: $e = (0.01768 + (0.0007585 * \text{temperature}) - (0.00000605 * \text{temperature}^2)) * (\text{solar} * 120000 / 365.25)$ $\text{Pres_ind} = (0.445 * \text{rain} * 1000) / (e^{0.75})$

TABLE 5.8: PRIMARY LEVEL PROCESSES IN GROWTH SIMULATION

Process No.	Description	Sub-Process Details
	Calculate the initial number of trees per hectare (SPH) and Basal area (BA)	
	Determine recruitment	2.1 – 2.9
	If the basal area is > 2 m ² /ha or there are more than 100 stems per hectare then determine mortality	3.1 – 3.4
	If the simulation year is > 30 and BA > 10 then calculate predicted stand level basal area growth (BA_T)	4.1 – 4.5
	Grow the individual tree diameters	5.1 – 5.5
	If simulation year is > 30 and BA > 10 and BA_T > BA and if the sum of individual tree BA growth is greater than modelled stand BA growth then condition back individual tree diameters to the level that equals BA_T For each tree: Recalculated DBH = (BA_T/BA) * Original DBH	
	Refresh plot level statistics and parameters	

TABLE 5.9: RECRUITMENT MODEL SUB-PROCESS

Process No.	Description
2.1	Read in recruitment function constants: Const a0 = -2.4992 Const a1 = 0.00197 Const a2 = -0.00534 Const b0 = 1.3769 Const b1 = 0.00243 Const b2 = -0.00136 Const b3 = -0.00645
2.2	Sum the number of trees currently in the 10-15cm DBH class (c10_15)
2.3	Sum the number of trees currently in the 15-20cm DBH class (c15_20)
2.4	Sum the number of trees currently greater than 30cm (c30)
2.5	Sum the basal area of trees currently greater than 30cm (p_ba30)
2.6	Probability of no recruitment occurring = $1 / (1 + \text{Exp}(a0 + (a1 * c10_15) + (a2 * p_ba30)))$
2.7	Potential_recruits = $\text{Exp}(b0 + (b1 * c10_15) + (b2 * c15_20) + (b3 * c30))$
Process No.	Description

2.8	If a random number between 0 and 1 is greater than P_no_ingrowth then the number of recruits = Potential_recruits, otherwise the number of recruits = 0.
2.9	A manual recruitment over-ride is employed if the stocking falls below a critical level after a harvest event. The critical level, the amount of planted recruitment and the lag period before the recruitment is imported are all specified on the simulator control panel. Manual Recruitment is calculated with the following formula: If (years_since_harvest = manual_recruit_lag) And (SPH < manual_recruit_trigger) then the number of recruits = manual_recruit_level – SPH

TABLE 5.10: MORTALITY MODEL SUB-PROCESS

Process No.	Description
3.1	Read in mortality function constants: Const a0 = 0.693047 Const a1 = 0.039986 Const a2 = -2.44546 Const a3 = 0.051906 Const a4 = -1.274727
3.2	Calculate relative basal area present: $rel_b = p_ba30 / BA$
3.3	For each tree calculate the probability of survival as follows: $p_survival = 1 / (1 + \text{Exp}(a0 + (a1 * DBH) + (a2 * \text{Log}(DBH)) + (a3 * BA) + (a4 * rel_b)))$
3.4	Tree data is stored in records. A record may represent up to 10 trees per hectare. For each tree in a record a random number between 0 and 1 is generated. If the random number is greater than p_survival then the tree is removed from the record.

TABLE 5.11: BASAL AREA GROWTH MODEL SUB-PROCESS3

Process No.	Description
4.1	Read in Basal Area Model Coefficients for current Growth Group (b0 – b12)
4.2	Sum the current number of trees per hectare present (SPH2)
4.3	Calculate the quadratic mean diameter (QMD) = $(BA / (SPH * pi / 40000))$
4.4	Calculate the stand density index (SDI) = $SPH * ((30 / QMD) ^{-1.605})$
4.5	Calculate Basal Area increment (BA_T) for one years growth: $BA_T = b0$ $BA_T = BA_T + (b1 * BA)$ $BA_T = BA_T + (b2 * \text{Log}(SPH))$ $BA_T = BA_T + (b3 * (SPH / SPH2))$ $BA_T = BA_T + (b4 * QMD)$ $BA_T = BA_T + (b5 * SDI)$ $BA_T = BA_T + (b6 * rain)$ $BA_T = BA_T + (b7 * temperature)$ $BA_T = BA_T + (b8 * slope)$ $BA_T = BA_T + (b9 * position)$ $BA_T = BA_T + (b10 * soil\ depth)$ $BA_T = BA_T + (b11 * fertility)$ $BA_T = BA_T + (b12 * prescotts\ index)$

³ See notes on the basal area growth model.

Notes on Basal Area Growth Model

The following assumptions are imposed on the basal area increment model:

- ⇒ Basal Area growth is not modelled for stands with less than 10m²/ha standing BA;
- ⇒ Basal Area growth is not modelled until after year 30 of the simulation;
- ⇒ Stands are not allowed to shrink – (ie. if the model predicts less basal area than that standing then the basal area growth is assumed to be zero);

TABLE 5.12: INDIVIDUAL TREE GROWTH MODEL SUB-PROCESS⁴

Process No.	Description
5.1	Read in Diameter Increment Model Coefficients for current Yield Association Group (d0 – d19 and cf). Note that dominance influenced models are used for the first 20 years or until the first harvest event, which ever comes first. Non-dominance based model coefficients are selected after this point.
5.2	For each tree undertake the diameter increment calculation: $ldi = d0$ $ldi = ldi + (d1 * dbh)$ $ldi = ldi + (d2 * \text{Log}(dbh))$ $ldi = ldi + (d3 * \text{Log}(\text{plot BA}))$ $ldi = ldi + (d4 * \text{plot BA})$ $ldi = ldi + (d5 * \text{over_topping_BA})$ $ldi = ldi + (d6 * \text{over_topping_BA2})$ $ldi = ldi + (d7 * \text{dominance1})$ $ldi = ldi + (d8 * \text{dominance2})$ $ldi = ldi + (d9 * \text{upper})$ $ldi = ldi + (d10 * \text{central})$ $ldi = ldi + (d11 * \text{lower})$ $ldi = ldi + (d12 * \text{rain})$ $ldi = ldi + (d13 * \text{temperature})$ $ldi = ldi + (d14 * \text{slope})$ $ldi = ldi + (d15 * \text{solar})$ $ldi = ldi + (d16 * \text{position})$ $ldi = ldi + (d17 * \text{soil_depth})$ $ldi = ldi + (d18 * \text{fertility})$ $ldi = ldi + (d19 * \text{Prescotts_Index})$
5.3	Calculate diameter increment = $(\text{Exp}(ldi) * cf) - 1$
5.4	If diameter increment < 0 Then diameter increment = 0
5.5	Calculate new tree diameter (dbh) = old dbh + diameter increment
5.6	Calculate new tree basal area = $(dbh / 200) ^ 2 * pi * .wt$

⁴ See notes on diameter increment model.

Notes on Individual Tree Growth

The following assumptions are imposed on the diameter increment model:

- ⇒ Recruitment grown on group selection gaps have a starting diameter between 5 and 10cm. While these trees remain less than 10cm, the individual diameter growth is based on a 10cm tree;
- ⇒ No tree is allowed to grow backwards (ie. shrink);

The following model specific variables are referenced:

- ⇒ ldi is a temporary variable storing the values from each of the model steps;
- ⇒ $\text{Over_topping_BA2} = \text{Over_topping_BA} / \text{Log}(\text{dbh})$ for each tree;
- ⇒ The dominance variables are allocated as follows:

If the Strategic Inventory Dominance class = 1 or 2 Then dominance1 = 1, otherwise dominance1 = 0

If the Strategic Inventory Dominance class = 3 Then dominance2 = 1, otherwise dominance2 = 0

The upper, central and lower variables are locality flags that describe the management area group for the plot. The flags broadly categorise the resource into UNE-Coastal, mid-north coastal, lower north coastal, Tableland.

5.5.3 Harvesting simulation process in detail

To convey the sequence of data flow and decision processes used for the silvicultural systems within the simulator, a series of information flow diagrams have been prepared. These are at a relatively high level however are designed to give the reader an insight and “second level” overview of the simulator workings. The first of these diagrams (Figure 5.4) demonstrates the information flow path for single tree selection silviculture. Figure 5.5 to Figure 5.7 demonstrate the key processes used for modelling group selection.

The legend describing the shapes used in the diagrams is presented below in Figure 5.3.

FIGURE 5.3: KEY TO INFORMATION FLOW DIAGRAMS

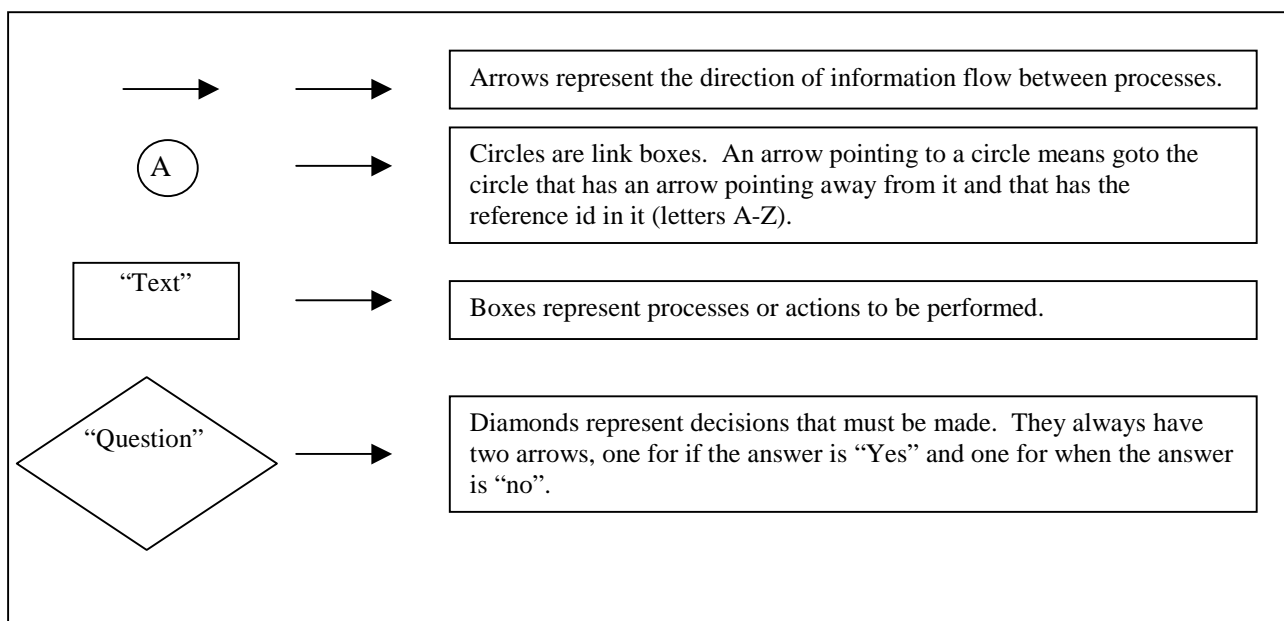


FIGURE 5.4 INFORMATION FLOW WITHIN SINGLE TREE SELECTION SILVICULTURAL SIMULATION

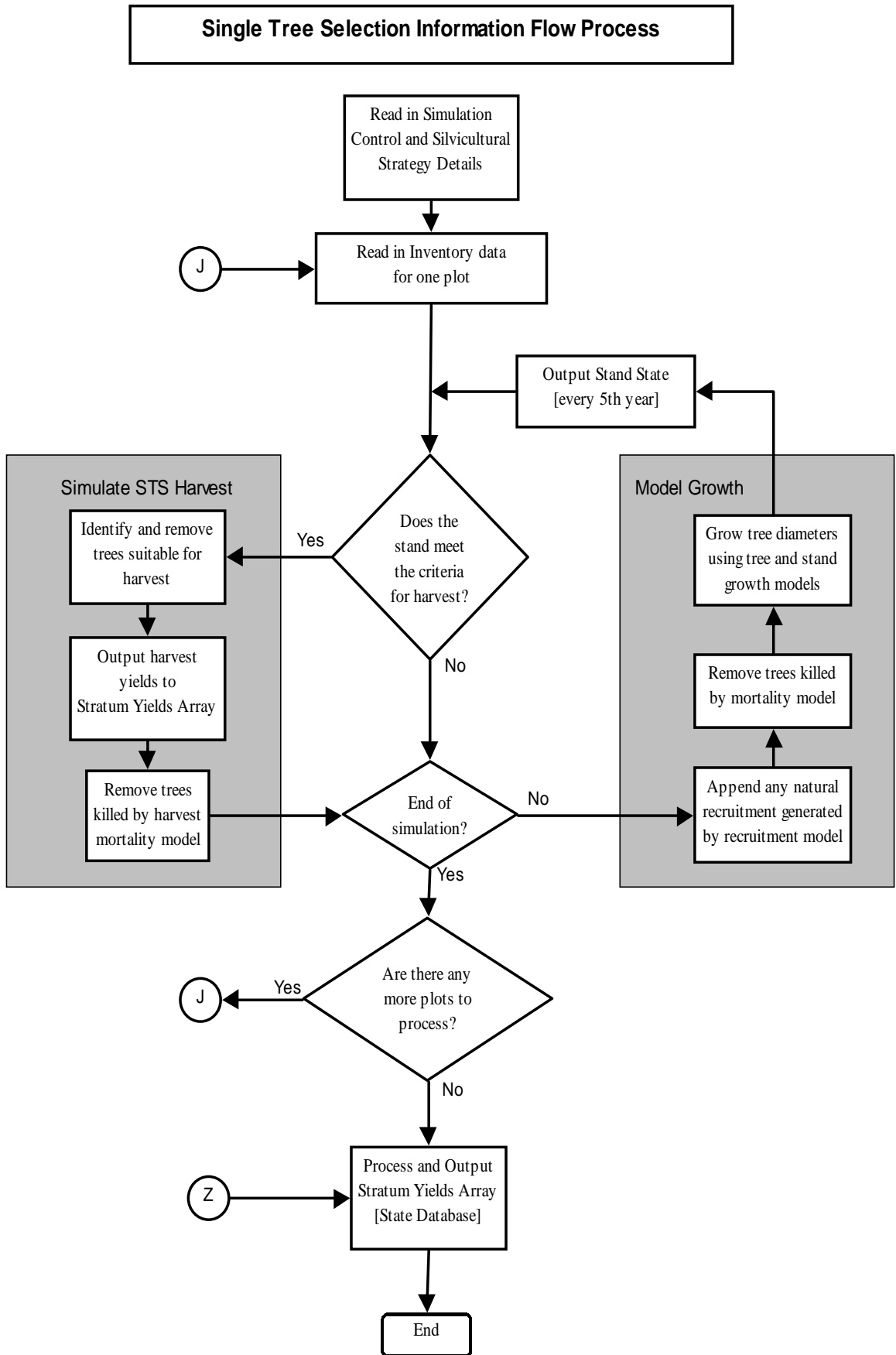


FIGURE 5.5: INFORMATION FLOW WITHIN GROUP SELECTION SILVICULTURE [PART 1]

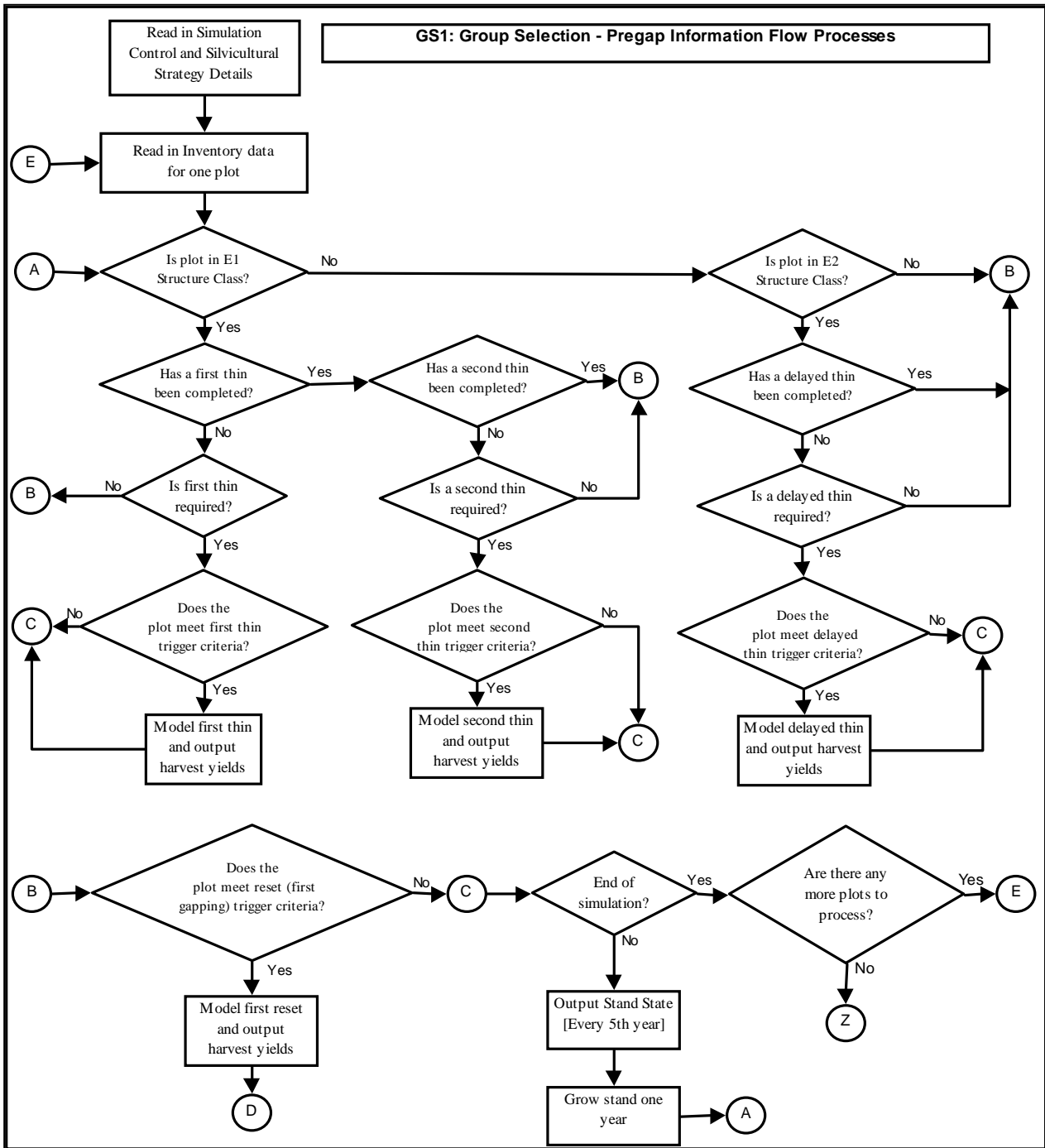


FIGURE 5.6: INFORMATION FLOW WITHIN GROUP SELECTION SILVICULTURE [PART 2]

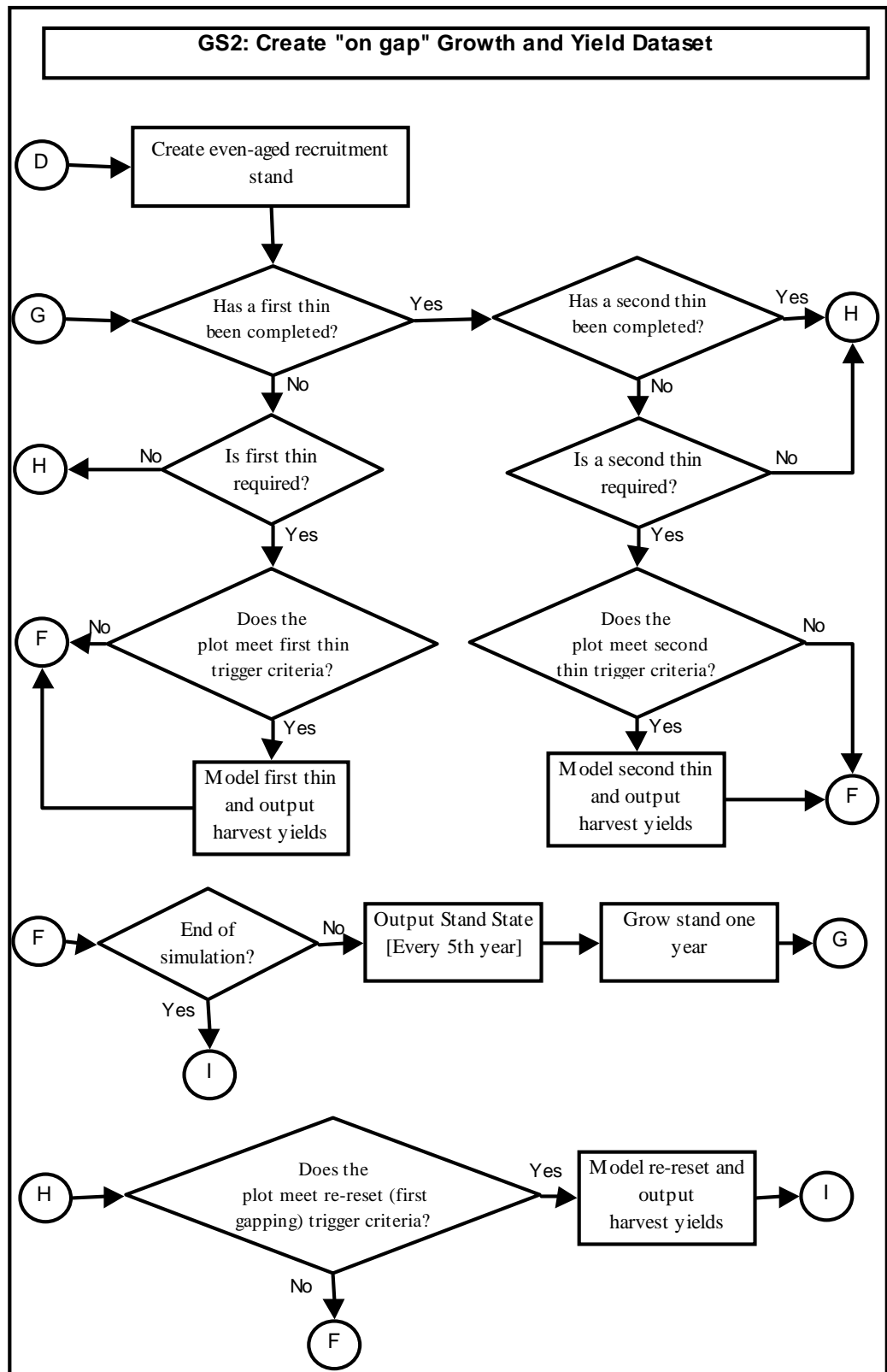
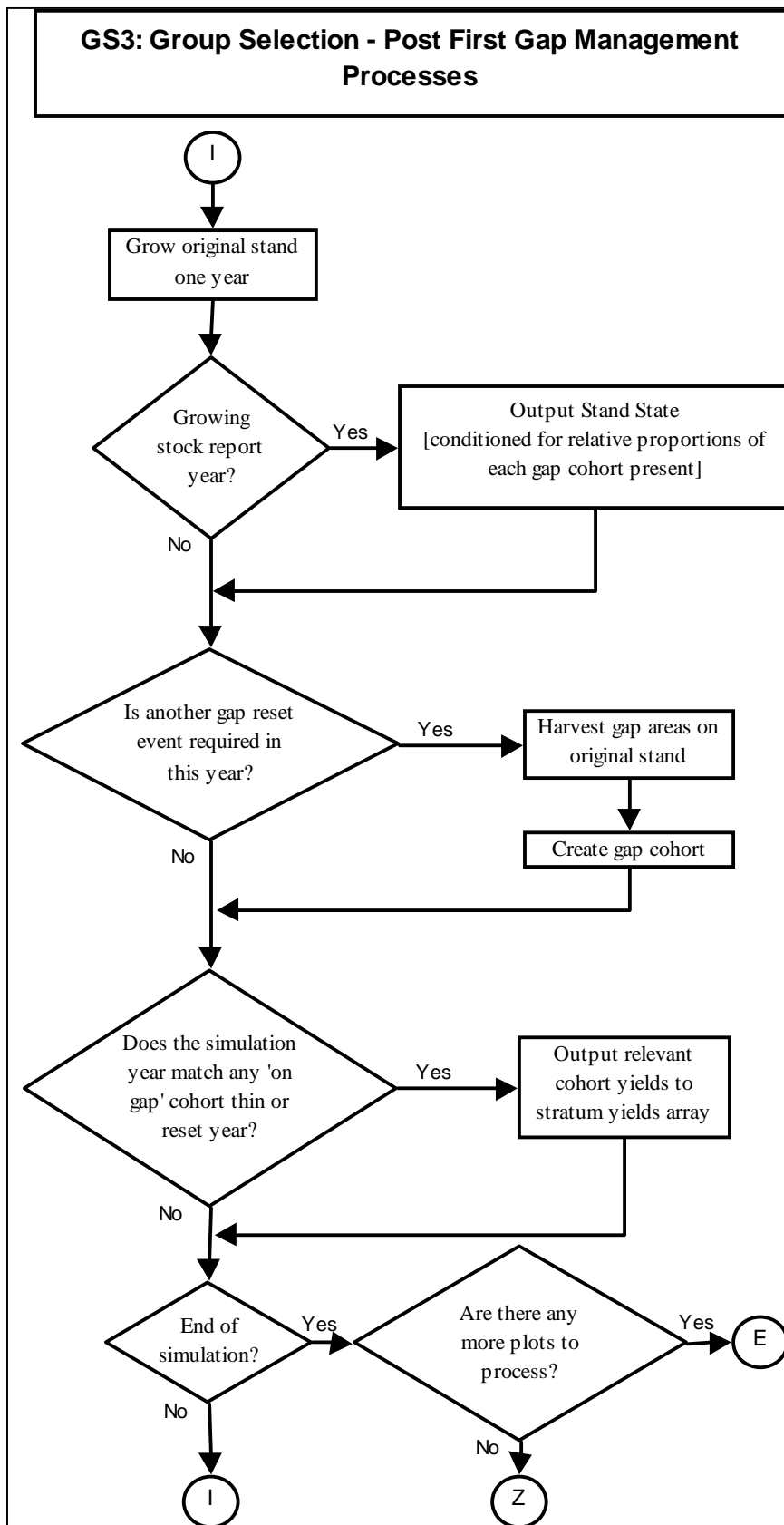


FIGURE 5.7: INFORMATION FLOW WITHIN GROUP SELECTION SILVICULTURE [PART 3]



5.5.4 Interpretation of yield tables

The main output from the Yield Simulator is a dataset referred to as the “Yield Table”. Yield tables are stored in the “State Database” worksheet within the system. A yield table reports the predicted standing and harvested yields of timber from the stratum. Because of the long simulation spans, the table summarises yield data to five yearly intervals. Any given yield table set is specific to the silvicultural prescriptions and harvesting intensities specified in the simulation run.

The “Removed Volumes” columns of the yield table report the modelled harvest event yields for each five year period. Because each plot in the simulator is modelled independently (and only contributes yield when it is mature and able to do so), the harvested yield predictions in some periods may appear very small (many periods may also report no yield at all). The low yield estimates in the table can be the source of some confusion with users because they appear to conflict with the minimum merchantable yield trigger setting adopted for a simulation run. The reasons for the apparent low yields are demonstrated in Table 5.13.

TABLE 5.13: INTERPRETING THE YIELD SIMULATOR STATE DATABASE

Calculating Yields in a Theoretical Stratum					Cell Name	Calculations
Stratum Net Area:	40	(ha's)			a	
No of Plots Measured:	4				b	
Area represented by each plot:	10	(ha's)			c	a/b
<hr/>						
Plot Number	Yield per Hectare by Period (1)					
	1-5	6-10	11-15	16-20		
1	30	-	15	-	d	
2	-	45	-	30	e	
3	18	-	-	15	f	
4	-	-	35	-	g	
<hr/>						
Sum of yields for each period:	48	45	50	45	h	d+e+f+g
Number of plots harvested in each period:	2	1	2	2	j	
Theoretical Prortion of Net Area Harvested:	50%	25%	50%	50%	k	j/b
Theoretical Area Harvested:	20	10	20	20	l	k*a
Average Yield Per Actual Plot Harvest Event:	24	45	25	22.5	m	h/j
Calculated Total Yield:	480	450	500	450	n	m*l
<hr/>						
Average Yield Per Hectare for the Stratum:	12	11.25	12.5	11.25	o	h/b
Calculated Total Yield:	480	450	500	450	p	o*a
<hr/>						
(1) - The simulator stores actual plot harvest yields in the "STS - Harvest Summaries" worksheet.						

In the example provided it can be seen that plot 1 was harvested twice in the first 20 years, the first event occurred somewhere between years 1 to 5 of the simulation, the second event in years 11-15. Plots 2 and 3 also had two harvest events, although not in the same periods, and plot 4 was only harvested once in period 11-15. The yields reported for the plots represent the “per hectare” equivalent yields from the simulated harvest events. It is possible to view all plot level harvest details for single tree selection simulations, these events are reported in the STS-Harvest Summaries worksheet when a simulation is completed.

The example in Table 5.13 shows that only two of the four plots present were harvested in the first 5 years. If these yields are combined, a total yield can be calculated for the period, in this case equalling 48m³/ha (row “h”). When calculating the average yield per hectare for state database, this figure is divided by the total number of plots present, ie. $48/4 = 12\text{m}^3/\text{ha}$ (as shown in row “o”). The result of this calculation is able to be applied to the whole net area of the stratum to demonstrate that 480 m³ of timber is yielded. This is how the yield calculation is applied in the FRAMES Yield Scheduler.

The yield estimate in column “o”, although statistically valid and applicable to the scheduler, is not able to be used to visualise the harvest events involved or compare the estimates with actual harvest event records. In order to undertake these calculations, extra information is required that determines that actual number of plots harvested. In the example this data is recorded in row “j”. Dividing the total yield for the period by the actual number of plots harvested represents an estimate of the “average” harvest event for the period (see row “m”). In the example a total of 2 plots were “actually” harvested in the 1st five years, resulting in $48/2 = 24\text{m}^3/\text{ha}$ being reported for the period (row “m”).

As plots were randomly allocated across the stratum, it is possible to assume that having 50% of the plots harvested means that 50% of the net area was harvested (each plot represents an equal part of the net area). To prove that this methodology presented is valid, the calculation of total volume is completed by multiplying the average yield for the harvest events (row “m”) by the theoretical area harvested (row “l”). The result of 480m³ (row “n”) is the same as the stratum total calculated in row “p”.

In the version of the Yield Simulator used for the UNE and LNE negotiations (Ver 4d), the information required to calculate average harvest event yield estimates must be calculated manually from the plot yield reports presented in the STS-Harvest Summaries worksheet. To get a complete picture of the event, the calculations must be completed for each of the timber quality categories modelled:

- Yield of High Quality products in m³/ha;
- Yield of Low Quality products in m³/ha;
- Yield of Pulp Quality products in m³/ha;
- Yield of Waste Quality products in m³/ha; and

Future versions of the Yield Simulator will automate the calculations for “average harvest event yields” for these timber products and present them in separate output tables.

6. SUMMARY OF KEY PRODUCTS

The primary product produced by the Yield Simulator Project is the software package that facilitates the modelling of growth and yields for native eucalypt forest FRAMES inventory data. The final version completed for north coast CRA negotiations comes stamped with a Version 4d identification code on the control panel. Two systems were created for this version, one specific to the Lower North East (LNE) CRA Region and one specific to the Upper North East (UNE) CRA Region.

Complementary to the Yield Simulator package is a second important product that was produced as a result of the net harvest area modifier subproject. This GIS Grid cover stores a calculated net area modifier value for each 25 by 25 metre grid cell present on state forest. Again, separate covers were created for each of the UNE and LNE CRA Regions.

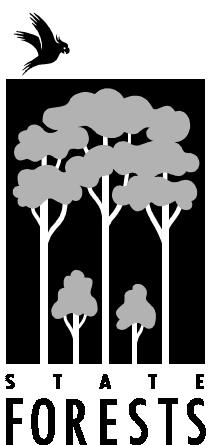
APPENDIX 1 – TREE DEFECT MODIFIERS PROJECT REPORT

Forest Resources and Management Evaluation Systems

Upper North East And Lower North East CRA
Regions

Tree Defect Modifiers Project Report

Draft Final Report: 18/02/00



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1. Study Objectives

The objectives of the FRAMES Tree Defect Modifier Study are:

1. To quantify significant differences between inventory product volume estimates and harvested product volumes. This potential difference is termed Regrade and will be expressed as a percentage of the MARVL inventory volume estimates.
2. To develop modifiers based on the results of the study that can be used in the FRAMES Yield Simulator.

2. Introduction

The Tree Defect Modifier Study is a subproject of the FRAMES Yield Simulator Development Project. It has been undertaken to calibrate inventory based volume estimates for a range of operational factors not able to be assessed in standing trees. The key factors that addressed in this calibration include:

1. The impact of internal unseen defect;
2. Differences in volumation techniques between inventory systems and the State Forests Sales System;
3. The impact of product segregation methodologies.

The most significant factor addressed in the study is the impact of internal timber defect that cannot be assessed until trees have been harvested and the log ends made visible.

2.1 *Effect of Defects on Log Grading*

Many types of defect can be found in native hardwood tree species. Defects can result from a range of factors: deterioration associated with age; injury from damage agencies such as insects, fire and wind; and fungal infections associated with insect borers or branch occlusion processes. Defects reduce processing efficiency and the desirable properties and value of the final wood products to varying extents. External features such as hollows, dead limbs, lumps, bumps and scarring often indicate the presence of defect in a tree stem. However, the nature and extent of a defect in native hardwood species cannot be assessed with any degree of certainty from external characteristics alone, particularly while the tree is still standing.

In practice log grading is performed at the log dump in the forest where the tree stem is 'serviced' (ie. cross-cut into product lengths and waste sections are removed). Logs are graded into different processing categories (ie. quota sawlog, veneer log, pole, girder, salvage log, pulp, and waste) based on the type and severity of defects present in a log in relation to the log dimensions. Wood density and colour characteristics will also influence species selection for particular products.

Where there is some doubt about the quality of a log before sale to any particular miller or wood processor, the Supervising Forest Officer may measure internal and external defects to assign a product grade. Defect assessment is by a standardised log grading method which compares defect measures to an agreed industry standard. These standards are called Compulsory Utilisation Schedules.

Compulsory Utilisation Schedules have been established for all Management Areas. They describe the maximum defect currently acceptable for compulsory sawlogs of any given dimension. Other separate specifications describe the types and extent of defects allowable for veneer logs, small sawlogs, poles, piles, girders and salvage logs, as well as sweep and dimension requirements for pulp logs. These are defined within each Region after consultation between State Forests of NSW and the wood processors that purchase these logs.

2.2 Log Grading for Operational Inventory

The **M**ethod for **A**ssessment of **R**ecoverable **V**olume by **L**og types (**MARVL**), as used for native forest pre-harvest inventory, relies on the experience and judgement of trained field crew members to accurately assign one or more stem quality classifications to a standing tree stem. MARVL inventories in plantation pine generally use a combination of objective stem characteristics such as sweep class, knot size and internode length to define the product grades. However, for operational inventories in hardwood forests the current practice is to describe sections of tree stems as having a certain product grade 'potential'. The required stem qualities are intrinsically defined by generally accepted product specifications, or at the simplest level, into high quality, low quality, pulp and waste classes. The location, forest type, species, tree growth stage (ie. age), and stem surface characteristics are all considered when judging internal wood quality and hence the product code to be assigned. In some instances, an axe may be used to 'sound' trees by striking a solid blow to the stem. The resulting tone can sometimes indicate the presence of internal defects, particularly hollow pipe and termite nests. While relationships between wood quality and other factors are based on local experience, historically speaking they have proven reasonably accurate for standing log assessment and been widely accepted at an operational level in hardwood forest inventory in NSW.

2.3 Log Grade Verification and Defect Assessment

To assign product grades to logs more accurately, log graders must have some indication of the internal wood quality. This may be done when the stem is crosscut at the log dump. The advantage of assessing tree stems on the ground, in cross-section and with bark removed is a more accurate determination of the types and extent of internal defects, and hence a better basis for deciding wood quality. This study tested the accuracy of MARVL merchantable volume estimates by a comparison with actual merchantable volumes measured and calculated after harvesting.

Tree stems assessed by MARVL were harvested, serviced into product lengths and then graded and measured using the standardised log measurement method. The pre-harvest data was analysed by the MARVL Version 3 system using a volume function set adopted for the FRAMES Strategic Inventory. The post-harvest data was analysed using the volume formula within the State Forest log sales system software (FORSALE).

The difference between inventory product volume estimates and actual harvested product volume is referred to in this document as Regrade volume. Where Regrade is statistically significant, correction factors (modifiers) can be applied. These modifiers will be used to adjust predicted product yields in harvesting events simulated by the Yield Simulator. It must be noted that Regrade is dependant upon currently applied grading practices, and that grading practices may change in future with product specification changes and log merchandising training.

The study was undertaken in selected compartments during licensed harvesting operations that were under way from June to October, 1997.

3. Methodology and Procedures

The Tree Defect Sub-Project methodology is divided into 5 main categories as follows:

- Task 1. Defining the sampling area and sampling methodology;
- Task 2. Recruitment and training of inventory crews;
- Task 3. Field procedures;
- Task 4. Customising software for data entry and analysis;
- Task 5. Data entry;

3.1 Defining the Sampling Area and Sampling Methodology

3.1.1 Determination of the Sampling Areas

The population to be sampled in the defect study was defined as harvestable trees in native eucalypt compartments within State Forests' North Coast which had harvest plans already approved as at 1st June 1997. Practical considerations ruled the selection of sample harvest areas that were actually sampled during this project. The following information was collected from Districts in order to collate and schedule the compartments to be sampled:

1. Location of Operation
2. Harvest Plan Map
3. Type of Operation (list of all product types to be harvested);
4. Commencement Date and Estimated Completion Date;
5. Tree Marking Policy in the District (retention or removal or complete);
6. Silvicultural Intent (eg. thinning operation, 'restart' operation);
7. Availability of Supervising Forest Officers to assist with data collection.

Sampling occurred between June and October 1997. The compartments that were sampled are listed in Table 1.

Table 1. Data collection sites for the Tree Defect Project.

Management Area	District	State Forest	Compartment
Coffs Harbour	Urunga	Wedding Bells	542
Coffs Harbour	Urunga	Bagawa	781
Coffs Harbour	Urunga	Lower Bucca	589
Grafton	Grafton	Grange	367
Casino	Casino	Camira	74
Styx River	Walcha	Styx River	549
Urbenville	Urbenville	Yabbra	150
Dorrigo	Dorrigo	Ellis	65
Walcha/Nundle	Walcha	Riamukka	95
Tenterfield	Glen Innes	Forestland	188
Taree	Taree	Yarrat	79
Gloucester	Gloucester	Giro	20
Kempsey	Kempsey	Kalateenee	7

3.1.2 Size and Shape of Sample Area

The shape of the sample areas within compartments was defined as the net harvestable area of state forest surrounding the log dump. Sampling was excluded from any location within filter strips, wildlife corridors or other exclusion zones as defined within the Harvest Plan of Operations for that compartment or as marked out by the Supervising Forest Officer in the forest. Only trees marked for removal within the surrounding forest area were sampled. In localities that used a “Tree Retention” marking policy, the SFO or tree faller was asked to select the trees that were going to be felled in the ordinary course of harvesting.

3.1.3 Tree Sampling Methodology

The sampling methodology underwent a number of changes from the original proposal. Initially the method was designed around randomly located 0.1 hectare plots. The plots were assessed using the standard MARVL Operational Inventory procedure and then harvested. The harvested stems were followed back to the dump and the dimensions and grade of each log recorded, including defect assessment. A post-harvest assessment in each plot recorded the status of each tree in the plot (ie. retained, harvested, destroyed) and the level of harvest damage to retained trees.

This method was trialed and then used for data collection in three compartments. It was the favoured method because data was directly comparable to other FRAMES inventory data. The fixed area plots also allowed Regrade estimates to be determined on a per hectare basis. Unfortunately however the field implementation of the method proved incompatible with the normal harvesting process. There were long delays between plot establishment and harvesting of each plot which more than doubled the estimated data collection period in each compartment. In addition, randomly located plots provided far fewer samples of harvested trees than expected.

The method was refined to focus on the primary objective - collection of information to show the level of regrade that is applicable to native forest inventory estimates. The post-harvest assessment was removed, and randomly located plots were replaced with individual tree selection. Only trees selected for harvesting were assessed using MARVL stem quality descriptions. There were no changes made to the measurement and recording of log dimension and grade at the dump.

3.2 Recruitment and Training of Inventory Crews

Data collection was performed by a three person crew consisting of:

1. Crew Leader (Inventory Forester Grade 1 temporary);
2. Inventory Assistant (Forest Labourer casual);
3. Supervising Forest Officer (Marketing).

The SFO was sourced from each District to provide local liaison with contractors, and local experience with log merchandising and defect assessment.

The Crew Leader and the Inventory Assistant were trained in MARVL inventory procedures and the procedures developed for log measurement and data collection for the Tree Defect Project.

3.3 Field Procedures

The sampling system is divided into two stages, pre-harvest tree assessment and post-harvest log measurement.

3.3.1 Pre-harvest MARVL tree assessment;

The selection of trees from within the net harvestable area was completed using harvest plan maps (scale generally 1:15000) supplied by district officers. Trees that were to be harvested were selected at random using bearings and distances predetermined from random number tables. This methodology forced the selection of trees across the range of species and quality classes therefore ensuring that there was no sampling bias. In sampling with this methodology, it was possible to ensure that potential upgrade (trees which prove to be of a higher grade than expected) and downgrade (trees which prove to a lower grade than expected) all had an equal probability of being sampled.

Using pre-calculated random distance and bearing lists, the following procedure was used to locate sample points within harvest areas of the compartment:

1. The inventory crew selected an active log dump within the sample area and established a suitable Take Off Point (TOP) on a retained tree at the site.
2. TOP and Dump number data was recorded on the measurements *pro forma*.
3. The TOP point was recorded on the harvest plan map and a series of sample points plotted for each random distance and bearing combination present on the pro-forma. The points were mapped using a protractor and multi-scale ruler, taking consideration of the difference between magnetic bearing and map grid bearing.
4. The sample points were located in the forest using hip chain and compass.

5. The sample point was identified with a painted cross on the ground. The tree that was closest to the sample point (that was also marked for removal) was selected as the tree for measurement.

3.3.2 Pre-harvest measurement of the sample tree

Information was required that described the site and the tree being studied. Variables are used to describe the sample area included:

Sample area level

1. Sample area identifying number
2. State Forest identifier
3. Compartment identifier
4. Measure date
5. Crew members
6. Yield association
7. Stand Structure Index
8. Site height class

Tree level

9. Tree identifying number
10. Species code
11. DBHOB
12. Dominance
13. Crown quality
14. MARVL tree description, including height
15. Tree top height

These variables were assessed and recorded using the standard FRAMES Strategic Inventory prescriptions as defined for that project.

3.3.3 Post-harvest measurement of products

The following information was collected for sample trees after felling:

16. Sample area identifying number
17. Tree identifying number
18. Stump height
19. Stem breakage point (if breakage occurred on impact)

The inventory crew was on site during harvesting of all sample trees, and during servicing of each stem at the log dump. Allowable defects along the length of each log and in the cross-sectional profile of the log were assessed and measured by the Supervising Forest Officer using the standard log measurement and grading rules¹. The following information was collected from each log obtained from each tree:

20. Stem breakage point (if breakage occurred on impact)
21. Sample area identifying number
22. Tree identifying number
23. Log Section Number (ascending order from butt to head)
24. Large End Diameter (under bark)
25. Large End Defect Core (pipe allowance)
26. Centre Diameter (under bark)
27. Small End Diameter (under bark)
28. Small End Defect Core (pipe allowance)
29. Section Length
30. Length Deduction
31. Log product quality (high quality large, high quality small, low quality, pulp, waste)
32. Log product (quota sawlog, pole, pile, girder, veneer, small sawlog, salvage log, pulp, waste)
33. Presence of defects that were considered in the assessment of pipe allowance for the log (ie. present in the log)
34. Presence of defects that were considered in the assessment of length deduction for the log (ie. present in the log)

The grades assigned to logs were in some instances limited by the market availability or market demand for some log products. For example, some potentially pole grade logs were sold as small sawlogs or even pulp in the absence of a pole market. Likewise some veneer grade logs were sold as compulsory sawlogs in the absence of a veneer market or where the fulfilment of quota agreements had priority over value optimisation. A significant level of pulp grade material was graded as waste due to the absence of a pulp market.

3.3.4 Precision Auditing

The nature of this inventory greatly reduced the possibility of precision auditing. MARVL assessed trees were generally harvested within one day of measurement, and logs were hauled to mills often within hours after log grading and measurement. Only a very small window of opportunity for independent auditing existed but with the Strategic Inventory under way at the same time, the Precision Auditing team were unable to devote any resources to this project. The project supervisor field supervised approximately 20% of the data collection to verify that the inventory crew maintained the required measuring standards.

¹ The standards defined in the State Forests Hardwood Log Measurement Manual, prepared by Brian Salter, were adopted for log measurements undertaken at the log dump.

3.4 Customising Software for Data Entry and Analysis

A MARVL Version 3 data interchange file (from the FRAMES Strategic Inventory) was used for data entry. To account for the stump volumes an additional stem quality code was defined and added to the dictionary (ie. S = Stump). To determine stump volumes when analysing the data, stump was also defined as a product in the cutting strategy. This enabled a direct comparison between the MARVL product volumes and the actual product volumes from the same tree.

An Excel spreadsheet was developed to allow entry and storage of all log dimension and defect measurements. The spreadsheet calculated the volume of each log using the State Forests FORSALE methodology.

3.5 Data Entry and Verification

Tree Defect Project data was entered by the Project Supervisor and by the Inventory Crew Leader. Missing or incorrect fields in the original field data were occasionally encountered during data entry. Table 2 indicates the method of dealing with known data collection problems. All entered data was double-checked by verifying the interchange file details against the original data sheets.

Table 2: Data entry management rules.

Error Type	Compartment	Data Management
Tree Number	All Compartments	All tree numbers were accounted for. If a tree assessed during MARVL inventory was felled and rejected at the stump, it was recorded in the comments section of the pro-forma, but defect was not measured. Rejected trees were recorded as waste trees for gross volume comparisons, but were omitted from analysis of defects levels.
Log Number	All Compartments	All log numbers were accounted for. Sections butted to waste at the stump were measured and added to the log measurement pro-forma after grading was completed at the dump.
LED, SED	All Compartments	Missing LED or SED occurred very infrequently (11 times in over 2600 records). An estimated diameter was calculated based on an average rate of 1cm per metre taper between the two known diameters on the log.
CDUB	All Compartments	The CDUB was not measured for approx. 15% of all logs. The CDUB of waste sections and pulp logs was rarely measured. On some occasions it was not possible to measure other merchantable log types. This was mostly due to surface abnormalities at the log centre or inaccessibility. The CDUB for all unmeasured sections was estimated by averaging the LED and SED.
Length	All Compartments	One length record was missed. The tree was excluded from analysis.

Error Type	Compartment	Data Management
Defects	Wedding Bells SF, Coff Harbour MA	Data collection at Wedding Bells was undertaken during initial training of the inventory crew. All defect measurements were unreliable mainly due to incorrect interpretation of data requirements. They have been excluded from analysis.
Defects	Ellis SF, Dorrigo MA	The SFO applied a standard 10 cm minimum pipe and 40 cm minimum length deduction to all quota logs. The effect of this on total defect calculation was negligible. The data was used for analysis.
Pipe Allowance	All Compartments	Pipe was measured as presented. No minimum standard applied (except as noted above).
Length Deductions	All Compartments	Length deductions were measured as presented. No minimum standard applied. For pulp logs and waste sections with many limbs, the SFO was asked to estimate the length deduction into fractions of the log length - quarter, half, two-thirds, etc.
Presence of Defects	All Compartments	The type of defects that were noted in deciding pipe and length deductions were based on the general categories that are familiar to SFO's and working knowledge of wood defects. The local vernacular for a defect type was difficult to define in some instances.

4. Analysis and Results

In the five months of data collection, the defect study crew measured 755 standing trees that were crosscut into over 1400 logs. Table 3 summarises the data with the count of trees that had each defined product category present.

Table 3: Number of trees sampled by timber quality category.

Timber Quality Class	No of sample trees
Trees with Large High Value Products Present	573
Trees with Small High Value Products Present	208
Trees with Low Value Products Present	156
Trees with Pulp Products Present	144
Total number of Trees Sampled	755

The pre-harvest data was processed by the MARVL Version 3 system using the volumation functions and cutting strategy options developed for the FRAMES Strategic Inventory. The post-harvest log data was volumated using Huber's volume formula as applied in the State Forest log sales system methodology (FORSALE).

The verified defect modifier pre-harvest and post-harvest datasets for these trees were collated and analysed using Microsoft Excel software. Although a global analysis was

possible that summarised the trends by timber quality category only, investigations found that grouping the data into yield association classes produced statistically meaningful stratification.

Yield Associations are aggregations of Forest Types in which silvicultural management and product outturn is similar. There are seven Yield Association groups that have been adopted in the FRAMES Strategic Inventory. Table 4 presents a summary of the analysis for large high value logs with the equivalent Yield Association Stratification.

Table 4: Summary of tree defect modifier data for large value logs.

Yield Association Group	No of sample trees	Sum of MARVL volume (m ³)	Sum of FORSALE volume (m ³)	Actual (FORSALE) as a % of MARVL	Significant at 95% level
1. Moist Blackbutt	29	76.53	58.35	76.2	Yes
2. Moist coastal Eucalypts	106	247.83	207.33	83.7	Yes
3. Semi-moist and taller dry Eucalypts	77	99.75	108.43	108.7	No
4. Dry Blackbutt and Spotted Gum	194	254.06	167.43	65.9	Yes
5. Dry sclerophyll Types	0				
6. Moist tableland Eucalypts	118	196.9	104.46	53.1	Yes
7. Dry tableland Eucalypts	49	72.97	30.69	42.2	Yes
Combined Summary	622	1021	707	69.3	

Stratification that also included structure class and site height was also considered however these options were discarded after analysis demonstrated that the statistical relationships were not as good. Combinations of structure and yield association may have been useful however created too much data subdivision and reduced the samples to unacceptable sizes.

The results highlight that 622 of the 755 trees sampled contained high quality large sawlogs. The table also shows that only 6 yield association groups were sampled in the study. The dry sclerophyll types were not be sampled because there was only limited harvesting of these types in 1997. It was not possible to include the association in the time available for field measurements.

The statistical significance of the relationships were analysed with a T test comparing the means of pre-harvest MARVL volumes with post-harvest ForeSale Volumes at the yield association group and product class level. The results show whether the means were different at the 95% confidence level.

The results identify that on average the FORSALE log merchandising system recorded only 70% of the large high value volume estimated by the MARVL inventory system. The differences vary between yield association types, ranging from a low of only 42% in the dry tableland types up to just over 100% in the semi-moist and taller dry eucalypt types. The increased volume found in the semi-moist and taller dry yield association appears to be attributed to the field assessors tending to visually downgrade standing trees that were in fact able to cut high quality logs at the log dump.

The low extreme of 42% “recovery” in the dry tableland types is somewhat surprising however these forest types grow in relatively difficult conditions. The extremes of cold,

moisture deficit and fire clearly contribute to larger than expected incidents of internal defect.

Although the defect study recorded information about all products assessed and harvested, the results were not possible to extrapolate for the non-high quality sawlogs. This was primarily due to the following factors:

1. Access to markets for alternative timber products (high quality smalls, low quality salvage logs, pulp etc) is varied and inconsistent. Some operations did not have certain product markets so would cut all non-sawlogs to salvage timber. Others were sometimes forced to waste timber that could be sold in other areas.
2. Although HQ small log and salvage markets did exist for some of the localities, we found that the product specifications varied. This meant that it was not possible to compare results in a meaningful way.

5. Implementation of Results in the Yield Simulator

The results of the defect study were employed in the yield simulation environment at the tree volume estimation level. The modifier was implemented by adjusting any initial estimate of high quality large volume using the defect modifier proportion calculated for trees in that yield association group. As no clear trends could be extrapolated from the study on which products absorbed the HQ sawlog regrade, the volume was automatically re-apportioned with 50% added to the low quality timber category and 50% going to pulpwood.

As the calculated modifier for Semi-Moist and Taller Dry Hardwoods was not statistically significant, the original volume estimate was retained. This result was represented in the simulator with a defect modifier value of 100%.

A panel of field managers was surveyed for suggestions on how to address the data gap in the dry sclerophyll yield association. Discussions with this group confirmed that the Dry Blackbutt and Spotted Gum Association has features that would make it the most appropriate association to represent the missing data. The modifier value of 65.9% was copied to the dry sclerophyll types.

The final modifier values used in the simulator are presented in Table 5.

Table 5: Defect Modifier Proportions applied in the Yield Simulator

Yield Association Group	Raw Modifier % (actual vol/MARVL Vol)	Significant at 95% level	Modifier value (%) used in the Yield Simulator
1. Moist Blackbutt	76.2	Yes	76.2
2. Moist coastal Eucalypts	83.7	Yes	83.7
3. Semi-moist and taller dry Eucalypts	108.7	No	100
4. Dry Blackbutt and Spotted Gum	65.9	Yes	65.9
5. Dry sclerophyll Types			65.9
6. Moist tableland Eucalypts	53.1	Yes	53.1
7. Dry tableland Eucalypts	42.2	Yes	42.2
Combined Summary	69.3		

APPENDIX 2 – NET HARVEST AREA MODIFIER PROJECT REPORT

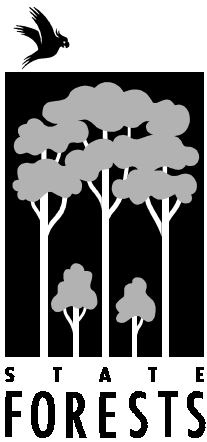
Forest Resources and Management Evaluation Systems

Upper North East and Lower North East

CRA Regions

Net Harvest Area Modifier Project Report

Draft Final Report 28/02/00



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1. Executive Summary

- The Net Harvest Area modifier provides a spatial reduction to predicted harvestable area. It is calculated using a subset of exclusion categories not catered for elsewhere in FRAMES. The exclusion categories that are factored into the modifier include:
 - Steep areas not previously mapped;
 - Inaccessible and rocky areas that are not otherwise stored in the GIS;
 - Filter strip/riparian buffer extensions including unmapped drainage system length extensions (unmapped drainage lines), filter strip width extensions and incorrectly mapped drainage.
- The net area modifier study has been used to create a GIS grid surface that stores the modified net harvest area proportion for the grid location. The modifier value for a cell is influenced by the soil regolith, rainfall erosivity, slope and distance to nearest filter strip boundary values of the cell.
- The Net Area modifier study demonstrates that on average only 75% of the mapped harvestable area is actually harvested.
- If the areas around filter strips are assumed to be harvestable then the study can be used to demonstrate that approximately 88% of the mapped harvestable area is potentially harvestable.
- The modifier function is applied to the FRAMES Net Harvest Area. Calculations of modified net harvestable area are made in the Net Harvest Area Query System¹, using data from the modifier grid surface.

¹ See the RFA Project “Application of Protective Measures and Forest Practices into a Quantitative Database”, Project no. NA57/ESFM.

2. Introduction

This report summarises the methodology employed to develop the FRAMES Net Area Modifiers for Upper North East (UNE) and Lower North East (LNE) CRA Regions. A total of 59 compartments were selected for the project. The compartments were selected in 1997 on the criteria of recent logging and covering the ranges of geographical distribution and types of forest within the region. Harvesting within the compartments occurred between June 1995 and December 1996.

Aerial photography at 1:15,000 scale was taken over the harvested compartments in early 1997. Interpretation of this photography was undertaken by experienced aerial photography interpreters to delineate actual harvest area and areas excluded from harvesting. Field work and consultation with local field staff were essential components for achieving accuracy and consistency. The modifier is important to FRAMES because the net harvestable area as calculated from mapped exclusions differed from the net harvestable area mapped from the actual harvesting events. The area modifier attempts to express this difference as a proportion (%) of an area that will be harvested based on the geo-spatial features present.

So that there is no “double accounting” for harvest exclusion features, the net harvest area modifier only deals with a subset of the logging exclusion categories and the actual harvested area. The subset of exclusion categories accounted for in the net harvest area modifier were:

- Steep areas not previously mapped.
- Inaccessible (other than steep) including rocky areas and topographically isolated areas.
- Filter strip/riparian buffer extensions including unmapped drainage, incorrectly mapped drainage and buffers on buffers.

The subset of exclusion categories used does not include any existing mapped layers or other FRAMES components (eg. NPWS Conservation Protocol strike rate categories, Strategic Inventory pre merchantable areas).

As the sample compartments were harvested in 1995/96, they were covered by different regimes of NPWS Conservation Protocols and EPA Pollution Control licences. The major effect of this variation is riparian buffer/filter strip width applied to drainage structures. The study caters for the variation by having the modifier influenced by the filter strip boundary rather than fixed features like the actual drainage systems. In this way the study was able to detect changes in harvestability of an area due to the proximity of the boundary and apply the same influence to the new boundaries created by the later conditions.

3. Methodology

3.1. Areas selected for study

The following rules were used for selecting compartments for the net area study:

- The harvesting of the compartment was started and fully completed between 1995 and 1996.
- The corresponding harvesting plan(s) were of a modern format (planned after 1/1/95).
- The harvesting was a conventional sawlog driven operation.

In order to ensure that a broad range of sites were selected, at least two compartments from each district in the CRA regions were included. A total of 59 compartments met the criteria and were selected for the project in the UNE and LNE CRA Regions. The compartment list is included as Appendix 1.

3.2. Aerial Photo Interpretation

Harvested compartments that were selected for this study had the areas harvested drawn onto aerial photographs to 0.5 hectares accuracy. Areas not harvested were classified based on the reasons for not harvesting. The standardised list of harvest study codes that were used to classify polygons delineated in the interpretation work is listed in Table 1. The reasons for not harvesting were used in the data analysis component of the project to exclude particular features from the dataset. If there was more than one reason for not harvesting an area then all reasons were tagged to the polygon, however the dominant reason was listed first.

Table 1: Codes used in API interpretation

Net Area Study Polygon Type	Codes Used in GIS
Harvested Areas	H
PMP Exclusion	P
Rainforest (non-harvestable forest types)	R
Steep	S
Rock and/or Inaccessible	I
Old Growth	O
Flora Protection	F
Fauna Protection (Animals)	A
Filter Strip Extensions (Creeks)	C
Pre-merchantable (Tiddlers)	T
Unmerchantable	U
Harvesting Logistics	L
Supervisor Error	E
Unsure – no reason	?

3.3. Independent Field Verification

The API expert undertook extensive field validation of the code work. A trained State Forests Net Harvest Area Modifier crew undertook independent field verification of the API line work. The team visited every compartment and audited approximately 10-15% of the polygons. No significant changes to polygon codes were required, however the field team did investigate and provide codes for all areas that the API officer could not classify from the photography (areas he coded with a "?").

3.4. Data Entry

The validated API line work was digitised into an ArcInfo coverage by State Forests corporate GIS data acquisition team. The line work consists of a complete cover of non-overlapping polygons. This line work then formed part of the combined GIS coverage developed in the data analysis component of this project.

3.5. Collation of the Spatial Dataset for Analysis

For each **net area study compartment**, the corporate GIS covers listed below were unioned (combined) to create an integer grid analysis dataset.

- A. Soil Regolith – indicates the dominant occurrence of a class of regolith
- B. Rainfall Erosivity Isopleth - one value per compartment
- C. Slope - may comprise a range from 0 to 90 degrees inclusive
- D. Yield Association (as per the FRAMES Strategic Inventory Association Grouping)
- E. Filter Strips - 20m buffer (each side) applied to all API detected drainage structures
- F. Distance to nearest filter strip boundary - based on the shortest distance to the closest filter strip boundary from the centre-point of each 25m cell surrounding the filter strip boundaries. Integer distance in metres.
- G. Locality code (CRA Region, SF Name, SF No., Compartment No.)
- H. FRAMES Area study Code - Harvest codes from API work.

The soil stability, rainfall intensity, slope, broad forest quality and filter strip covers (A-E) all intuitively influence the locality of harvesting so were combined to make a stratification layer for modifier development. As the soil regolith and yield association layers are categories of ordinal information, all five layers were categorised for the process. The categories used are summarised below in Table 2.

Table 2: Stratification categories and codes for Net Area Project Analysis.

Stratum Category	Category Values	Strata Value
A. Soil Regolith Class	1	1
	2	2
	3	3
	4	4
	Not present	9
B. Rainfall Erosivity Isopleth	0-2000	1
	2000-4000	2
	4000-6000	3
	6000 +	4
	Not present	9
C. Slope	0° - 10°	1
	10° - 20°	2
	20° - 25°	3
	25° - 30°	4
	30°+	5
D. Yield Association	1 – 8, 10, 18	1
	9, 11, 12	2
	0, 13 – 17	9
E. Distance to filter strip boundary	Inside filterstrip area	9
	0-25 m	1
	25-50 m	2
	50-75 m	3
	75-100 m	4
	> 100 m	5

Each polygon created from the combination of covers was listed as a separate record in the attribute table. The GIS was used to calculate the area (in metres squared) and perimeter (in metres) for each polygon. This dataset was exported to Microsoft Access for aspatial analysis.

Note that due to the timing of the area modifier study, the harvest events required the enforcement of 1995/96 conservation protocols. These included the minimum protection widths for drainage features as defined in Table 3². Because it was not possible to automate the generation of filter strip buffers under these protocols, a standardised GIS buffer width approach was adopted. Under the protocols in force, trees could not be felled into filter strips however tree crowns could be felled into protection strips. Based on these criteria, a modelled buffer width of 20metres was chosen. This width covered all including the worst case scenario for filter strips, and was considered to provide a small buffer effect for protection strips. The modelled 20metre buffer was applied to all drainage systems detected by the aerial photography work, thereby catering for both standard LIC drainage as well as unmapped drainage line length extensions that were present.

Table 3: Minimum Protection widths for drainage features in native forests (April 1995-August 1996).

Type of Protection	Water Pollution hazard category									
	1		2				3			
			< 18 degrees slope		> 18 degrees slope		< 18 degrees slope		> 18 degrees slope	
	<100 ha	> 100 ha	<100 ha	> 100 ha	<100 ha	> 100 ha	<100 ha	> 100 ha	<100 ha	> 100 ha
Filter Strip	5m	10m	10m	10m	10m	10m	10m	15m	15m	20m
Protection Strip	0m	0m	0m	5m	10m	10m	10m	10m	10m	10m
Total width	5m	10m	10m	15m	20m	20m	20m	25m	25m	30m

3.6. Data cleaning

Of the 160,000 polygons created by the spatial overlay process, some missing or incorrect fields were encountered in the spatial database. Table 4 indicates the methods for dealing with known harvest code data problems.

² Reproduced from the Pollution Control Licence in force between April 1995 and August 1996.

Table 4: Adjustments made to API data attributes

Original Harvest Code	New Harvest Code	Reason
218H	218H	Hardwood Plantation (this code was incorporated as a new exclusion criteria)
219	U	Non eucalypt association
220	U	Non eucalypt association
221	U	Non eucalypt association
PMP117	P	PMP
PP	P	PMP
VPT	?	As the source of this error could not be detected, the polygons were removed from the database.
Z		Slithers – these polygons were removed from the database.
NH	Various by compartment	Incorrect API coding. These localities were re-inspected and manually corrected.

Forest Types Issues

A review of forest types information found that type 218H (Hardwood plantation) occurred in 9 of the fifty-nine compartments. As plantation was to be excluded from the study, all 218H polygons were removed from the net mapped area except for some polygons in Cpt. 276, Newry SF, and Cpt. 81, Chichester SF. Although these two compartments had been typed as native forest, the API line work identified them as plantation (coded “218H” in the Harvesting Code field). Because the polygon areas were small and were being harvested in the event as the surrounding native forest, they were retained as part of the native forest estate.

Small polygons (slithers)

As a result of overlaying many GIS covers into the one composite cover for analysis, a number of very small polygons, referred to as slithers, were created in the database. To improve processing performance any polygon which was less than 0.1 metre squared was deleted from the dataset.

Some slithers slightly larger than 0.1m² were created where API linework did not extend all the way to compartment boundaries. These polygons were also removed from the database.

Missing Photo's

A review of the dataset found that Cpts. 176 & 177, Yabbra SF and Cpt. 231, Middle Brother SF were missing from the analysis dataset despite being photographed, interpreted and field verified. It would appear that the photos went missing in transit between Coffs Harbour and Sydney because they were not digitised by GIS Branch.

3.7. Net Area Classification

Each polygon in the study was coded to identify whether they fell into the gross, net mapped or net loggable area. The rules used to categorise the polygons are defined below.

Gross Area: The following criteria were used to identify the gross area of the study compartments:

- full stereo photo coverage present,
- a meaningful harvesting code present,
- the polygon area was greater than 0.1m²,
- the polygon was within the Native Forest Estate and not Eucalypt plantation³.

Net Mapped Area (NMA): Net Mapped Area is the remaining component of the gross area after polygons with following characteristics have been removed:

- slope > 30°,
- within 20 metre buffer of “API mapped” drainage features,
- areas categorised under the Wood Resources Database as physically or economically inaccessible (WRS Class 3),
- areas categorised as non-harvestable in State Forests Preferred Management Priority (PMP) System (see Appendix 2),
- areas with unproductive forest types (based on State Forests Research Note 17 forest typing – see Appendix 3).

³ As identified by the Forest Type Code 218H (refer Forestry Commission NSW, Research note 17).

The Net Mapped Area defines the mapped or theoretical area available for harvesting based on available GIS information.

Net Loggable Area (NLA): The Net Loggable Area is a step down from the NMA based on information found in the harvest planning, actual harvesting or post-harvest API process that precluded harvesting from occurring. The NLA excludes polygons with the following features:

- Eucalypt plantation (Forest Type 218H),
- Areas marked during the harvesting event as being within a non-harvestable PMP classification (P),
- Rainforest (R),
- Old Growth (O),
- Flora or Fauna protection reserves (F,A),
- Pre-merchantable and Unmerchantable forest (T,U),
- Areas unable to be harvested because of logistical reasons (L),
- Areas not logged due to supervisor error (E),
- Areas where no harvesting occurred and which had no clear reason for non-harvesting (?).

The Net Loggable area forms the basis for the modifier dataset used in the model.

4. Results and Discussion

4.1. Analysis of the Stratification

The combination of API interpretation polygons and GIS based stratification generated approximately 160,000 records in the modifier database. A summary of data ranges and features used in the stratification is listed below in Table 5. The table compares the proportions of each variable in the study compartments to those in each of the UNE and LNE Regions.

Review of the table indicates that the LNE region has relatively more soil regolith class 1 and a slightly higher proportion of steeper country. All other variables demonstrate similar trends across the categories.

The trends for the entire CRA Region suggest similar patterns of representation to the proportions found in the study compartments. There was some variation encountered in the relative proportions in the distance to filter strip variable, however all categories had good representation in the analysis. The higher proportion of area for the study compartments that is inside filter strips can be explained by the methodology used to capture all drainage variations including filter strip length extensions.

Overall the study compartments have a good representation of all stratification variables found across the regions and therefore represent a robust cross-section of the localities for which the models are applied.

Table 5: Analysis of Area by Stratification Category

Stratum Category	Category Value	Area within Study Compartments (Hectares)	Proportion of Study Compartments	Area within UNE (Hectares)	Area within LNE (Hectares)
Soil Regolith Class	1	7,715	69%	57%	84%
	2	3,201	29%	32%	9%
	3	282	3%	11%	5%
	Not Present	24	0%	1%	2%
Rainfall Erosivity Isopleth	0-2000	665	6%	9%	12%
	2000-4000	7,000	62%	67%	52%
	4000-6000	2,478	22%	16%	23%
	6000+	1,080	10%	9%	13%
Slope (degrees)	0-10	4,032	36%	46%	32%
	10-20	3,876	35%	34%	35%
	20-25	1,390	12%	10%	14%
	25-30	987	9%	6%	10%
	30+	937	8%	5%	9%
D. Yield Association	1-8, 10, 18	7,668	68%	51%	62%
	9, 11, 12	2,095	19%	28%	17%
	Not Harvestable	1,460	13%	20%	21%
E. Distance to filter strip boundary	Inside Filter Strip	2,117	23%	15%	14%
	0-25 m	2,549	20%	25%	24%
	25-50 m	2,195	14%	21%	21%
	50-75 m	1,607	9%	16%	17%
	75-100 m	1,022	15%	12%	12%
	>100 m	1,733	19%	12%	12%

4.2. Analysis of Harvesting

With all cleaned spatial and aspatial data collated into one dataset, the bulk of the reporting for the study is based on a sum of areas by each harvest study code combination. This complete report is attached as Appendix 4.

An overview of the results is presented below in Table 6. Refer to section 3.7 for definitions of the terminology used. The analysis shows that State Forests planning tools and pre-harvest field inspections identified 6700 ha's that would not be harvested (60% of the gross area of the study compartments). However harvesting was only able to access 3,245 hectares, leaving a further 1300 theoretically harvestable hectares still unlogged.

Table 6: Analysis summary for the 59 harvested compartments.

Land Classification	Area (ha's)	Percentage
a) Gross Area of Study Compartments – GA	11,257	100%
b) Net Mapped Area – NMA	6,501	58% (b/a)
c) Net Harvestable Area – NHA	4,316	38% (c/a)
d) Net Logged Area – NLA	3,239	75% (d/c)
e) Area Logged Outside NHA	138	4% (e/d)
f) Net harvestable area not harvested	1,082	25% (c-d/c)

The factors that restricted harvesting in the “predicted” net loggable area include physical limitations that are combinations of unmapped rock or inaccessibility (harvest study code I), steep areas (harvest study code S) and filter strip extensions (harvest study code C). Table 7 details the actual breakdown of areas by each harvesting code combination within the net loggable area. This report is summarised in pie chart form in Figure 1.

Table 7: Summary of Harvest Study Code Combinations within the Net Loggable Area

Harvest Study Code	Net Loggable Area (hectares)	Proportion of Net Loggable Area
C	577.7	13.4%
H	3,238.4	75.0%
HT	0.9	0.0%
I	15.0	0.3%
IC	2.4	0.1%
S	171.2	4.0%
SC	107.3	2.5%
SI	200.5	4.6%
SIC	3.2	0.1%
Total	4,316.5	100%

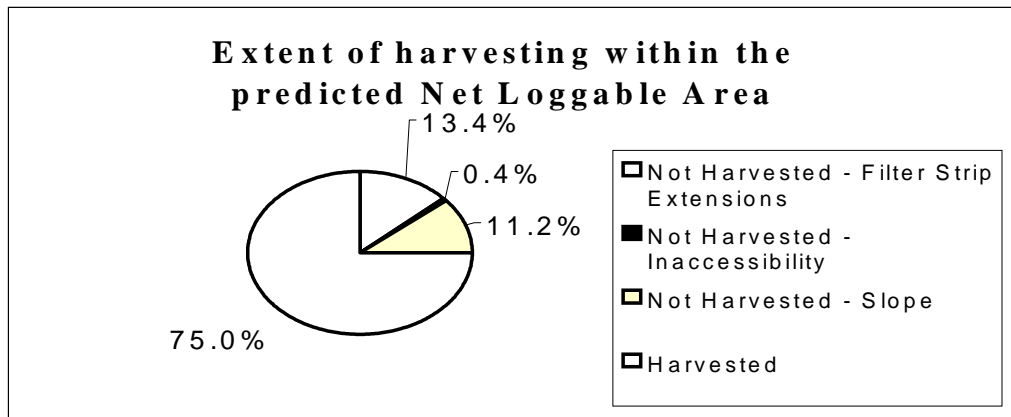
Figure 1: Chart of harvestability within the net loggable area.

Figure 1 demonstrates that only about 75% of the net harvestable area was actually harvested. Of the remaining 25% that was not logged, nearly half was attributed to the proximity of filter strips and the other half was impacted by the steepness, even though the only areas present had a GIS modelled slope which was less than 30°.

4.3. Modifier Model Dataset Preparation

The net area modifier analysis draws on relationships between spatial occurrences of harvesting within the net loggable area and five GIS modelled features (slope, regolith, erosivity, forest height and distance to filter strip). By filtering the data to only those records within the net loggable area, the modifier is restricted from “double-accounting” for factors that considered in other FRAMES tools. For instance unmerchantable forest areas which are automatically removed in the Net Harvest Area Query System were clipped from the net loggable area. Also flora and fauna exclusions (factored into ESFM type “C” strike rate calculations) were also removed from the loggable area for the study. The only exclusion factors that were included to influence the modifier are:

- Physically steep areas that are < 30° slope;
- Unmapped rock and inaccessible areas;
- Areas near filter strips (but not within filter strips) that were not harvested because of the risk of breaching the filter strip boundary.

The analysis was completed after the logging and stratification feature data were converted to a 25 metre grid surface. Each grid cell contained a value for each of the stratification features and also a binomial (presence/absence of harvesting) value. A modifier dataset was created by summing the net loggable area and area logged for each unique combination of stratification variables. The modifier value for each combination was calculated as the ratio of harvested area to net loggable area.

Regression analysis was used to create a statistically valid model representation of the trends. As the modifier variable (referred to as the dependent variable) is a proportion, it cannot be used in regression analysis without first being transformed (see arcsine or angular transformation in Sokal and Rohlf - 1995, p. 427-8). This transformation is aimed at making

a binomial distributed variable approximate a normal distribution so that the assumptions in regression analysis can apply. It was transformed as:

- prop**=arcsine($\sqrt{\text{Modifier}}$) where
- arcsine is the inverse sine of the variable and
 - $\sqrt{}$ is the square root of the variable.

Thus the response variable is prop which is approximately normally distributed.

The independent (predictor) variables in the regression analysis are the are GIS feature variables (slope, regolith, erosivity, forest height and distance to filter strip). Since these variables have been reported in classes (ie. they are categorical), it was necessary to use dummy variables in the model. The dummy variables were produced as follows:

Creating dummy variables for Soil Regolith Class

```
if soil=1 then soil1=1 else soil1=0
if soil=2 then soil2=1 else soil2=0
if soil=3 then soil3=1 else soil3=0
```

Creating dummy variables for Rainfall Erosivity Isopleth

```
if rainfall=1 then rain1=1 else rain1=0
if rainfall=2 then rain2=1 else rain2=0
if rainfall=3 then rain3=1 else rain3=0
```

Creating dummy variables for Topographic Slope

```
if slope=1 then slope1=1 else slope1=0
if slope=2 then slope2=1 else slope2=0
if slope=3 then slope3=1 else slope3=0
```

Creating dummy variables for Yield Association (YA)

```
if yield_as=1 then ya1=1 else ya1=0
```

Creating dummy variables for Distance from Filter Strip Boundary

```
if filterst=1 then dist1=1 else dist1=0
if filterst=2 then dist2=1 else dist2=0
if filterst=3 then dist3=1 else dist3=0
if filterst=4 then dist4=1 else dist4=0
```

Note: For each variable, the number of dummy variables is equal to the number of categories (c) minus the one.

4.4. Model Selection and Fitting

The RSQUARE procedure in SAS (SAS 1989) was used to select the sets of dummy variables that were statistically valid and could be include in the model. Then the selected variables were fitted using REG procedure in SAS to give this final Model:

The Predicted Modifier = $(\text{sine}(\text{prop}))^2$ where

$$\text{prop} = 0.557359 + 0.153338 * \text{soil1} - 0.249989 * \text{soil2} + 0.493694 * \text{rain2} + 0.469514 * \text{rain3} + 0.477297 * \text{slope1} + 0.336660 * \text{slope2} + 0.096938 * \text{slope3} - 0.095263 * \text{ya1} - 0.418808 * \text{dist1} - 0.191666 * \text{dist2} - 0.069234 * \text{dist3}$$

This model was based on 249 observations and had the following fit statistics: $R^2=0.68$; Mean bias=-0.0046; and RMSE=0.210.

It was not possible to identify which dependent variables contributed more to the model because of their categorical nature (zero or one).

A second model was subsequently required which represented a scenario of allowing trees to fall in the filter strip extension areas (“buffer on buffer” areas). This scenario was created by copying the original analysis dataset and converting any harvest study polygon with a single code “C” to a code “H” (areas not harvested purely because of their proximity to filter strips were assumed to be harvested).

The New Model also took the form: The Predicted Modifier = $(\text{sine}(\text{prop}))^2$ where

$$\text{prop} = -0.166102 + 0.682980 * \text{soil1} + 0.313405 * \text{soil2} + 0.552480 * \text{soil3} + 0.506652 * \text{rain2} + 0.586655 * \text{rain3} + 0.554068 * \text{slope1} + 0.397549 * \text{slope2} + 0.169486 * \text{slope3}$$

The second model had the following fit statistics: $R^2=0.73$; Mean bias=-0.0040; and RMSE=0.186. This model was fitted using 255 observations.

Based on the study dataset, the modifier model demonstrated that only 74.99% of the study area that was mapped in the Net Loggable Area was harvested. In the scenario where filter strip extensions (ie areas that were not harvested because of the risk of trees falling into the actual filter strip) were assumed to be harvested, the proportion of net loggable area that would be accessed increased to 88.41%. The “real” impact of slope accounts for the majority of unlogged areas within the NHA in this case (the differences between actual slope and GIS modelled slope less than 30 degrees).

4.5. Applying the Model to the UNE and LNE CRA Regions

A grid coverage was produced for the entire UNE and LNE CRA Regions by unioning the following corporate GIS covers (using the strata categories developed for the study compartments):

A. Soil Regolith – indicates the dominant occurrence of a class of regolith
B. Rainfall Erosivity Isopleth - one value per compartment
C. Slope
D. Yield Association Group
E. Distance to nearest filter strip boundary – using 1998 protocols as applied to the modelled drainage developed for the “Application of the protective measures and forest practices into a quantitative database” project. Details are summarised in Table 9.

The values generated for each grid cell are used in the modifier equations described in Section 4.4 to determine the predicted harvestable proportion for the cell. The resulting values, which ranged between zero and one, represent the proportion of the grid cell likely to be accessed in a harvest event. The “modified” area of a grid cell is calculated by multiplying the area of the cell by the proportion factor. This equation is demonstrated below in Table 8.

Table 8: Example of modifier equation implementation.

25 by 25 metre Grid Cell Area (ha’s)	Modifier Value	Modified Area (ha’s)
0.0625	1	0.0625
0.0625	.75	.046875
0.0625	.42	.02625
0.0625	0	0

To calculate the modified net area of a polygon, the modified grid cell areas within the polygon are summed together ie:

$$\text{Modified Polygon Area Estimate} = \sum (\text{Grid Cell Modified Area's})$$

Note that if a grid cell (or a polygon) is already excluded from harvesting due to other mapped reasons, for example rainforest, slope > 30°, drainage filter strip, then the modified area estimate is ignored and the net harvestable area remains as zero. The modifier information is only applied to cells/polygons that are inside the net harvest area.

The CRA final report for the “Application of protective measures and forest practices into a quantitative database” provides a useful reference on how the full range of GIS coverage’s and the net harvest area modifier model are integrated into an automated area reporting system within FRAMES.

Table 9: Filter Strip Widths used in Distance to Filter Strip Boundary Calculations for CRA negotiations.

	Inherent Hazard 1 (metres either side)	Inherent Hazard 2 (metres either side)	Inherent Hazard 3 (metres either side)
Unmapped	10	10	15
1 st Order	10	15	20
2 nd Order	15	20	25
3 rd Order	20	25	30

4.6. Evaluation of Drainage System Modelling Approaches

One of the key requirements of the methodology for this study was to ensure that filter strip effects are correctly incorporated and linked with the net area query system used. Two drainage system features had to be considered:

- Filter strip length extensions – components of drainage system structures that occur beyond the mapped LIC drainage;
- Filter strip width extensions – areas perpendicular to the filter strip buffer that are not harvested due to the risk of trees falling into the actual filter strip.

A further factor to be considered was the limited extent of LIC drainage model available for the CRA Regions. To ensure that all localities within the Regions were able to reflect the impact of drainage systems and filter strips, a GIS modelled representation of LIC drainage was created⁴. This model was also used to represent the filter strip length extensions.

Having filter strip length extensions incorporated into the spatial area query system meant that the impact of length extensions in the modifier study had to be removed. Using the full extent of actual drainage identified by the aerial photography interpretation process provided the compatibility. By placing filter strip buffers around all drainage encountered in the field, the impact of LIC drainage system length extensions was removed (there would not be any areas detected as being unlogged that were the direct impact of unmapped drainage structures).

The variation encountered between actual drainage and LIC drainage for the study compartments is shown in Table 10. The actual drainage shows less impact on the Net Loggable Area from filter strip exclusions however this difference in filter strip area is

⁴ See Application of protective measures and forest practices into a quantitative database – Section 5.1

accounted for in the reduction of overall Net Loggable Area. The table shows that unmapped drainage structures would account for between 4 and 5% of the area loss effect.

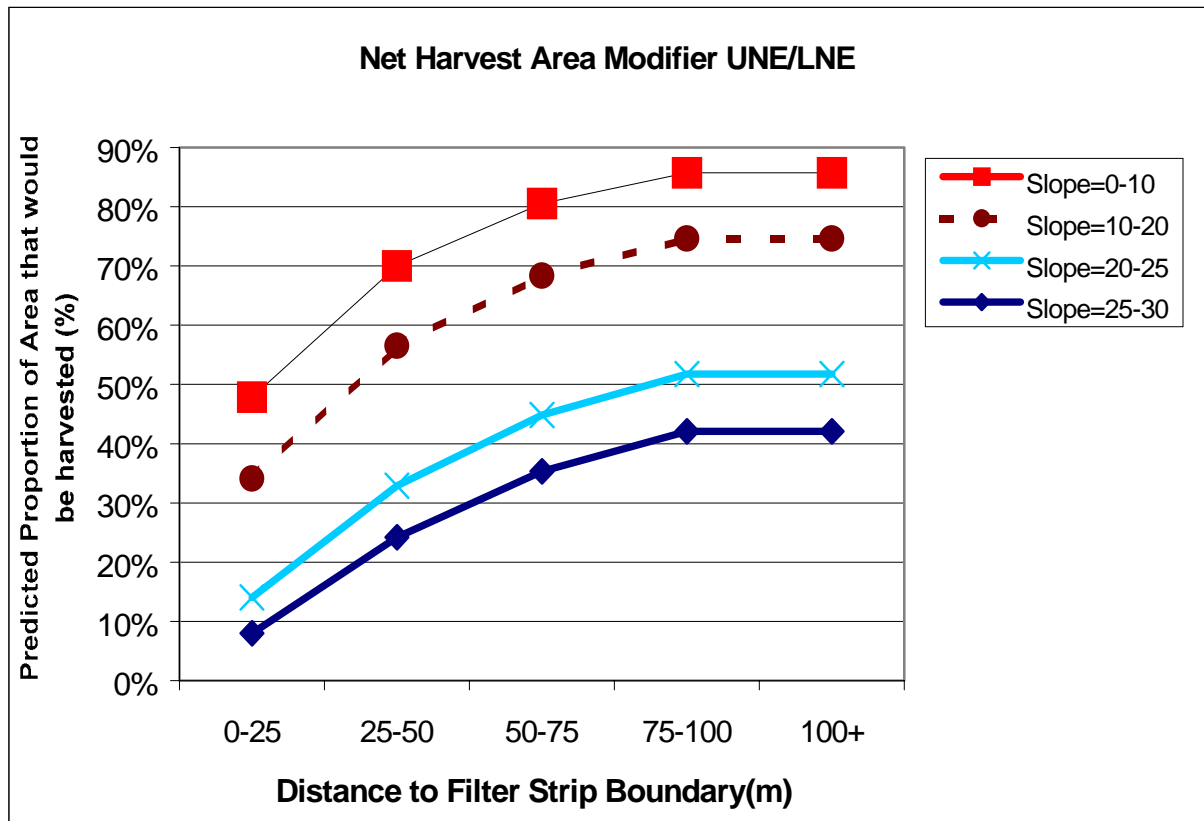
Table 10: Variations in study results due to drainage system modelling technique.

Harvest Code	UNE/LNE CRA Region			
	Using LIC Drainage		Using Actual Drainage	
	Area (hectares)	% of total	Area (hectares)	% of total
Creek	936.1	20%	594.0	14%
Creek/Steep	0.0	0%	0.0	0%
Harvested	3,360.5	73%	3,311.0	77%
Inaccessible	25.8	1%	24.2	1%
Inaccessible/ Creek	4.3	0%	2.9	0%
Steep	110.6	2%	265.2	6%
Steep/Creek	169.4	4%	111.6	3%
Total	4,606.7	100%	4,309.0	100%
Average Modifier	27%		23%	

4.7. Modifier Trends

The proportion of an area that will be harvested is dependent on the combination of stratification variables present (soil regolith, rainfall erosivity, the height of the trees present, the proximity to the closest filter strip boundary and slope). Figure 2 shows the effect of distance to filter strip boundary and slope on the modifier equation. In this example all other values remain fixed (soil regolith = 2, rainfall isopleth = 2, Yield Association = 1).

Figure 2: Chart of Modifier Trends.



The chart in Figure 2 demonstrates that model is very sensitive to both the distance and slope variables. The other variables influence the model however to a considerably lesser extent. The distance to filter strip variable will vary across a range of about 40%, showing approximately 95% harvestability in flat areas that are over 75metres from the boundary down to 50% harvestability for localities with the same slope but within 15 metres of the boundary. At the other extreme, in extremely steep locations close to the filter strip boundary as little as 10% of the area will be harvestable.

5. References

SAS Institute Inc., 1989. SAS/STAT User’s guide. Version 6, Fourth Edition, Volume 2. Cary, NC: SAS Institute Inc., 846 p.

Biometry: The principles and practice of statistics in biological research, Sokal RR and JF Rohlf, 1995, WH Freeman and Co. New York. p. 427-8

6. Appendices

Appendix 1: Compartments used in the NHA Modifier Study

No.	Region	State Forest	SF No.	Cpt No.
1	LNE	BROKEN BAGO	184	1035
2	LNE	BROKEN BAGO	184	1036
3	LNE	BROKEN BAGO	184	1037
4	LNE	BROKEN BAGO	184	1038
5	LNE	BROKEN BAGO	184	1039
6	LNE	BROKEN BAGO	184	1041
7	LNE	BULGA	285	12
8	LNE	BULGA	285	15
9	LNE	BULGA	285	28
10	LNE	BULGA	285	46
11	LNE	BULGA	285	49
12	LNE	BULGA	285	89
13	LNE	CHICHESTER	292	78
14	LNE	CHICHESTER	292	79
15	LNE	CHICHESTER	292	80
16	LNE	CHICHESTER	292	81
17	LNE	COMBOYNE	698	144
18	LNE	DIEHAPPY	823	132
19	LNE	ENFIELD	337	59
20	LNE	ENFIELD	337	60
21	LNE	ENFIELD	337	62
22	LNE	NEWRY	487	273
23	LNE	NEWRY	487	274
24	LNE	NEWRY	487	276
25	LNE	NEWRY	487	277
26	LNE	NEWRY	487	279
27	LNE	PUTTY	1015	523
28	LNE	PUTTY	1015	549
29	LNE	PUTTY	1015	550
30	LNE	TAMBAN	526	44
31	LNE	TAMBAN	526	48
32	LNE	TAMBAN	526	49
33	LNE	WANG WAUK	295	163
34	UNE	DOUBLEDUKE	15	159
35	UNE	GIRARD	303	49
36	UNE	GIRARD	303	51
37	UNE	GIRARD	303	52
38	UNE	GRANGE	771	351
39	UNE	GRANGE	771	352
40	UNE	GRANGE	771	353
41	UNE	GRANGE	771	354

No.	Region	State Forest	SF No.	Cpt No.
42	UNE	GRANGE	771	355
43	UNE	GRANGE	771	356
44	UNE	GRANGE	771	370
45	UNE	GRANGE	771	372
46	UNE	GRANGE	771	373
47	UNE	GRANGE	771	378
48	UNE	GRANGE	771	384
49	UNE	GRANGE	771	386
50	UNE	GRANGE	771	387
51	UNE	GRANGE	771	388
52	UNE	GRANGE	771	395
53	UNE	MOUNT BELMORE	361	421
54	UNE	MOUNT BELMORE	361	423
55	UNE	MOUNT BELMORE	361	424
56	UNE	WILD CATTLE CREEK	488	529
57	UNE	WILD CATTLE CREEK	488	532
58	UNE	WILD CATTLE CREEK	488	537
59	UNE	WILD CATTLE CREEK	488	538

Appendix 2: Harvesting status of PMP Codes

PMP Code	Description	Harvestability
1.1.1	Multiple Use Native Forest – General	Harvestable
1.1.2	Multiple Use Native Forest – Recreation	Not Harvestable
1.1.3	Multiple Use Native Forest – Education	Not Harvestable
1.1.4	Multiple Use Native Forest – Research	Harvestable
1.1.5	Multiple Use Native Forest - Catchment Protection	Harvestable
1.1.6	Multiple Use Native Forest - Visual Resource Protection	Harvestable
1.1.7	Multiple Use Native Forest - Flora and/or Fauna Protection	Not Harvestable
1.1.8	Multiple Use Native Forest - Historical Values	Not Harvestable
1.1.9	Multiple Use Native Forest - Aboriginal sites	Not Harvestable
1.2	Undeveloped Native Forest	Not Harvestable
1.3	Preserved Native Forest	Not Harvestable
3.1	Cleared Land	Not Harvestable
3.2		Not Harvestable

Appendix 3: Harvestability Classification for Forest Types in UNE and LNE CRA Regions

Forest Type	Yield Association Code	Yield Association Description	Harvestability
36	1	Blackbutt – moist	Harvestable
36/10	1	Blackbutt – moist	Harvestable
36/46	1	Blackbutt – moist	Harvestable
36b	1	Blackbutt – moist	Harvestable
37a	1	Blackbutt - moist	Harvestable
37ac	1	Blackbutt - moist	Harvestable
37	2	Blackbutt - dry	Harvestable
37/234	2	Blackbutt - dry	Harvestable
37b	2	Blackbutt - dry	Harvestable
37b/38	2	Blackbutt - dry	Harvestable
38	2	Blackbutt - dry	Harvestable
38/39	2	Blackbutt - dry	Harvestable
38a	2	Blackbutt - dry	Harvestable
38b	2	Blackbutt - dry	Harvestable
39	2	Blackbutt - dry	Harvestable
39a	2	Blackbutt - dry	Harvestable
39b	2	Blackbutt - dry	Harvestable
41/92	2	Blackbutt - dry	Harvestable
36/48	3	Flooded Gum	Harvestable
37/48	3	Flooded Gum	Harvestable
46/48	3	Flooded Gum	Harvestable
47/48/53	3	Flooded Gum	Harvestable
48	3	Flooded Gum	Harvestable
48/10	3	Flooded Gum	Harvestable
48/36	3	Flooded Gum	Harvestable
48/53	3	Flooded Gum	Harvestable
48c	3	Flooded Gum	Harvestable
53	4	Brushbox	Harvestable
53/10	4	Brushbox	Harvestable
53/2	4	Brushbox	Harvestable
53/46	4	Brushbox	Harvestable
53/46+11	4	Brushbox	Harvestable
53/46+12	4	Brushbox	Harvestable
53+12	4	Brushbox	Harvestable
53a	4	Brushbox	Harvestable
53b	4	Brushbox	Harvestable
53fg	4	Brushbox	Harvestable
45	5	Moist Coastal Eucs	Harvestable
45/10	5	Moist Coastal Eucs	Harvestable
45+234	5	Moist Coastal Eucs	Harvestable
45a	5	Moist Coastal Eucs	Harvestable

Forest Type	Yield Association Code	Yield Association Description	Harvestability
45b	5	Moist Coastal Eucs	Harvestable
46	5	Moist Coastal Eucs	Harvestable
46/53	5	Moist Coastal Eucs	Harvestable
46+11	5	Moist Coastal Eucs	Harvestable
46+53	5	Moist Coastal Eucs	Harvestable
46a	5	Moist Coastal Eucs	Harvestable
46b	5	Moist Coastal Eucs	Harvestable
47	5	Moist Coastal Eucs	Harvestable
47/53	5	Moist Coastal Eucs	Harvestable
47a	5	Moist Coastal Eucs	Harvestable
47b	5	Moist Coastal Eucs	Harvestable
49	5	Moist Coastal Eucs	Harvestable
49/53	5	Moist Coastal Eucs	Harvestable
50	5	Moist Coastal Eucs	Harvestable
51	5	Moist Coastal Eucs	Not Harvested
52	5	Moist Coastal Eucs	Not Harvested
54	5	Moist Coastal Eucs	Harvestable
55	5	Moist Coastal Eucs	Harvestable
56	5	Moist Coastal Eucs	Harvestable
60	6	Semi-moist and taller dry Eucs	Harvestable
60/70	6	Semi-moist and taller dry Eucs	Harvestable
60a	6	Semi-moist and taller dry Eucs	Harvestable
62/74a	6	Semi-moist and taller dry Eucs	Harvestable
62a	6	Semi-moist and taller dry Eucs	Harvestable
62a/74a	6	Semi-moist and taller dry Eucs	Harvestable
62ac	6	Semi-moist and taller dry Eucs	Harvestable
62ra	6	Semi-moist and taller dry Eucs	Harvestable
68	6	Semi-moist and taller dry Eucs	Harvestable
81	6	Semi-moist and taller dry Eucs	Harvestable
87	6	Semi-moist and taller dry Eucs	Harvestable
70a	7	Spotted Gum – Moist	Harvestable
71	7	Spotted Gum – Moist	Harvestable
71a	7	Spotted Gum - Moist	Harvestable
76	7	Spotted Gum - Moist	Harvestable
76a	7	Spotted Gum - Moist	Harvestable
70	8	Spotted Gum - Dry	Harvestable
70/72	8	Spotted Gum - Dry	Harvestable
70/74	8	Spotted Gum - Dry	Harvestable
70b	8	Spotted Gum - Dry	Harvestable
71b	8	Spotted Gum - Dry	Harvestable
72	8	Spotted Gum - Dry	Harvestable
72/74	8	Spotted Gum - Dry	Harvestable
72/74a	8	Spotted Gum - Dry	Harvestable
72/74ac	8	Spotted Gum - Dry	Harvestable
72a	8	Spotted Gum - Dry	Harvestable

Forest Type	Yield Association Code	Yield Association Description	Harvestability
72ac	8	Spotted Gum - Dry	Harvestable
74	8	Spotted Gum - Dry	Harvestable
74a	8	Spotted Gum - Dry	Harvestable
74ra	8	Spotted Gum - Dry	Harvestable
74rb	8	Spotted Gum - Dry	Harvestable
101	9	Dry Sclerophyll & Woodland	Not Harvested
123	9	Dry Sclerophyll & Woodland	Harvestable
123a	9	Dry Sclerophyll & Woodland	Harvestable
123b	9	Dry Sclerophyll & Woodland	Harvestable
126	9	Dry Sclerophyll & Woodland	Harvestable
220/62	9	Dry Sclerophyll & Woodland	Harvestable
220/80	9	Dry Sclerophyll & Woodland	Harvestable
220/85	9	Dry Sclerophyll & Woodland	Harvestable
40	9	Dry Sclerophyll & Woodland	Harvestable
40/41	9	Dry Sclerophyll & Woodland	Harvestable
41	9	Dry Sclerophyll & Woodland	Harvestable
41/126	9	Dry Sclerophyll & Woodland	Harvestable
41b	9	Dry Sclerophyll & Woodland	Harvestable
47c	9	Dry Sclerophyll & Woodland	Harvestable
60c	9	Dry Sclerophyll & Woodland	Harvestable
62	9	Dry Sclerophyll & Woodland	Harvestable
62/126	9	Dry Sclerophyll & Woodland	Harvestable
62/128	9	Dry Sclerophyll & Woodland	Harvestable
62/74ac	9	Dry Sclerophyll & Woodland	Harvestable
62/74b	9	Dry Sclerophyll & Woodland	Harvestable
62/92	9	Dry Sclerophyll & Woodland	Harvestable
62+220	9	Dry Sclerophyll & Woodland	Harvestable
62b	9	Dry Sclerophyll & Woodland	Harvestable
62b/122	9	Dry Sclerophyll & Woodland	Harvestable
62b/74b	9	Dry Sclerophyll & Woodland	Harvestable
62r	9	Dry Sclerophyll & Woodland	Harvestable
62rb	9	Dry Sclerophyll & Woodland	Harvestable
63a	9	Dry Sclerophyll & Woodland	Harvestable
64	9	Dry Sclerophyll & Woodland	Not Harvested
64/84	9	Dry Sclerophyll & Woodland	Harvestable
64/84+23	9	Dry Sclerophyll & Woodland	Harvestable
65	9	Dry Sclerophyll & Woodland	Harvestable
65/126	9	Dry Sclerophyll & Woodland	Harvestable
65/70b	9	Dry Sclerophyll & Woodland	Harvestable
65/74	9	Dry Sclerophyll & Woodland	Harvestable
65/74b	9	Dry Sclerophyll & Woodland	Harvestable
65/85	9	Dry Sclerophyll & Woodland	Harvestable
65b	9	Dry Sclerophyll & Woodland	Harvestable
67	9	Dry Sclerophyll & Woodland	Harvestable
72/74b	9	Dry Sclerophyll & Woodland	Harvestable

Forest Type	Yield Association Code	Yield Association Description	Harvestability
72b	9	Dry Sclerophyll & Woodland	Harvestable
74/92	9	Dry Sclerophyll & Woodland	Harvestable
74b	9	Dry Sclerophyll & Woodland	Harvestable
80	9	Dry Sclerophyll & Woodland	Harvestable
82	9	Dry Sclerophyll & Woodland	Not Harvested
83	9	Dry Sclerophyll & Woodland	Harvestable
84	9	Dry Sclerophyll & Woodland	Harvestable
84/92	9	Dry Sclerophyll & Woodland	Harvestable
85	9	Dry Sclerophyll & Woodland	Harvestable
87c	9	Dry Sclerophyll & Woodland	Harvestable
92	9	Dry Sclerophyll & Woodland	Harvestable
93	9	Dry Sclerophyll & Woodland	Harvestable
98	9	Dry Sclerophyll & Woodland	Not Harvested
150	10	Tableland Eucalypts - Moist	Harvestable
151	10	Tableland Eucalypts - Moist	Harvestable
152	10	Tableland Eucalypts - Moist	Harvestable
152/234	10	Tableland Eucalypts - Moist	Harvestable
153	10	Tableland Eucalypts - Moist	Harvestable
154	10	Tableland Eucalypts - Moist	Harvestable
155	10	Tableland Eucalypts - Moist	Harvestable
159	10	Tableland Eucalypts - Moist	Harvestable
161a	10	Tableland Eucalypts - Moist	Harvestable
162a	10	Tableland Eucalypts - Moist	Not Harvested
163	10	Tableland Eucalypts - Moist	Harvestable
163/234	10	Tableland Eucalypts - Moist	Harvestable
163+234	10	Tableland Eucalypts - Moist	Harvestable
163a	10	Tableland Eucalypts - Moist	Harvestable
163a/230	10	Tableland Eucalypts - Moist	Harvestable
167	10	Tableland Eucalypts - Moist	Harvestable
168	10	Tableland Eucalypts - Moist	Harvestable
101+163	11	Tableland Eucalypts - Dry	Not Harvested
153b	11	Tableland Eucalypts - Dry	Harvestable
161	11	Tableland Eucalypts - Dry	Harvestable
161b	11	Tableland Eucalypts - Dry	Harvestable
162b/234	11	Tableland Eucalypts - Dry	Not Harvested
163b	11	Tableland Eucalypts - Dry	Harvestable
163b/234	11	Tableland Eucalypts - Dry	Harvestable
163b+234	11	Tableland Eucalypts - Dry	Harvestable
220R+163	11	Tableland Eucalypts - Dry	Harvestable
65/161	11	Tableland Eucalypts - Dry	Harvestable
122	12	Tableland Stringybarks	Harvestable
122/163	12	Tableland Stringybarks	Harvestable
122+234	12	Tableland Stringybarks	Harvestable
122a	12	Tableland Stringybarks	Harvestable
163b/122	12	Tableland Stringybarks	Harvestable

Forest Type	Yield Association Code	Yield Association Description	Harvestability
163c	12	Tableland Stringybarks	Harvestable
163c/234	12	Tableland Stringybarks	Harvestable
163c+234	12	Tableland Stringybarks	Harvestable
163N	12	Tableland Stringybarks	Harvestable
170	12	Tableland Stringybarks	Harvestable
176	12	Tableland Stringybarks	Not Harvested
101/234	13	Negligible Productive Types	Not harvested
105	13	Negligible Productive Types	Not harvested
111	13	Negligible Productive Types	Not harvested
111+234	13	Negligible Productive Types	Not harvested
117	13	Negligible Productive Types	Not harvested
117/119	13	Negligible Productive Types	Not harvested
119	13	Negligible Productive Types	Not harvested
122b	13	Negligible Productive Types	Not harvested
126/234	13	Negligible Productive Types	Not harvested
126c	13	Negligible Productive Types	Not harvested
128	13	Negligible Productive Types	Not harvested
129	13	Negligible Productive Types	Not harvested
130	13	Negligible Productive Types	Not harvested
136b	13	Negligible Productive Types	Not harvested
138	13	Negligible Productive Types	Not harvested
138/234	13	Negligible Productive Types	Not harvested
141	13	Negligible Productive Types	Not harvested
142	13	Negligible Productive Types	Not harvested
142/163	13	Negligible Productive Types	Not harvested
142/163c	13	Negligible Productive Types	Not harvested
207	13	Negligible Productive Types	Not harvested
30	13	Negligible Productive Types	Not harvested
30/31	13	Negligible Productive Types	Not harvested
30/31/92	13	Negligible Productive Types	Not harvested
30/32	13	Negligible Productive Types	Not harvested
30/92	13	Negligible Productive Types	Not harvested
38/97	13	Negligible Productive Types	Not harvested
41/234	13	Negligible Productive Types	Not harvested
41/97	13	Negligible Productive Types	Not harvested
61	13	Negligible Productive Types	Not harvested
62b/234	13	Negligible Productive Types	Not harvested
62c	13	Negligible Productive Types	Not harvested
63b	13	Negligible Productive Types	Not harvested
64+234	13	Negligible Productive Types	Not harvested
65/234	13	Negligible Productive Types	Not harvested
65c	13	Negligible Productive Types	Not harvested
74/126	13	Negligible Productive Types	Not harvested
74/234	13	Negligible Productive Types	Not harvested
74b/234	13	Negligible Productive Types	Not harvested

Forest Type	Yield Association Code	Yield Association Description	Harvestability
74bc	13	Negligible Productive Types	Not harvested
74c	13	Negligible Productive Types	Not harvested
82c	13	Negligible Productive Types	Not harvested
84/119	13	Negligible Productive Types	Not harvested
84/126	13	Negligible Productive Types	Not harvested
84+234	13	Negligible Productive Types	Not harvested
92/105	13	Negligible Productive Types	Not harvested
92/119	13	Negligible Productive Types	Not harvested
92/126	13	Negligible Productive Types	Not harvested
92c	13	Negligible Productive Types	Not harvested
97	13	Negligible Productive Types	Not harvested
97/117	13	Negligible Productive Types	Not harvested
97/119	13	Negligible Productive Types	Not harvested
97/126	13	Negligible Productive Types	Not harvested
97/234	13	Negligible Productive Types	Not harvested
1	14	Rainforest	Not harvested
1/21	14	Rainforest	Not harvested
10/21	14	Rainforest	Not harvested
11	14	Rainforest	Not harvested
12	14	Rainforest	Not harvested
13	14	Rainforest	Not harvested
16	14	Rainforest	Not harvested
17	14	Rainforest	Not harvested
1a	14	Rainforest	Not harvested
1b	14	Rainforest	Not harvested
2	14	Rainforest	Not harvested
2/3	14	Rainforest	Not harvested
21	14	Rainforest	Not harvested
21/87	14	Rainforest	Not harvested
21t	14	Rainforest	Not harvested
22+26	14	Rainforest	Not harvested
23	14	Rainforest	Not harvested
23/26	14	Rainforest	Not harvested
24	14	Rainforest	Not harvested
25	14	Rainforest	Not harvested
26	14	Rainforest	Not harvested
26/234	14	Rainforest	Not harvested
3	14	Rainforest	Not harvested
3/11	14	Rainforest	Not harvested
4	14	Rainforest	Not harvested
5	14	Rainforest	Not harvested
5/11	14	Rainforest	Not harvested
6	14	Rainforest	Not harvested
6/21	14	Rainforest	Not harvested
6/23	14	Rainforest	Not harvested

Forest Type	Yield Association Code	Yield Association Description	Harvestability
6/25	14	Rainforest	Not harvested
6/26	14	Rainforest	Not harvested
7	14	Rainforest	Not harvested
7/26	14	Rainforest	Not harvested
7c	14	Rainforest	Not harvested
7c/220	14	Rainforest	Not harvested
8b	14	Rainforest	Not harvested
218h	15	Plantation - Hardwood	Not included
218s	16	Plantation - Softwood	Not included
107	17	Non-eucalypt Associations	Not harvested
211	17	Non-eucalypt Associations	Not harvested
211/233	17	Non-eucalypt Associations	Not harvested
213	17	Non-eucalypt Associations	Not harvested
214	17	Non-eucalypt Associations	Not harvested
216	17	Non-eucalypt Associations	Not harvested
217	17	Non-eucalypt Associations	Not harvested
218	17	Non-eucalypt Associations	Not harvested
219	17	Non-eucalypt Associations	Not harvested
220	17	Non-eucalypt Associations	Not harvested
223	17	Non-eucalypt Associations	Not harvested
224	17	Non-eucalypt Associations	Not harvested
225	17	Non-eucalypt Associations	Not harvested
230	17	Non-eucalypt Associations	Not harvested
231	17	Non-eucalypt Associations	Not harvested
233	17	Non-eucalypt Associations	Not harvested
234	17	Non-eucalypt Associations	Not harvested
234/62	17	Non-eucalypt Associations	Not harvested
235	17	Non-eucalypt Associations	Not harvested
31	17	Non-eucalypt Associations	Not harvested
31/29	17	Non-eucalypt Associations	Not harvested
31/32	17	Non-eucalypt Associations	Not harvested
31/62/92	17	Non-eucalypt Associations	Not harvested
31/92	17	Non-eucalypt Associations	Not harvested
31/92/11	17	Non-eucalypt Associations	Not harvested
31/92/93	17	Non-eucalypt Associations	Not harvested
31/97	17	Non-eucalypt Associations	Not harvested
32	17	Non-eucalypt Associations	Not harvested
32/92	17	Non-eucalypt Associations	Not harvested
94	17	Non-eucalypt Associations	Not harvested
n	17	Non-eucalypt Associations	Not harvested
NOT SF	17	Non-eucalypt Associations	Not harvested
122L	error	#N/A	Not harvested
163T	error	#N/A	Not harvested
43	error	#N/A	Not harvested
Not Typed	error	#N/A	Not harvested

Forest Type	Yield Association Code	Yield Association Description	Harvestability
s	error	#N/A	Not harvested
U	error	#N/A	Not harvested
Untyped	error	#N/A	Not harvested

Appendix 4: Summary of Area by Harvest Study Code Combination

Harvest Study Code	Area (hectares)	Proportion of Area
?	84.4	0.8%
218H	13.7	0.1%
A	39.7	0.4%
AC	5.2	0.0%
ACT	4.1	0.0%
AR	10.3	0.1%
ASOC	5.7	0.1%
AT	0.5	0.0%
ATU	2.0	0.0%
C	1,301.6	11.6%
CA	0.5	0.0%
CFA	7.9	0.1%
CT	312.1	2.8%
CTU	3.0	0.0%
CU	28.0	0.2%
E	5.2	0.0%
F	59.7	0.5%
FA	21.9	0.2%
FU	186.9	1.7%
H	3,624.5	32.3%
HT	0.9	0.0%
I	40.1	0.4%
IC	6.6	0.1%
ILCT	3.9	0.0%
IO	17.8	0.2%
IOC	2.3	0.0%
IT	0.2	0.0%
IU	2.2	0.0%
L	169.1	1.5%
O	51.6	0.5%
OC	163.5	1.5%
OCU	13.8	0.1%
OU	125.8	1.1%
P	91.3	0.8%
PA	10.2	0.1%
PI	10.5	0.1%
PS	3.0	0.0%
PT	1.8	0.0%
R	636.8	5.7%
RCFA	5.0	0.0%
S	680.4	6.1%
SC	252.6	2.3%

Harvest Study Code	Area (hectares)	Proportion of Area
SCT	18.6	0.2%
SCU	6.1	0.1%
SF	1.0	0.0%
SI	1,213.1	10.8%
SIC	10.0	0.1%
SIO	6.4	0.1%
SIOC	12.8	0.1%
SIOU	1.1	0.0%
SIU	7.8	0.1%
SL	4.8	0.0%
SO	91.4	0.8%
SOC	112.1	1.0%
SOCU	7.0	0.1%
SOU	31.6	0.3%
ST	6.9	0.1%
STU	10.4	0.1%
SU	40.3	0.4%
T	792.2	7.1%
TE	0.7	0.0%
TSI	1.1	0.0%
TU	402.7	3.6%
TUC	3.3	0.0%
TUI	1.5	0.0%
TUSI	9.1	0.1%
U	414.0	3.7%
UL	0.9	0.0%
UR	6.6	0.1%
URT	1.2	0.0%
UT	1.2	0.0%
Total	11,222.4	