Yield Simulator

Southern Region
A project undertaken as part of the NSW Comprehensive Regional Assessments
May 2001

YIELD SIMULATOR

SOUTHERN REGION

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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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 at Forest Resources Branch, Forest Policy and Resources Division, State Forests N.S.W.

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PROJECT SUMMARY

This report describes a project undertaken as part of the comprehensive regional assessment 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 initial systems development took approximately 18 months to complete for the UNE and LNE CRA Regions. That phase of the project involved the use of three field inventory crews, three professional foresters and additional assistance from district and regional staff. Subsequent development and refinement for the Southern CRA Region added approximately 6 person months to the project.

As the Yield Simulator document is large and complex in nature, the authors found that various sections should be able to be referenced in isolation from the rest of the material. To facilitate both sequential and specific referencing of the document, a certain amount of repetition is introduced to the inputs and methods chapters.

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).

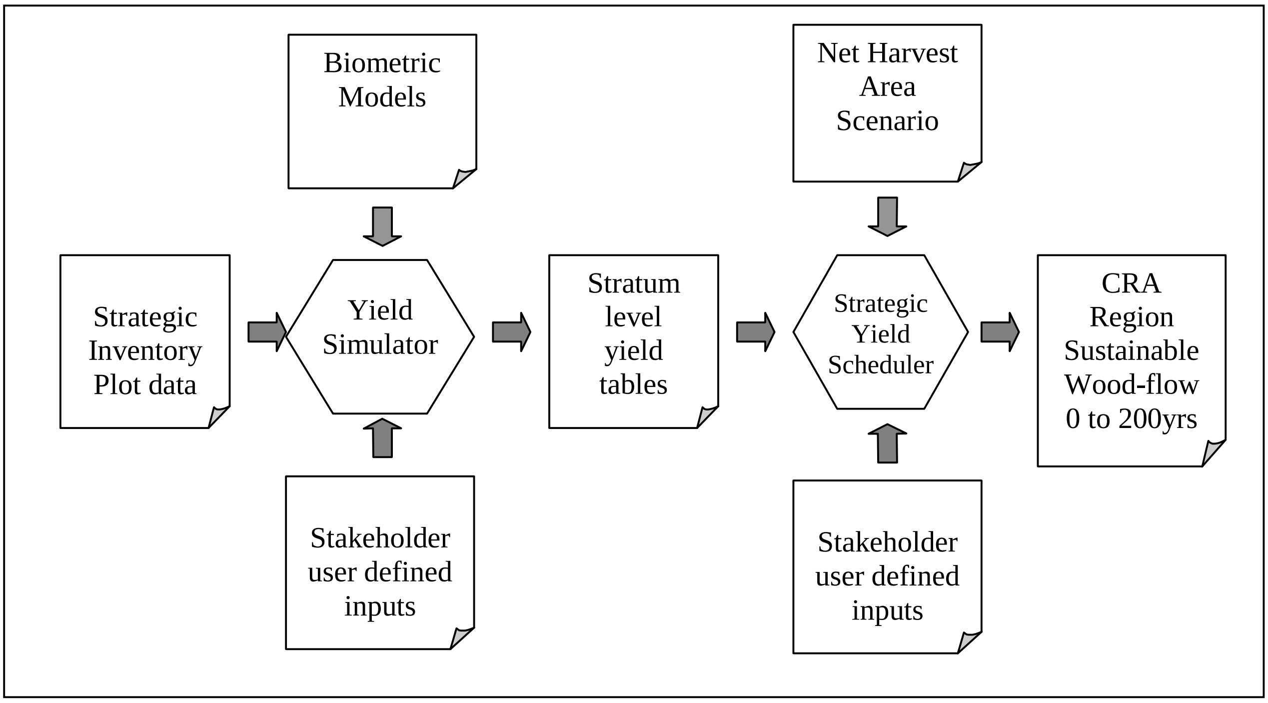
These processes are presented graphically in Figure 3.1.

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 user specified simulation time is reached.

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



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.

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 (up to 200 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.

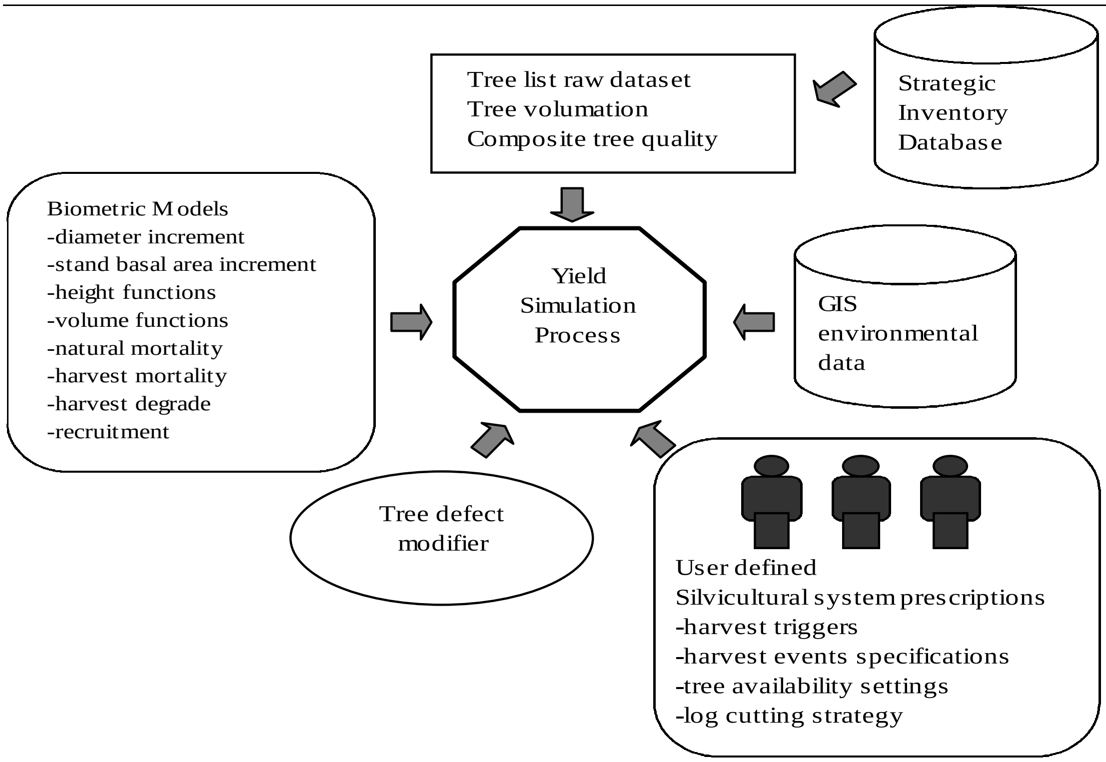
4. KEY INPUTS

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 the SCRA region has 696 inventory plots containing over 29,000 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 4.2)

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, scares, 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 3.6 metres of high quality wood (class A).
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)
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)
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 SPOTTED GUM

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	0.00	0.00	0.00	0.00	1.00
H	150-200	0.00	0.00	0.00	0.56	0.44
H	200-250	0.00	0.00	0.00	0.71	0.29
H	250-300	0.00	0.00	0.00	0.75	0.25
H	300-350	0.00	0.29	0.01	0.45	0.26
H	350-400	0.00	0.53	0.00	0.18	0.29
H	400-450	0.03	0.49	0.03	0.17	0.28
H	450-500	0.30	0.21	0.07	0.13	0.29
H	500-550	0.52	0.03	0.08	0.11	0.27
H	550-600	0.55	0.00	0.05	0.13	0.27
H	600-650	0.56	0.00	0.08	0.10	0.25
H	650-700	0.55	0.00	0.07	0.06	0.32
H	700-1000	0.50	0.00	0.06	0.12	0.32
H	1000+	0.40	0.00	0.05	0.25	0.30

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 on model forms and development methodologies refer to the SCRA Biometric Models Project Final Report.

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 10 tree level diameter models were required to cater for the 10 broad species groups identified (Table 4.3). As all environmental variables are available for all area, only one set of models were required to be developed.

TABLE 4.3: SPECIES GROUPS USED FOR GROWTH MODELLING

Species Group Code	Group Description
1	Blackbutt group
2	Fastigata
3	Ironbark group
4	Peppermint group
5	Spotted Gum
6	Silvertop Ash
7	Stringybark group
8	Non-commercial species
9	Alpine Ash
10	Tumut Hardwoods

Research as well as Permanent Growth Plot (PGP) data were used in diameter increment models. The research data contains thinning experiments which mean that a broad range of stand dynamics and structural changes are represented.

The UNE/LNE diameter growth model dependence on tree dominance has been replaced with a derived measure for dominance called “relative dominance”. Relative dominance (RD) is calculated by dividing the over-topping basal area for a tree by the total basal area. Values for relative dominance approach zero for dominant trees and one for suppressed trees. By substituting relative dominance for the direct dominance measure the model is no longer limited by the impact of harvesting and temporal change on crown position.

4.3.4 Stand basal area models

Stand basal area growth models are 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 are proportionately redistributed back to a level that equals the predicted stand growth. Conditioning of long term growth patterns is required to ensure unusual stand conditions or tree combinations do not cause unexpectedly high growth rates.

Three stand basal area models are incorporated into the SCRA Yield Simulator. These include one model specific to Spotted Gum Yield Associations, one for Alpine Ash and one combined model for all other species.

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 located within the SCRA. The model is based on the relationship between recruitment and stand structural features (stand quadratic mean diameter, stand density and a site moisture index).

Trees recruited to a stand need to have species and timber quality information allocated. This is done with a monte-carlo style simulation methodology where the attributes are linked to proportions found in the original yield association group. The distributions of these variables were calculated from the raw tree lists and stored in the “Species Data” worksheet within the system. 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 undertaken in various forest types across NSW State Forests.

4.3.6 Natural mortality model

The tree mortality function was included to model the 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. Without this function the inventory plots would develop abnormally high stocking rates (stems per hectare).

Data was separated into three groups for modelling:

- One specific to Spotted Gum;
- One specific to Alpine Ash;
- One general model for other species.

The species specific models allow the simulator to represent the dynamics of growth better for these varied and significant species clusters. The structure of the model has been improved by incorporating individual tree position in the stand (using the over-topping basal area term). Variables incorporated in the mortality model include:

- Tree diameter;
- Tree species;
- Tree over-topping basal area;
- Plot basal area;

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.

The trends of the harvest mortality model suggest that large high quality trees have the lowest probability of being destroyed in harvest events.

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 initially 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.

Having outlined the silvicultural framework required the panel 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. Some minor refinements have been made for the SCRA model to cater for the different markets and merchantability criteria used.

Supplementary workshops with SCRA field managers confirmed that these simulation options provide the necessary flexibility to address silvicultural requirements of the South Coast and Tumut Sub Regions. They also enable other stake holders 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.

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 or combined high/low quality volume per hectare required to trigger a harvest event
- Minimum diameter of logs that can contribute to the 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?
- 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 or combined high/low quality volume per hectare required to trigger a harvest event
- Minimum diameter of logs that can contribute to the 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 initial gapping event cycles required
- The 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
- species determination
- timber quality classification
- 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 4.4.

TABLE 4.4: YIELD ASSOCIATION GROUPS USED IN THE YIELD SIMULATOR

Full Association Description	Yield Association Groups
Blackbutt/Sydney Blue Gum	1 & 2
Spotted Gum	3
Silvertop Ash	4
Stringybark/Coast Grey Box/Forest Red Gum/Woollybutt	5 & 6
Brown Barrel/Messmate	9
Gum	10
Apples/Peppermint/Scribbly Gum	7 & 11
Bago/Maragle Alpine Ash	18
Riverina Hardwoods	19-22

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) Rainfall erosivity isopleth
b) Slope
c) Distance to nearest filter strip buffer boundary[1]
d) Locality code (CRA Region, SF Name, SF No., Compartment No.)
e) Harvesting Study Code (from API work)

Distance to filter strip boundary for the study compartments was measured from the Land Information Bureau (LIC) drainage model. When the study results were translated to the entire CRA region, the modifier equation was applied also using LIC drainage. This varied from the methodology applied for UNE and LNE where LIC drainage was not available for the entire CRA regions.

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[1] For the SCRA study compartments, filter strips were generated using a standardised 15metre buffer on each side of LIC 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 under the CRA projects NA04/FRA and NA13/FRA.

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 27 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 twenty seven study compartments that had full stereo photo coverage and had been given a meaningful harvesting code (ie. Not including slithers which were apparent as a result of overlaying separate GIS layers) and that was identified as Native Forest Estate and not Eucalypt plantation[2].

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 m^2,
- slope > 30°,
- within a 15 metre buffer of "LIC" 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 primarily 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 27 HARVESTED COMPARTMENTS

Land Classification	Area (ha's)	Percentage
Gross Area of Study Compartments – GA	6,876	100%
Net Loggable Area – NLA	3,330	48% (b/a)
Harvested Area – HA	2,624	38% (c/a)

The analysis shows that State Forests planning tools and pre-harvest field inspections identified 3550 ha's that would not be harvested (50% of the gross area of the study compartments). However harvesting was only able to access 2,620 hectares, leaving a further 930 theoretically harvestable hectares still unlogged. The factors restricting harvesting from those areas are physical limitations including:

1. Unmapped rock or inaccessibility (harvest study code I),
2. Steep areas (harvest study code S),
3. Buffers caused by boundaries that cannot be breached (filter strips, tenure and rainforest), and

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

4. Other factors associated with filter strips such as unmapped creek extensions (harvest study code C).

The net area modifier analysis draws on relationships between the presence of harvesting within the net loggable area and three GIS modelled features (slope, erosivity, and distance to non-harvestable boundary). 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:

$$\text{Proportion(Harvest)}=[1 + \exp(-(1.768247-0.495352*(\text{erosivity}/1000)-0.725218*(\text{slope}*\pi/180) +0.026581*\text{distance}))]^{-1}$$

This model was fitted using 33135 pixel observations. The variables presented and analysis technique are described in more detail in the Net Area Modifier project report is included as Appendix 2.

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 79% of the study area that was mapped in the Net Loggable Area was harvested.

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 CRA region. These grid surfaces held the attribute data required for the model (GIS modelled slope, rainfall erosivity class and distance to non-harvestable 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:

Modified Polygon Area Estimate = $\sum$ (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 July 1999. The defect modifier study incorporated results of measurements of over 300 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 methodology of 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’. Data was sampled for the study across nine yield association groups however as two of these groups had very low sample sizes the overall averages were adopted for those amalgams. 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

Defect Modifier Analysis for Large High Value Logs in Southern CRA Region				
Yield Association Group Description	**Yield Association Group Code**	**Sum of MARVL Volume**	**Sum of FORSALE Volume**	**ACTUAL as % of MARVL**
Blackbutt/ Sydney Blue Gum	1	149.8	128.7	85.9%
Spotted Gum	2	111.9	108.0	96.5%
Silvertop Ash	3 (*)	32.4	11.3	34.8%
Stringybark/Coast Grey Box/For. Red Gum/Woollybutt	4	269.2	185.2	68.8%
Brown Barrel/Messmate	5	38.1	30.4	79.8%
Gum	6	58.4	42.0	71.9%
Apples/Peppermint/Scribbly Gum	7 (*)	NA	NA	
Alpine Ash	8	320.5	226.7	70.8%
Riverina Hardwoods	9	357.5	321.3	89.9%
Overall Result:		1,337.7	1,053.7	78.8%

Notes: (*) - The population average was adopted for these yield association groups due to low sample sizes.

The results identify that on average the FORSALE log merchandising system records 79% 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 69% in the stringybark types up to just 96% in spotted gum.

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 most 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 State Forests Coastal and Tableland 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.

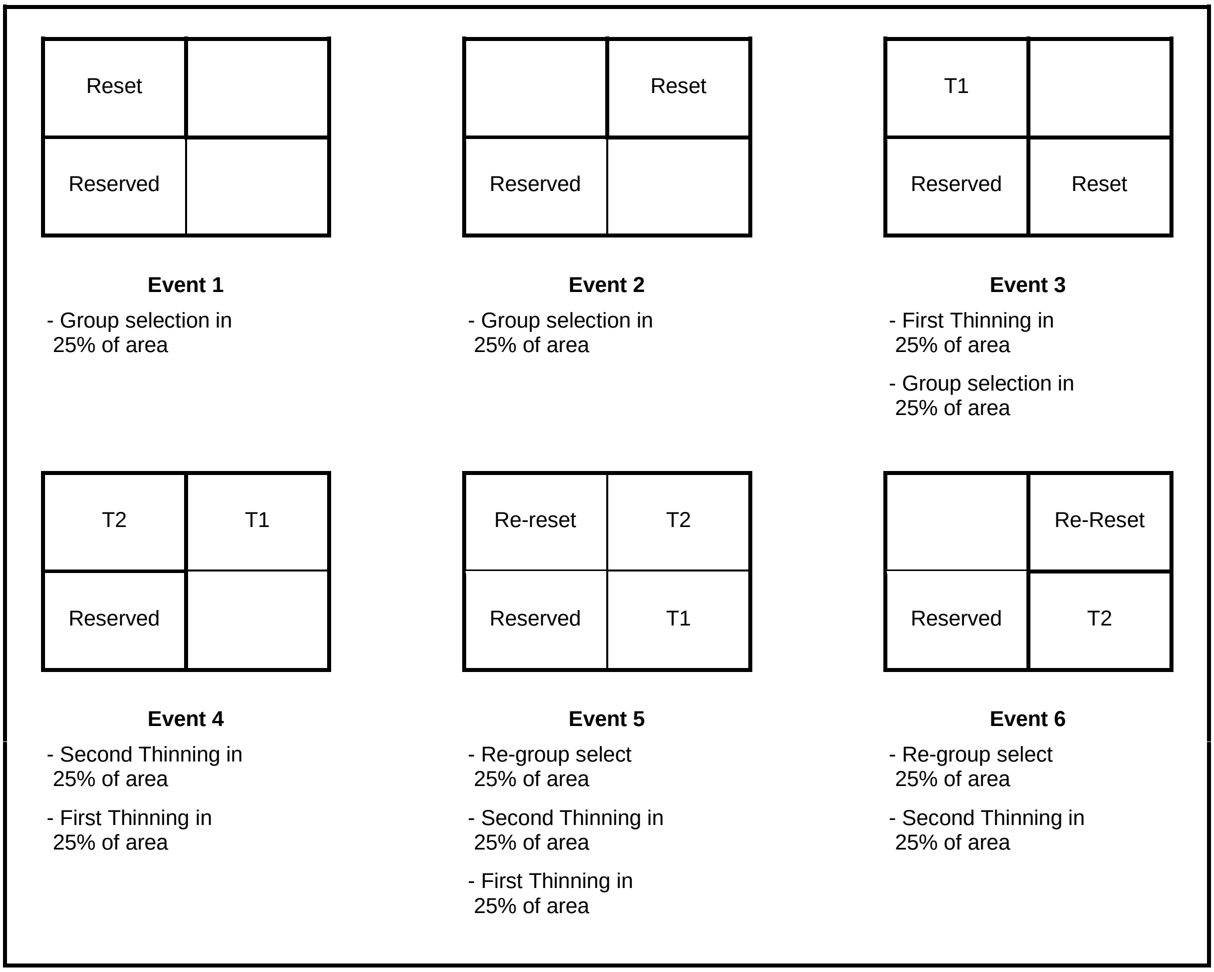
Australian Group Selection (AGS)

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



Event 1

- Group selection in 25% of area

Event 2

- Group selection in 25% of area

Event 3

- First Thinning in 25% of area
- Group selection in 25% of area

Event 4

- Second Thinning in 25% of area
- First Thinning in 25% of area

Event 5

- Re-group select 25% of area
- Second Thinning in 25% of area
- First Thinning in 25% of area

Event 6

- Re-group select 25% of area
- Second Thinning in 25% of area

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 high quality volume or combined high/low quality volume per hectare required for harvest*
  This parameter specifies the minimum harvestable volume that must be present to justify a harvest event.

- *Minimum Diameter of logs that can contribute to the volume threshold*
  Specifies the minimum diameter (at breast height) of the trees that can be used in the calculation of harvestable 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 high quality volume or combined high/low quality volume per hectare for reset*
  Specifies the minimum harvestable large high quality volume that must be present for the initial reset operation.

- *Minimum Diameter of logs that can contribute to the volume estimate for reset*
  Specifies the minimum diameter (at breast height) for the trees that can be used in the calculation of 'High Quality large or combined high/low quality 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, 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 or combined high/low quality volume per hectare for re-reset*
  Specifies the minimum harvestable volume that must be present to trigger the resetting or re-gapping operation on already gapped areas.

- *Minimum Diameter of logs that can contribute to the volume estimate for re-reset*
  Specifies the minimum diameter (at breast height) for the trees that can be used in the calculation of volume for the next and subsequent reset operations in gapped areas.

For AGS, it may also be desirable to undertake stand level thinning of regrowth areas before gapping operations are commenced. The system permits any stand to have first and second ‘whole of stand’ thinning (T1 and/or T2). The following thinning controls allow the user to specify these thinning prescriptions.

- *Pre-gap first thin retained BA*
  Specifies the minimum basal area that must be retained in pre-gapping thinning events.

- *Pre-gap first thin volume required*
  Specifies the minimum volume required to trigger a thinning harvesting event. The volume is made up of any products except waste.

- *Pre-gap second thin retained BA*
  Specifies the minimum basal area that must be retained in pre-gap second thinning operations.

- *Pre-gap second thin volume required*
  Specifies the minimum volume that must be available in pre-gap second thinning operations. 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 25% of the standing basal area
Moderate	Remove no more than 35% of the standing basal area
Heavy	Remove no more than 45% 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 all 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)	90% (b)	100% (a)
Low Quality	0% (h)	75% (g)	100% (f)	100% (e)
Pulpwood	15% (l)	15% (k)	15% (j)	15% (i)
Waste	15% (p)	15% (o)	10% (n)	10% (m)

In this example it is assumed that only low volumes of pulpwood and waste are harvested in Single Tree Selection (STS). Some extra 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 that the previous. The following simple matrix illustrates how a hypothetical plot might be treated if divided into 6 gapping events (ie. 6 cohorts).

Gap	Simlation 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 "thinning from below and beside". The thinning algorithm removes trees in a series of ‘bites’, checking each time that the retained basal area has not dropped below the desired level. The sequence of removal prioritises includes:
1. Trees that are less than 30cm and not HQ
2. Other trees that are not HQ or LQ
3. Other trees that are not HQ
4. HQ trees that are less than 30cm
5. HQ trees that are less than 50cm
6. HQ trees that are less than 70cm
7. Remaining HQ trees

The selection of trees within each ‘bite’ 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:

- *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 permanently 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.

- *Recruitment Frequency proportion boost*
  Specifies the recruitment adjustment factor for gap diameter. The system assumes that a –5% factor represents a 40m gapping diameter, 0% represents 70m and 15% represents 100m.

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**
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)	20	15	10
Gap size (m)	0%	15%	15%

In light group selection for instance, 15% of the area would be gapped in the first harvest event, then 20 years subsequently another 15% would be gapped. It would take 6 gapping events, or 120 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	(Visual 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 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

<table>
<tr><th>Option</th><th colspan="3">Description</th></tr>
<tr><td rowspan="8">1</td><td colspan="3">Standard Cutting Strategy - 40cm cdub, 3.6m 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 3.6 metres.</td></tr>
<tr><td>Large high value class</td><td>Minimum SED (mm)</td><td>Minimum length (m)</td></tr>
<tr><td>1</td><td>390</td><td>2.4</td></tr>
<tr><td>2</td><td>380</td><td>3.6</td></tr>
<tr><td>3</td><td>370</td><td>5.0</td></tr>
<tr><td>4</td><td>360</td><td>7.0</td></tr>
<tr><td>5</td><td>350</td><td>9.0</td></tr>
<tr><td>6</td><td>340</td><td>11.0</td></tr>
<tr><td>2</td><td colspan="3">NPWS Option: 30cm sed, 2.4m min length
High Quality Large sawlogs were cut with a SED of 30cm, and a minimum length of 2.4 metres.</td></tr>
</table>

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. Species and timber quality information is assigned based on the proportion of trees by species and quality code in regrowth stands of the appropriate yield association group. The values for each species is calculated from the original strategic inventory data.

Other recruitment settings include:

- *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 ‘natural’ 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 different conditions for regeneration due the presence of large canopy openings (40 to 100m in diameter).

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 that will populate the gaps. The stocking density used to recruit new gaps is based on the average small regrowth stocking levels for that yield association group, modified by the gap size ‘recruitment frequency factor’ (Section 5.3.2). The user has the option of manually altering the default regrowth frequency 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.

5.4 COMPUTER SOFTWARE SYSTEMS DEVELOPMENT

The initial Yield Simulator systems development took approximately 18 months to complete for the UNE and LNE CRA Regions. Subsequent modifications and enhancements for SCRA required 3 months. The application has been 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 style 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.

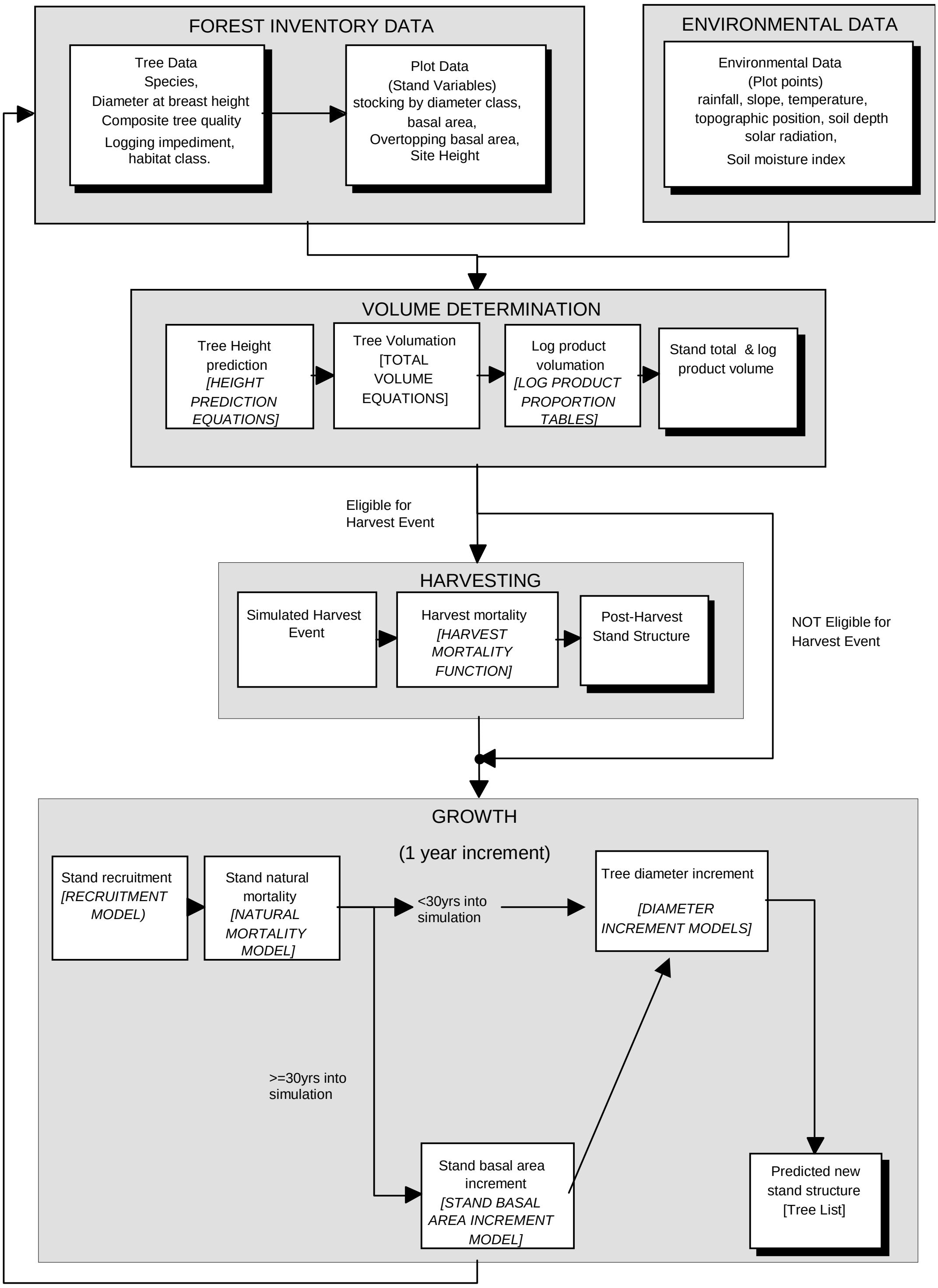
The system models each plot independently in the simulation environment (each plot only contributes yield when it is capable of doing so). This methodology caters extremely well for the dynamics of native forest stratum, allowing the localised plot level maturity to be reflected in the yield tables that 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, Silvicultural prescriptions). 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 200 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 5b7 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 * temperature) - (0.00000605 * temperature ^ 2)) * (solar * 120000 / 365.25) Pres_ind = (0.445 * rain * 1000) / (e ^ 0.75)

TABLE 5.8: PRIMARY LEVEL PROCESSES IN GROWTH SIMULATION

Process No.	Description	Sub-Process Details
1.	Calculate the initial stand density index, number of trees per hectare (SPH) and Basal area (BA)	
2.	Determine recruitment	2.1 – 2.6
3.	If the basal area is > 2 m²/ha or there are more than 100 stems per hectare then determine mortality	3.1 – 3.6
4.	If the simulation year is > 30 and BA > 10 then calculate predicted stand level basal area growth (BA_T)	4.1 – 4.4
5.	Grow the individual tree diameters	5.1 – 5.9
6.	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	
7.	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 = -8.4626 'Intercept Const a1 = -0.0796 'ba Const a2 = 3.0027 'log(ba) Const a3 = 0.0156 'qmdi Const b0 = -10.579544 Const b1 = -0.035371 Const b2 = -4.642827 Const b3 = 4.631009 Const b4 = 0.018889

Process No.	Description
2.2	Calculate quadratic mean diameter qmdi = Sqrt((plot_ba / plot_sph) * 4 / pi) * 100
2.3	Probability of no recruitment occurring = 1 / (1 + Exp(-(a0 + (a1 * plot_ba) + (a2 * Log(plot_ba)) + (a3 * qmdi))))
2.4	Potential_recruits = Exp(b0 + (b1 * plot_ba) + (b2 * Log(plot_ba)) + (b3 * Log(sdi1)) + (b4 * Pres_ind))
2.5	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.
2.6	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 is 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 = -2.3518 Const a1 = -0.1034 Const a2 = 0 Const a3 = 0 Const a4 = 5.168 Const a5 = 0.1483 Const a6 = -2.9567 Const a7 = -0.0921
3.2	For each tree calculate the probability of survival as follows: x = a0 x = x + a1 * dbh x = x + a2 * (10 / dbh) x = x + a3 * (dbh ^ 2 / 1000) x = x + a4 * Log(dbh) x = x + a5 * (Plot BA) x = x + a6 * Log(Plot BA) x = x + a7 * Over_topping_BA Probability of survival = p_survival = (1 + Exp(-x)) ^ -1
3.3	If a tree's quality is "High" Then p_survival = p_survival + (0.5 * (1 - p_survival)) for that tree
3.4	If a tree's quality is pulp or waste and the tree's diameter is within 25% of the maximum diameter for the species then p_survival = p_survival - 0.15;
3.5	If a tree's quality is pulp or waste and the tree's diameter is within 10% of the maximum diameter for the species and the plot basal area is greater than the basal area limit for the yield association group then p_survival = p_survival - 0.2;
3.6	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.

Assumptions:

⇒ If a tree has a dbh less than 15cm then the model is applied assuming a dbh of 15cm;

⇒ High quality trees have the probability of mortality halved;

⇒ Pulp and waste trees have their mortality influenced by how close the tree's size is relative to the species maximum potential size. Size limits are stored in the "Species Data" worksheet of the Yield Simulator System.

TABLE 5.11: BASAL AREA GROWTH MODEL SUB-PROCESS

Process No.	Description
4.1	Read in Basal Area Model Coefficients for current Growth Group (b0 – b9)
4.2	Sum the current number of trees per hectare present (SPH2)
4.3	Calculate the current stand density index (SDI2) = Σ(sdi) for all trees
4.4	Calculate Basal Area increment (BA_T) for one years growth: ba_t = b0 ba_t = ba_t + (b1 * Log(plot ba)) ba_t = ba_t + (b2 * Log(initial sph)) ba_t = ba_t + (b3 * (initial sph / sph2)) ba_t = ba_t + (b4 * Log(sdi1)) ba_t = ba_t + (b5 * (sdi1 / sdi2)) ba_t = ba_t + (b6 * position * 0.01) ba_t = ba_t + (b7 * solar) ba_t = ba_t + (b8 * soil_depth) ba_t = Exp(ba_t)

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);

⇒ If the plot basal area is greater than 60m2/ha then the stand cannot grow more than 0.2 m2/ha/yr.

⇒ Total standing basal area is constrained by maximum limits set at the yield association group level. The following table summarises the limits:

Yield Association Group Code	Yield Association Group Description	Standing Basal Area Limit
1	Blackbutt/Sydney Blue Gum	50
2	Spotted Gum	60
3	Silvertop Ash	70
4	Stringybark/Coast Grey Box/Forest Red Gum/Woollybutt	50
5	Brown Barrel/Messmate	60
6	Gum	50
7	Apples/Peppermint/Scribbly Gum	50
8	Bago/Maragle Alpine Ash	70
9	Riverina Hardwoods	50

⇒ If the total standing basal area is greater than the limit then basal area growth = 0.1 m2/ha/yr

⇒ If the total standing basal area is greater than 1.2 times the limit then basal area growth = 0.05 m2/ha/yr

TABLE 5.12: INDIVIDUAL TREE GROWTH MODEL SUB-PROCESS

Process No.	Description
5.1	Read in Diameter Increment Model Coefficients for current Yield Association Group (d0 – d18 and cf1,cf2).
5.2	For each tree undertake the diameter increment calculation: ldi = d0 ldi = ldi + (d1 * dbh) ldi = ldi + (d2 * (dbh ^ 2) / 1000) ldi = ldi + (d3 * 10 * (1 / dbh)) ldi = ldi + (d4 * Log(dbh)) ldi = ldi + (d5 * Log(plot ba)) ldi = ldi + (d6 * plot ba) ldi = ldi + (d7 * Log(plot ba) * Log(dbh)) ldi = ldi + (d8 * over_topping_ba) ldi = ldi + (d9 * (over_topping_ba / plot ba)) ldi = ldi + (d10 * (Log(over_topping_ba + 0.01) / Log(dbh))) ldi = ldi + (d11 * Log(over_topping_ba + 0.01) * Log(plot ba)) ldi = ldi + (d12 * rain) ldi = ldi + (d13 * solar) ldi = ldi + (d14 * slope) ldi = ldi + (d15 * position) ldi = ldi + (d16 * moisture_index) ldi = ldi + (d17 * soil_depth) ldi = ldi + (d18 * temperature) where ldi is a temporary variable storing the values from each of the model steps
5.3	Calculate diameter increment = (Exp(ldi) * cf1) - cf2
5.4	If diameter increment < 0 Then diameter increment = 0
5.5	If diameter increment > 1.2 And dbh < 20 Then diameter increment = 1.2
5.6	If diameter increment > 2 Then diameter increment = 2
5.7	If tree quality = "waste" Then diameter increment = 0.3 * diameter increment
5.8	Calculate new tree diameter (dbh) = old dbh + diameter increment
5.9	Calculate new tree basal area = (dbh / 200) ^ 2 * pi * .wt

Notes on Individual Tree Growth

The following assumptions are imposed on the diameter increment model:

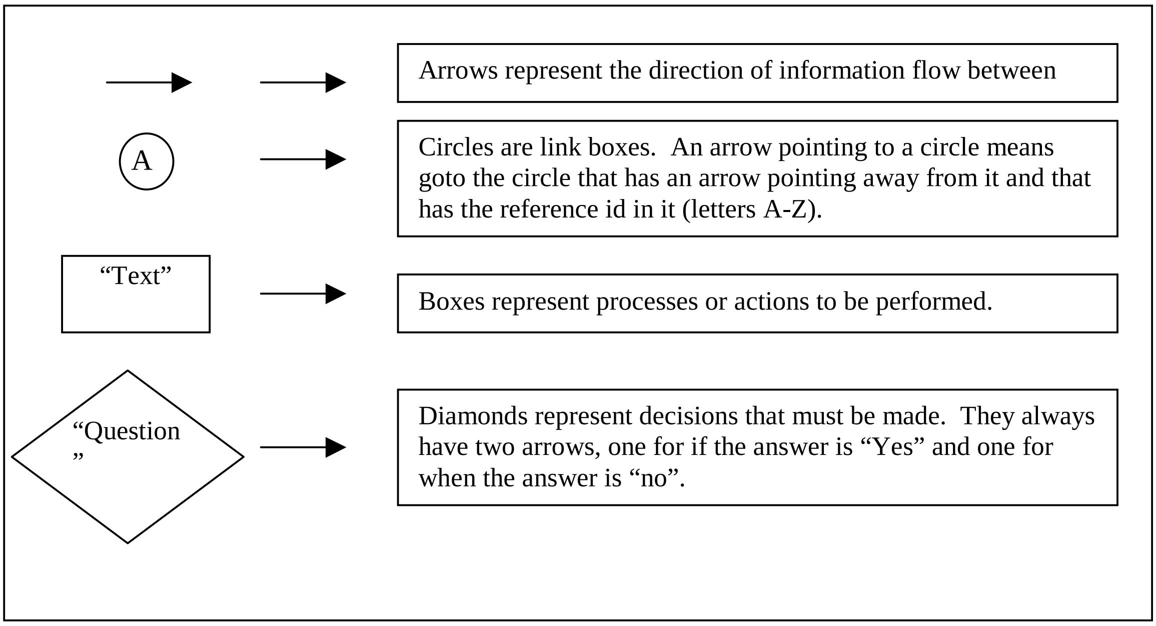
- ⇒ Recruitment grown on group selection gaps have a starting diameter between 5 and 10cm. While these trees remain less than 10cm, the individual diameter growth is based on a 10cm tree;
- ⇒ No tree is allowed to grow backwards (ie. shrink);
- ⇒ Trees less than 20cm are not allowed to grow more than 1.2cm/yr;
- ⇒ No tree is not allowed to grow more than 2cm/yr;
- ⇒ Waste trees are constrained to 0.3 times the predicted growth rate;
- ⇒ Trees within 30% of the maximum diameter for the species cannot grow more than 0.2cm/yr;
- ⇒ Trees within 10% of the maximum diameter for the species cannot grow more than 0.1cm/yr;
- ⇒ Trees at their maximum diameter for the species cannot grow further.

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 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



Arrows represent the direction of information flow between

Circles are link boxes. An arrow pointing to a circle means goto the circle that has an arrow pointing away from it and that has the reference id in it (letters A-Z).

Boxes represent processes or actions to be performed.

Diamonds represent decisions that must be made. They always have two arrows, one for if the answer is “Yes” and one for when the answer is “no”.

FIGURE 5.4 INFORMATION FLOW WITHIN SINGLE TREE SELECTION SILVICULTURAL SIMULATION

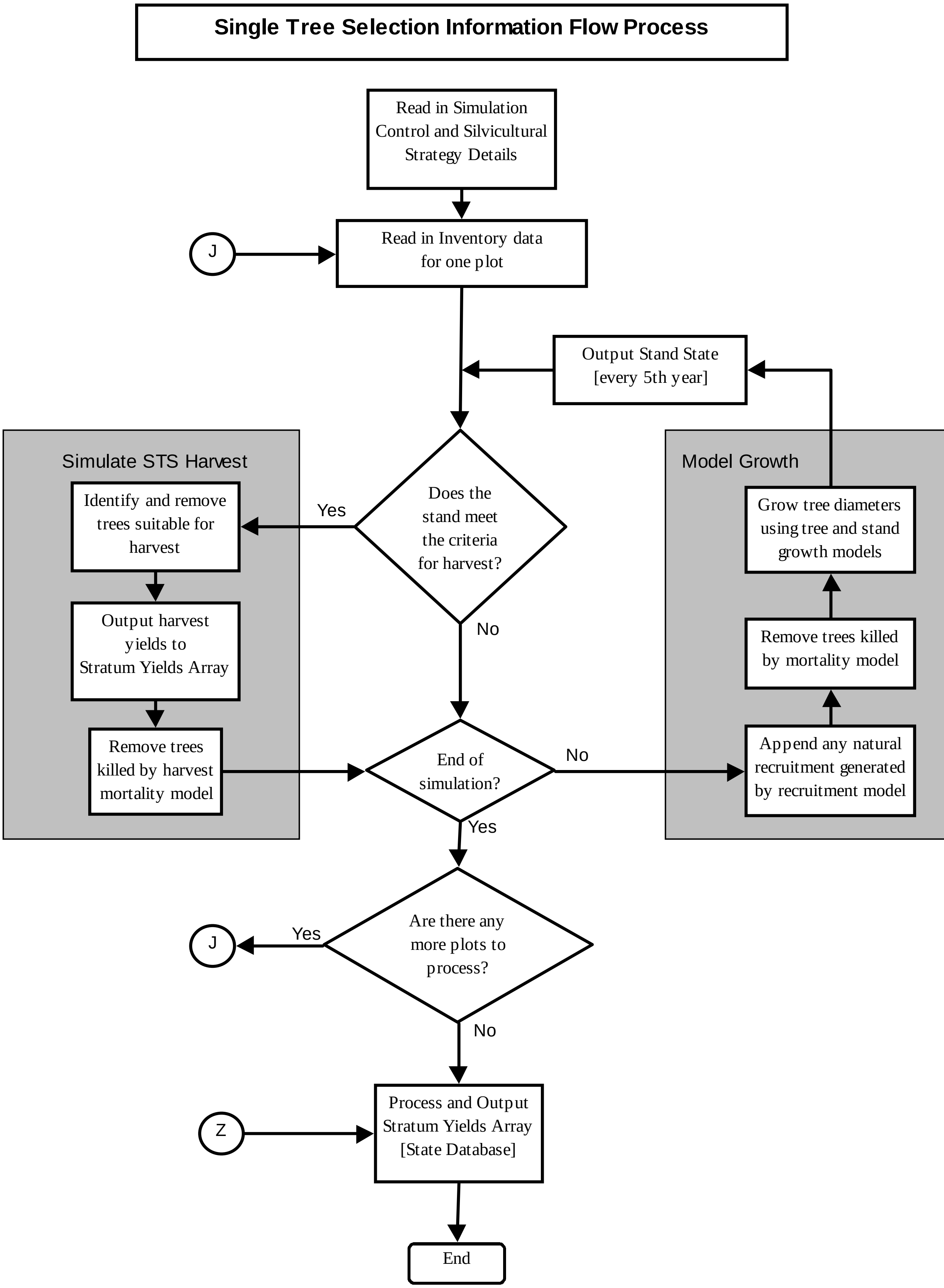


FIGURE 5.5: INFORMATION FLOW WITHIN GROUP SELECTION SILVICULTURE [PART 1]

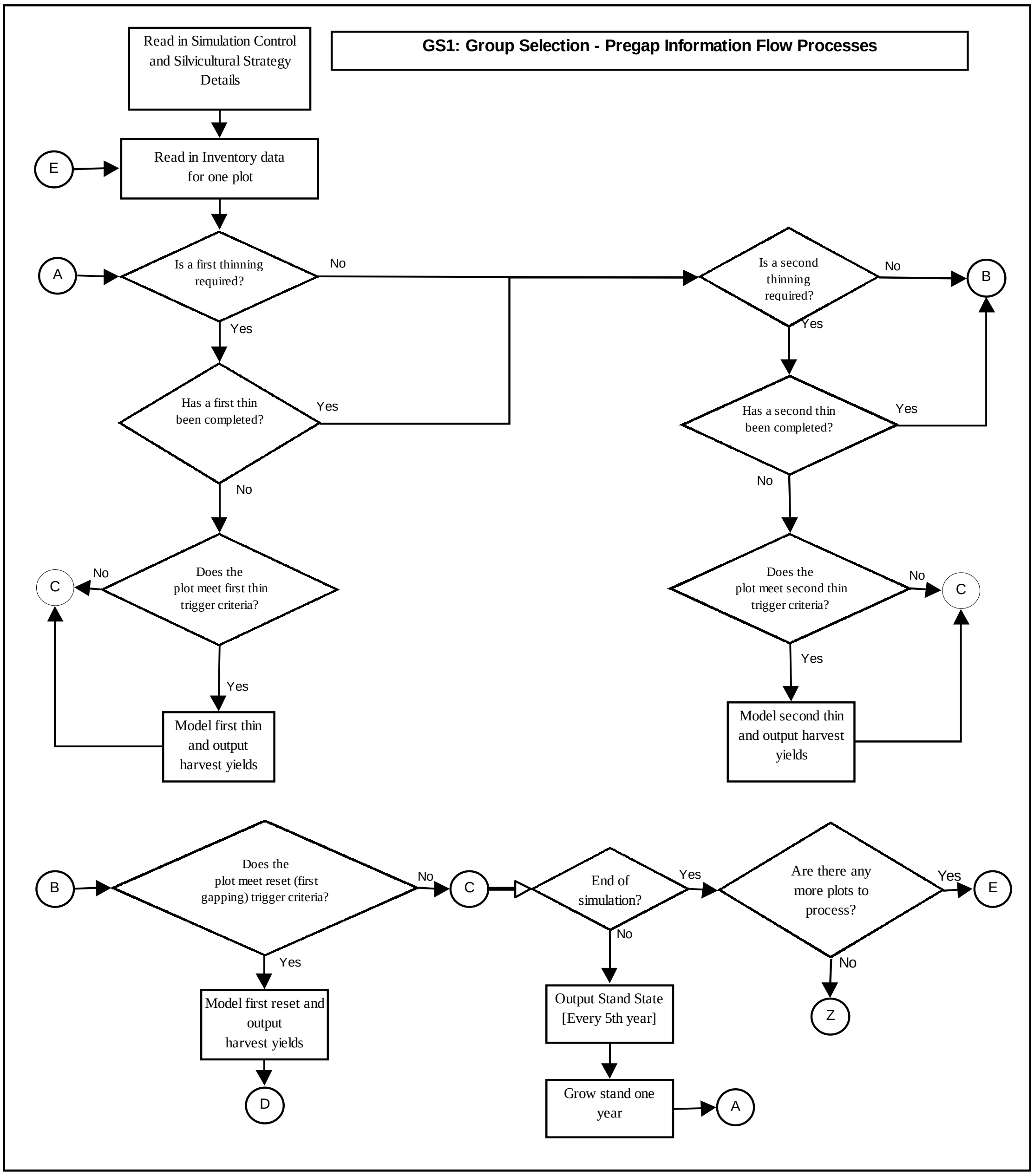


FIGURE 5.6: INFORMATION FLOW WITHIN GROUP SELECTION SILVICULTURE [PART 2]

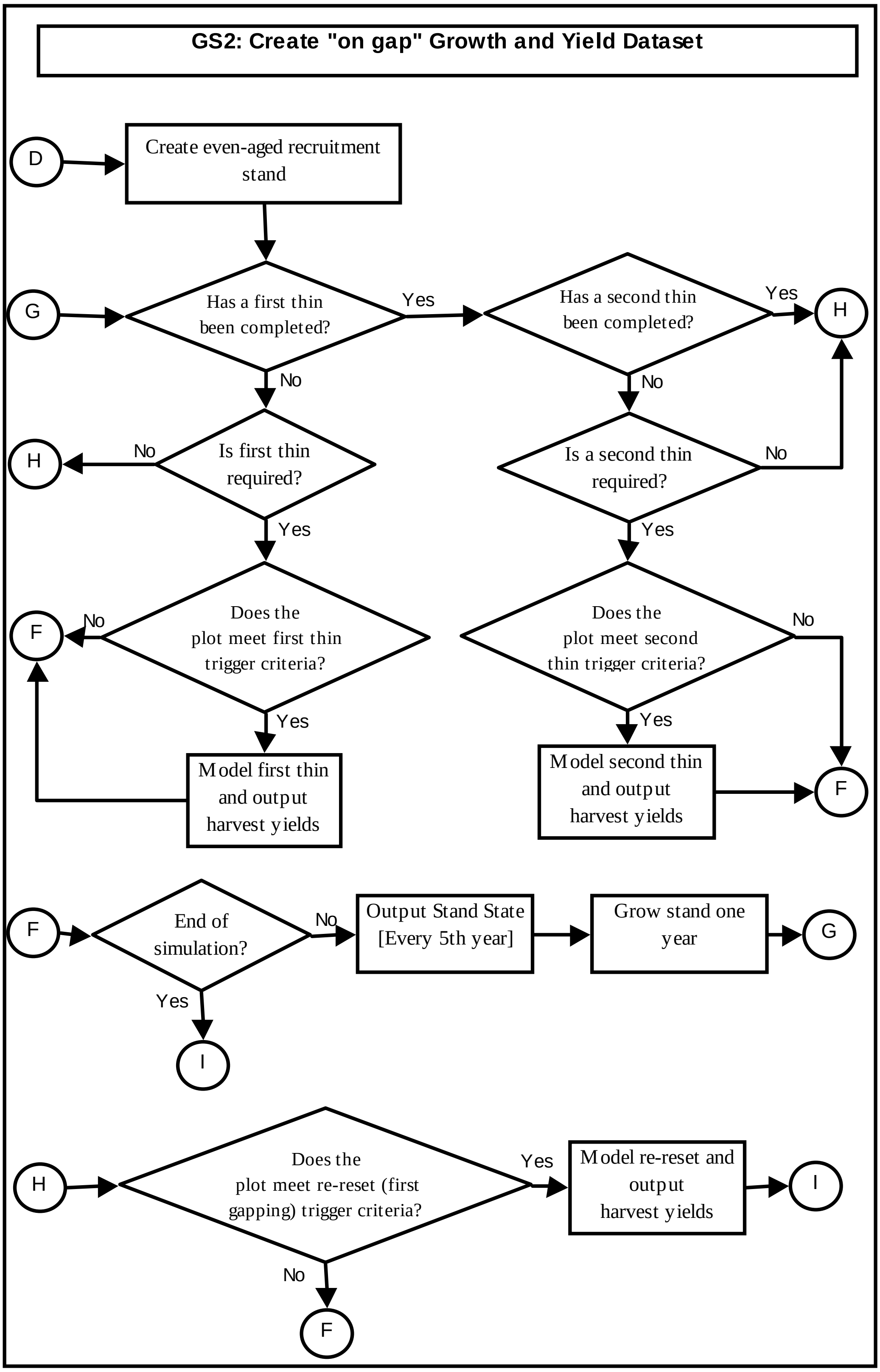
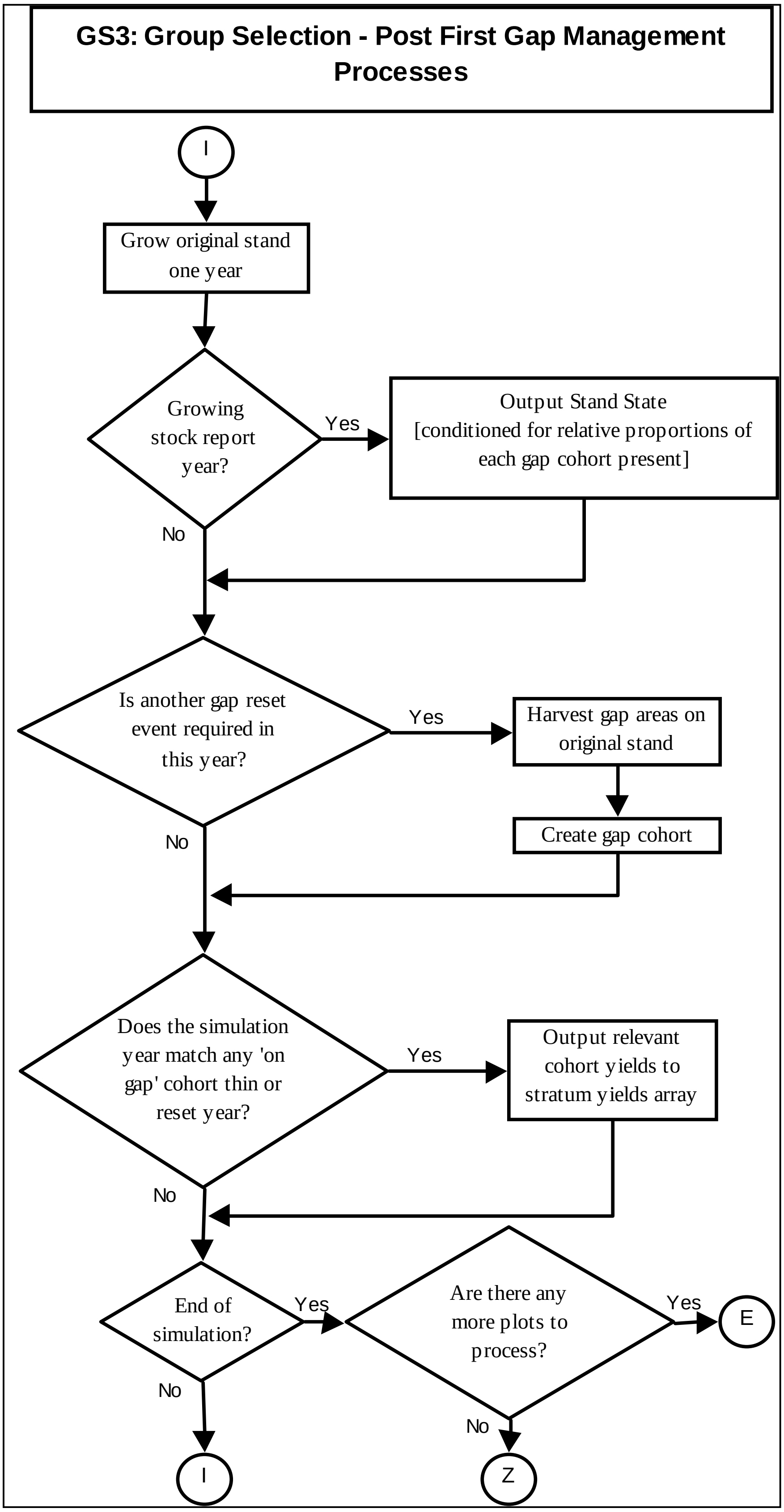


FIGURE 5.7: INFORMATION FLOW WITHIN GROUP SELECTION SILVICULTURE [PART 3]



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
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	
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	**1880**	n	m*l
Average Yield Per Hectare for the Stratum:	12	11.25	12.5	11.25		o	h/b
Calculated Total Yield:	480	450	500	450	**1880**	p	o*a

(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 = 12m3/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 = 24m3/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 SCRA negotiations (Ver 5b7), 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. VARIATIONS FROM UNE/LNE MODELLING APPROACH

This section provides a summary of methodological changes that have been implemented into the yield simulator that vary from the system used for UNE/LNE CRA Regions.

- Structural code enhancements have been incorporated which improve processing performance while permitting longer simulation runs (now nominally restricted to 250 years).

- Improvements have been made to the simulation control interface to clarify the user definable settings.

- Natural recruitment now uses the characteristics of regrowth stands associated with each yield association group to assign species and tree quality.

- The calculation of composite tree quality classes has been altered to reflect the merchantability standards and market availabilities of the South CRA Region. The following tree quality assignment rules were implemented:

Tree Quality Class	**Decision Rules**
H	At least 3.6 metres of high quality wood (class A).
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)
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)
W	Not capable of being classified as P

- Group selection silviculture is now more responsive to user requirements with both pre-gap and on-gap thinning now specifiable at the stratum level.

- The dominance factor that was used to represent gap size in the group selection scenario definitions has been removed because dominance is no longer used in the growth model. Recruitment frequency adjustment has replaced the dominance boost variable.

- Region specific biometric models have been incorporated.

- The state database format has been altered to be more explicit. This also increases flexibility when importing yield tables to in the interaction with Spectrum. New fields have been introduced:

- Silviculture (AGS/STS);
- Intensity (Light/Medium/Heavy)
- Return Time Scenario (1-9)
- Delay (0-10)
- Period (1-40)

- The “No Cut” simulation has been removed from the full batch run and is now a separate module.

- The growth models now also reflect differences in growth found to be caused by tree quality (waste tree growth rates have been reduced).

- The mortality and diameter growth models have been refined to reflect maximum tree diameters. The maximum tree diameters were calculated from the strategic inventory data and are stored in the Species Data worksheet.

- The NPWS Log Cutting Strategy option has been calculated and incorporated into the Simulator.

- Tree quality class distributions from the South Coast strategic inventory did not adequately reflect pre-merchantable tree quality. Reviews of the data identified that small trees appeared to be classified based on their current merchantability rather than their potential. This resulted in nearly 100% of trees in the 10-20cm category being classified as waste, an aberration that does not reflect the true nature of regrowth stands across the region.

  The tree quality issue was addressed by reassigning the quality codes for pre-commercial trees in the strategic inventory treelist. The data used for the re-allocation was drawn from stratum with regrowth characteristics. As trees between 60 and 70cm dbhob in these stands represent the most realistic picture regrowth quality, proportions were calculated from these diameter cohorts. The proportions are stored in the Species Data worksheet of the simulator system.

  To automate the quality redistribution process a new field was added to the simulator control panel that allows the user to specify the ‘maximum dbh for tree quality redistribution’. Any tree in the original inventory with a diameter less than the number specified gets reallocated. To totally bypass the reallocation algorithm, the user would specify a maximum dbh of ‘1’ cm.

  The reallocation methodology is the same as that used to assign species and tree quality information to new recruitment. A random number is generated and this is used to determine which new quality code to assign. If the proportion of H was 26.1% then there is a 26.1% chance of the new code being H.

  As trees with a dbh less than 40cm are well below current merchantable diameter limits and the quality deviation becomes apparent below this level, the reallocation diameter limit was set to 40cm dbhob.

The reallocation algorithm was not required to be applied to the Tumut inventory data.

7. 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 Southern CRA negotiations comes stamped with a Version 5b7 identification code on the control panel. Two systems were created for this version, one specific to the South Coast Sub Region and one specific to the Tumut Sub 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.

APPENDIX 1 – TREE DEFECT MODIFIER PROJECT REPORT

Forest Resources and Management Evaluation Systems

Southern CRA Region

Tree Defect Modifier Project Report

S T A T E
FORESTS

Forest Resources Branch
State Forests of
New South Wales
Building 2
423 Pennant Hills Road
Pennant Hills, Sydney
NSW 2120
Phone (02) 9980 4100

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. The presence of defect in a tree stem is often indicated by external features such as hollows, dead limbs, lumps and bumps and scarring. 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 preharvest 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 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 clearly indicate 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 standard volume formula within the State Forest log sales system software (ForSale).

The difference between inventory product volume estimates and actual harvested product volume is termed Regrade volume. Where Regrade is statistically significant, correction factors (modifiers) will be calculated. 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 underway from April to July 1999.

3. Methodology and Procedures

The Tree Defect Sub-Project was divided into 9 main tasks as follows:

Task 1. Defining the sampling area, sampling methodology and stratification
Task 2. Field procedure development;
Task 3. Recruitment and training of inventory crews;
Task 4. Data collection
Task 5. Customising software for data entry and analysis;
Task 6. Data entry;
Task 7. Analysis;
Task 8. Reporting

3.1 Defining the Sampling Area and Sampling Methodology

3.1.1 Sampling Areas

Sampling areas are defined as compartments within State Forests for which harvest plans were already approved. Practical considerations ruled the selection of harvest areas that were sampled during this project. State Forest compartments were selected based on the availability of Supervising Forest Officers at each District to assist with data collection within the time frame specified for the project. Sampling occurred in native forest harvesting operations within State Forests during April to July 1999. The names of sample sites are listed in Table 1.

Table 1. Locations for collection of data for the Tree Defect Project.

Management Area	**CRA Sub Region**	**State Forest**	**Compartment**
Bago/Maragle	Tumut	Bago	28
Tumut	Tumut	Buccleuch	8062
Narooma	South Coast	Wandella	3282
Narooma	South Coast	Bodalla	3012
Narooma	South Coast	Moruya	3239
Batemans Bay	South Coast	North Brooman	58
Batemans Bay	South Coast	North Brooman	63
Batemans Bay	South Coast	Mogo	199
Queanbeyan	South Coast	Tallaganda	2439
Queanbeyan	South Coast	Tallaganda	2476

The following information was provided by the Regions to assist in making selection(s) for sampling:

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, single tree selection operation).

The sample area corresponded to the net harvestable forest area 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 or selected for removal were assessed, with coordination with the tree faller to select the trees that were going to be felled in the ordinary course of harvesting.

3.1.2 Size and Shape of Sample Area

The inventory crew recorded the sample area boundary by plotting the approximate boundary onto the harvest plan map provided. The boundary demarcated the sampling area for stratification purposes only.

The sample area had no standardised size or shape. It conformed to the topography of the forest surrounding the dump site and was demarcated by natural boundaries such as gullies and associated exclusion zones. The furthest extent of the sampling area was limited by the snigging distance to the dump site.

3.1.3 Sampling Methodology

The method was refined from earlier northern region method to focus on the primary objective - collection of information to show the level of regrade that is currently applicable to native forest inventory estimates. Harvest areas were selected at random from the list of potential harvesting events occurring on each day of measurement. Once the measurement crew was on site, pre-harvest assessment work was completed using 100% sampling of all trees to be fallen by the contractor. Each tree selected in this way was assessed using the MARVL methods as per the Strategic Inventory to ensure compatibility between the predicted volumes.

The post-harvest assessment was confined to recording of the dimensions and grade of logs on the dump.

3.2 Recruitment and Training of Inventory Crews

Data collection was performed by a 3 person crew consisting of:

1. Crew Leader (Strategic Inventory experienced);
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.

All crew members were trained in the procedures for this project. Responsibility for the pre harvest assessment was with the crew leader and the SFO was relied upon for log grading on the dump.

Particular emphasis was made of the need to work in with the harvesting crews and a high emphasis was made of safety awareness.

3.2.1 Equipment

4WD vehicles and inventory equipment were provided by the regions. All staff were issued with high visibility clothing and hearing protection equipment for use in harvest areas.

3.3 Data Collection

The post harvest proforma was customised for use in the Southern CRA region but retained the essential fields from the previous Northern CRA region pro forma.

3.3.1 Sample Area Variables

Variables used to describe the sample area included location identifiers and some strata identifiers. The strata identifiers included Site Height, Yield Association and Stand Structure. The variables recorded in the field at each sample area, or defined later by post-stratification are listed below:

1. District Name;
2. State Forest Name;
3. Management Area Name;
4. Compartment Number;
5. Date;
6. Crew Members;
7. Sample Area Number;
8. Site Height;
9. Yield Association Identifier.

3.3.2 Tree Variables

In Management Areas where it is the policy to mark trees for **removal** prior to harvesting (e.g. Bago/Maragle), only these trees were assessed. In Management Areas (e.g. Batemans' Bay, Narooma, Queanbeyan/Badja) where it is the policy to mark trees for **retention**, then the Supervising Forest Officer or faller indicated the stems that would be harvested, and only those trees were MARVL assessed. The following information was recorded for each tree:

1. Tree Number;
2. Species Code;
3. Dbhob;
4. Dominance Class (Section 16.5);
5. Crown Condition Class (Section16.6);
6. MARVL timber product profile incorporating product description codes (Section 16.7);
7. Tree Top Height;
8. Slope;
9. Aspect Index (Section 16.4).

3.3.3 Log Dimension and Grade Variables

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 rules[1]. The resulting defect volume indicated the appropriate product grade for that log. The grade and the dimensions of each log were recorded.

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[1] For the post harvest assessment the Harvest Log Measurement Manual for use in South East Region (South Coast Sub Region) and local grading rules Riverina Region (Tumut Sub Region) were used.

The grades assigned to logs was in some instances limited by the market availablity 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 fulfillment of quota agreements had priority over value optimisation (ie. Boral operations). A significant level of pulp grade material was graded as waste due to the absence of a pulp market.

The following information was recorded for each log:

Southern CRA

1. Sample Area Number;
2. Tree Number;
3. Point of Stem Breakage (if breakage occurs at ground impact);
4. Stump Cut Height;
5. Log grade;
6. Log Section Number (ascending order from butt to head);
7. Centre Diameter under bark;
8. Section Length;
9. Length Deduction; *(South Coast only)*
10. Pipe Defect; *(South Coast only)*

3.3.4 Stump Height

After harvesting, the stump height of each sample tree was measured and recorded.

3.3.5 Precision Auditing

The nature of this inventory greatly reduced the possibility of independent 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 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 required measuring standards were maintained by the inventory crew.

3.4 Customising Software for Data Entry and Analysis

MARVL data entry files were customised to include the plot and tree variables outlined above. Yield Association was used for stratum.

For the Southern CRA the cutting strategy and function sets used were the same as those developed for the Strategic Inventory, specific to both the South Coast and Tumut Sub Regions.

An Excel worksheet was developed to allow entry and storage of all log dimension and defect measurements. The Southern worksheet calculated volume using Hubers equation (as per FORSALE).

3.5 Data Entry and Verification

Tree Defect Project data was checked by the Project Supervisor. Missing or incorrect fields in the original field data were encountered during data entry, and the following table indicates the method of dealing with known data collection errors. All entered data was verified by checking the interchange file against the original data sheets or with the inventory crew notes. Any mistakes were subsequently changed in the interchange file.

Table 2. Management of mistakes and omissions in original field data records.

Error	**Compartment**	**Data Management**
Log Number	All Compartments	All log numbers were accounted for. Sections butted to waste at the stump were measured and added to the log measurment pro-forma after grading was completed at the dump.
CDUB	Batemans Bay MA	The CDUB was not measured for 5 logs, all of them pulp or waste trees. The CDUB for all unmeasured logs was estimated by using the CDUB from the logs above and below, calculating the rate of taper and deriving the CDUB from the CDUB of the log below. These are noted.
Log grade	Narooma MA	Initial incorrect use of MARVL quality codes instead of log product code was detected and corrected for both the original and future measurements by the crew.
Break	South Coast	Occasional omission an entry in the Break field were assumed to be a null and corrected at data entry.
Log Dimensions	South Coast	Occasional errors in units in the post harvest measurements: Log length, CDUB and length deduction. Corrected in data entry.

3.6 Analysis and Results

Product log volumes were calculated per tree for both the pre and post harvest measures and comparisons were made within each yield association group and product class. Pre-harvest log volume was an output from the MARVL software program. Post harvest log volume was calculated using Huber's volume formula as per the current methods used by State Forest in the sale of logs. Statistical significance was tested using a T test per yield association group and product class. Below is the summary of results for the comparison between Large High Value product class from the pre harvest measure and quota sawlog from the post harvest measure.

Table 3

Yield Association			**Pre Harvest Volume LHval**	**Post Harvest Volume Quota**	**% Post to Pre**
Group	**Yield Assoc Numbers**	**Name**			
1	1 & 2	Blackbutt/ Sydney Blue Gum	149.811	128.714	86%
2	3	Spotted Gum	111.851	107.961	97%
3	4	Silvertop Ash	32.358	11.269	35%
4	5 & 6	Stringybark/Coast Grey Box/For. Red Gum/Woollybutt	269.160	185.223	69%
5	9	Brown Barrel/Messmate	38.146	30.43	80%
6	10	Gum	58.398	42.015	72%
7	7 & 11	Apples/Peppermint/Scribbly Gum	NA	NA	
8	18	Alpine Ash	320.451	226.738	71%
9	19 to 22	Riverina Hardwoods	357.541	321.322	90%
Overall Averages			**1,337.7**	**1,053.7**	**78.8%**

The results highlight that only 8 yield association groups were sampled in the study. The Apples/Peppermint/Scribbly gum types were not be sampled because no harvesting of these types occurred during the study. The silvertop ash types also had a very low sample size due to the limited harvesting of these areas. The overall averages were applied to these two groups due to their low sampling levels.

The results identify that on average the FORSALE log merchandising system recorded only 79% 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 35% in the limited sampling of silvertop ash types up to 97% in the spotted gum types.

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.

4. 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.

The final modifier values used are in the simulator are presented in Table 4.

Table 4: Defect Modifier Proportions applied in the Yield Simulator

Yield Association Group Description	Yield Association Group Code	ACTUAL as % of MARVL	Proportion used
Blackbutt/ Sydney Blue Gum	1	85.9%	85.9%
Spotted Gum	2	96.5%	96.5%
Silvertop Ash	3	34.8%	78.8%
Stringybark/Coast Grey Box/For. Red Gum/Woollybutt	4	68.8%	68.8%
Brown Barrel/Messmate	5	79.8%	79.8%
Gum	6	71.9%	71.9%
Apples/Peppermint/Scribbly Gum	7		78.8%
Alpine Ash	8	70.8%	70.8%
Riverina Hardwoods	9	89.9%	89.9%
Overall Averages:		78.8%	

5. Appendices

5.1 *Yield Association*

Yield Assoc. No.	**Yield Assoc. Name**	**Res Note 17 Types**
1	Blackbutt	36, 37, 39, 41, 42
2	Sydney Blue Gum	46, 49, 50
3	Spotted Gum	70, 73, 74, 75, 76
4	Silvertop Ash	112, 113, 114, 162
5	Stringybark	68, 84, 115, 116, 121, 123, 126, 128, 130, 132, 133, 169
6	Coast Box-Forest Red Gum-Woollybutt	63, 65, 85, 86, 88
9	Brown Barrel - Messmate	150, 151, 152, 154, 155, 156
10	Gum	157, 158, 159, 160, 165, 166, 141

5.2 *Aspect*

Record the magnetic bearing of the direction of maximum slope as a 1-digit code. Aspect codes are:

1 = 0 – 45 deg
2 = 45- 90 deg
3 = 90-135 deg
4 = 135-180 deg
5 = 180-225 deg
6 = 225-270 deg
7 = 270-315 deg
8 = 315-360 deg
9 = Flat - no appreciable aspect.

5.3 *Dominance Class*

1 = <u>Dominant</u>, crowns extending above the general canopy, receiving full light from above and partly from the side;

2 = <u>Co-dominant</u>, crown forms part of the general canopy, receives full light from above and little from the sides;

3 = <u>Sub-dominant</u>, crown extend into general canopy but beneath 1 and 2, receives a little light from above but none from the sides;

4 = <u>Suppressed</u>, crown entirely below general canopy, receives no direct light from above or sides.

5.4 Crown Condition

1 = Good, leafy vigorous crown;

2 = Fair;

3 = Poor, senescent, diseased or damaged crown.

5.5 MARVL Product Codes

E = ‘elite’ quality - able to make , now or in the future, veneer, pole, pile or girder.
A = high quality – now or future quota sawlog.
B = low quality – marginal sawlog/pulplog
P = pulp quality
W = waste
T = top height code, special case of waste.

APPENDIX 2 – NET HARVEST AREA MODIFIER PROJECT REPORT

Forest Resources and Management Evaluation Systems

Southern CRA Region

Net Harvest Area Modifier Project Report

Forest Resources Branch
State Forests of
New South Wales
Building 2
423 Pennant Hills Road
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NSW 2120
Phone (02) 9980 4100

Executive Summary

- The Net Harvest Area modifier provides a spatial reduction to predicted volume. It is calculated using a subset of exclusion categories not catered for elsewhere in FRAMES. The exclusion categories used in the modifier are:
    - Steep areas not previously mapped
    - Inaccessible (other than steep) including rocky areas and topographically isolated areas.
    - 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 equation produces an average harvest proportion of 82% with a range of 34% to 100%. The modifier is spatially applied and depends on the erosivity, slope and distance to nearest non-harvestable boundary.

- The key variation from the UNE/LNE study is that unmapped drainage for Southern CRA was not modelled. The effects of unmapped drainage on areas of exclusion were incorporated into the category of filter strip extensions. Unmapped drainage lines cannot be segregated from filter strip width extensions through this process.

- The buffer width used to represent harvesting protocols within the study compartments was re-evaluated for Southern CRA. A constant buffer width of 15m was applied to all mapped drainage. This provides a conservatively wide estimation of the protocols in place at the time. This is supported by the minimum modifier value being well above zero at the filter strip edge (minimum 34%).

- The modifier function is applied to the FRAMES Net Harvest Area and is calculated using current non-harvestable exclusion boundaries (filter strip/riparian buffers, rainforest polygon boundaries and State Forest tenure boundaries), GIS modelled slope and modelled rainfall erosivity index.

1 Introduction

27 compartments were selected for the project in the Southern CRA Region from both the South Coast Sub Region and the Tumut Sub Region. The compartments were selected in 1997 on the criteria of recent logging and covering the ranges of geographical distribution and types of forest in the Southern CRA Region.

Aerial photography at 1:15, 000 scale was taken over the compartments and 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 Regional field staff were essential components for achieving accuracy and consistency.

The net harvest area modifier deals only 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 did not include any existing mapped layers or other FRAMES components (e.g. NPWS Conservation Protocol strike rate categories, Strategic Inventory pre merchantable areas).

This project used a similar analysis technique to that applied in the Upper and Lower North-East CRA Region, however some modifications have been made to the methodology of this project. The most significant difference is the treatment of unmapped drainage. In the current study GIS coverages for the calculation of filter strips were based on LIC drainage which does not account for all drainage features that would be considered on the ground. In UNE/LNE CRA Region unmapped drainage features were able to be modelled and therefore were excluded in filter strips from the modifier dataset. The API work recorded all areas on the ground that were not harvested due to filter strip protocols. These codes are then used to measure the impact of actual drainage features outside the predicted filter strips.

The sample compartments were harvested in 1995/96 and 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 between compartments. It was not feasible to strictly apply all the varying conditions and instead an arbitrary buffer width on drainage was applied.

The Southern CRA project used vector based continuous variables where possible to provide a more accurate range of values in the dataset. The variables that were made available with continuous integer values for the Southern CRA study are soil regolith, rainfall isopleth, slope and distance to filterstrip boundary.

2 Methodology

2.1 Areas selected for study

27 compartments were selected for the project in the Southern CRA Region from both the South Coast Sub Region and the Tumut Sub Region. The compartments had been harvested between 1995 and 1996 and covered the range of geographical distribution and types of forest in the Southern CRA Region.

2.2 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. See Table 2.2 below. 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, the dominant reason was listed first.

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	?

2.3 Independent Field Verification

The API expert undertook extensive field validation of the code work. Independent field verification of the API linework was undertaken by a trained State Forests Net Harvest Area Modifier crew. The team visited every compartment and audited approximately 10-15% of the polygons.

2.4 Data Entry

Validated API linework was digitised into ArcInfo coverages for all compartments. The linework consists of a complete cover of non-overlapping polygons. This linework then formed part of the combined GIS coverage developed in the data analysis component of this project.

2.5 Data Analysis

2.5.1 Study Compartment Spatial Dataset Collation

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

Description of cover
A. Soil Regolith - indicates the dominant occurrence of a class of regolith
B. Rainfall Erosivity Isopleth - Integer number up to 4 digits, one value per compartment
C. Slope - may comprise a range from 0 to 90 degrees inclusive
D. Yield Association, or other measure of tall/not tall forest - 1 = Tall, 2 = Not Tall and 3 = Not Tall/Non-commercial. (see Appendix 2 for full description)
E. Ruggedness - integer values from 0 to 60
F. Filter Strips - 15m buffer (each side) applied to all LIC drainage structures.
G. 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.
H. Southern CRA Sub-region - Western or South Coast
I. State Forest Name
J. State Forest No.
K. Compartment No.
L. FRAMES Area study Code - Harvest codes from API work.

Each polygon created from the combination of covers was listed as a separate record in the attribute table. The area (in metres squared) and perimeter (in metres) was recorded for each polygon. This dataset then underwent aspatial analysis.

2.5.2 Data cleaning

A number of the harvesting codes provided from the API work were corrected to suit the purposes of this study. Some of the codes were altered to reflect the changes made to the original UNE/LNE dataset. The updated codes are present in Southern CRA Region Dataset. The reasons for each change are provided below.

Original Harvest Code	**New Harvest Code**	**Reason**
LD	H	Log dump points marked on map and given an area. Should be included in harvested area.
LOGGED	H	Incorrect code used
P4	C	Incorrect code (taken from a photo point) on map in Cpt 102, Boyne SF.
PMP	P	Changed to reflect UNE/LNE dataset
PP	P	Changed to reflect UNE/LNE dataset
S1	H	Photo point marked on map in Cpt 102, Boyne SF. Area surrounding point is harvested
W	U	Coded as Wattle - unmerchantable
X	P	Cleared land in the corner of Compartment.

2.5.3 Exclusions

Each polygon in the study was tagged with an exclusion code to identify whether it is part of the gross, net mapped or net loggable area. The methodology used was similar to that for the UNE/LNE study.

The Net Loggable area that formed the basis for the modifier dataset used in the model was defined by a series of exclusions. Polygons that were accepted in the Net Loggable area complied with the following criteria:

- Slope less than 31 degrees
- Group code of Tall or Not Tall (ie not Non-commercial)
- Not within drainage buffer boundaries (ie INSIDE = 0)
- Harvest Code of "C" or "CS" or "H" or "I" or "S" or "SC".

Filter strip extensions and steep areas (not mapped) are included in the Net Loggable Area, however only those polygons with the Harvest Code "H" are included in the calculations of area harvested.

The environmental variables were then assessed to determine whether there was any significant difference in values assigned across the remaining dataset. The measures of forest height, soil regolith and ruggedness were excluded from the model calculations, as there was little variation in results across the dataset.

2.5.4 Statistical analysis and model development

The modifier dataset contains the filtered set of records as specified above. Each record consists of a unique set of features, including the sum of the total area for that set of features.

2.5.4.1 Data Analysis

The dependent (response) variable (Modifier) is a proportion (the ratio of harvested area to net harvest area) so it ranges from 0 to 1. This means that the response variable is binomially distributed. A logistic function is appropriate for a binomial distributed variable and it will restrict the predicted values to a range of 0 to 1 as the original data, having 0 as the lowest value and 1 as the asymptote.

The independent variables were both continuous (erosivity, slope, and distance from filter strip) and categorical (soil regolith class (1-3) and forest height class (1-2)) as opposed to all being categorical for lower and upper north analysis.

2.5.4.2 Model Selection and Fitting

The LOGISTIC procedure in SAS (SAS 1989) was used to find the best model using the selection = score option. Soil regolith class and forest height class (the two categorical variables) were found to be redundant in the model. The reason for the class variables being non-significant in the model could be due the limited spread of data in the classes. Most data had soil regolith class 1 and forest height class 2. The final model selected and fitted using maximum likelihood estimation method in SAS was:

$$\text{Proportion(Harvest)}=[1 + \exp(-(1.768247-0.495352*(\text{erosivity}/1000)-0.725218*(\text{slope}*\pi/180) +0.026581*\text{distance}))]^{-1}$$

This model was fitted using 33135 pixel observations.

2.5.5 Southern CRA Region Spatial Data Collation

A coverage was produced for the entire Southern CRA Region by unioning the following corporate GIS covers (using actual integer values):

A. Soil Regolith - indicates the dominant occurrence of a class of regolith

B. Rainfall Erosivity Isopleth - Integer number up to 4 digits, one value per compartment

C. Slope - may comprise a range from 0 to 90 degrees inclusive

D. Measure of tall/not tall forest (derived from Yield Association Group) - 1 = Tall, 2 = Not Tall and 3 = Not Tall/Non-commercial. See Appendix 2 for full description.

E. Distance to non-harvestable boundaries - Using distance to the nearest non-harvestable boundary

- Riparian buffers/filter strips:
    - 1st Order Stream: 10 metres each side of the drainage structure;
    - 2nd Order Stream: 20 metres each side of the drainage structure;
    - 3rd Order Stream: 30 metres each side of the drainage structure;
    - 4th and higher order Stream: 50 metres each side of the drainage structure.
- Tenure boundary
- Rainforest (CRAFTI + RN17 rainforest) boundary

The values for erosivity, distance to non-harvestable boundary and slope for each grid cell are used in the equation to determine the harvest proportion for that grid and all grid cells with those values. The grid cell value for distance to non-harvestable boundary for each cell is based on the shortest distance to either drainage buffers (as used for FRAMES), rainforest boundaries or State Forests tenure boundary. The modifier equation developed from the study compartments is applied to the total State Forest area within the CRA Region, and subsequently clipped to the Net Harvest Area used in FRAMES.

3 Results and Discussion

3.1 Southern CRA Region Dataset trends

The Net Harvest Area Modifier dataset demonstrated that only 78.8% of the area in the study compartments that was thought to be available for harvesting was harvested. The figure below shows the breakdown of the Net Loggable Area by harvest code. This figure shows that filter strip exclusions have the largest impact on the Net Loggable Area, in comparison to slope which has a relatively minor impact on the Net Loggable Area.

Harvest Code	**Area (hectares)**	**Percent of Net Loggable Area**
Filter Strip Exclusion	690.52	20.73%
Harvested	2624.26	78.80%
Slope Exclusion	15.45	0.46%

This Figure shows the Net Loggable and actual harvested area as percentages of Gross Area.

	Area (hectares)	**Percentage of Gross Area**
Net loggable/Gross	3330.23 / 6876.01	48.43%
Harvested/Gross	2624.26 / 6876.01	38.17%

Three compartments were excluded during the model development (they were identified in the dataset by unique soil erosivity codes). These were compartments 8020, 8021 and 8022 of Buccleuch State Forest. These compartments were removed from the study as the results did not seem realistic or representative of this forest. They had uncharacteristically low productivity and there were no commercial trees in much of the compartment. Harvesting of compartment 8021 was actually completed after the aerial photos were taken and a small section of 8022 was never finished as the PCL licence expired.

3.2 Comparison with UNE/LNE Results

The figures obtained for the breakdown of Net Loggable Area by harvest code in the Southern study are fairly similar to the breakdown by code for the UNE/LNE study. This Figure shows a comparison of the original calculations for UNE/LNE study using actual drainage and compares this to the figures for both UNE/LNE and Southern using LIC drainage only. The actual drainage shows less impact on the Net Loggable Area from filter strip exclusions however this difference in filter strip area is accounted for in the reduction of overall Net Loggable Area.

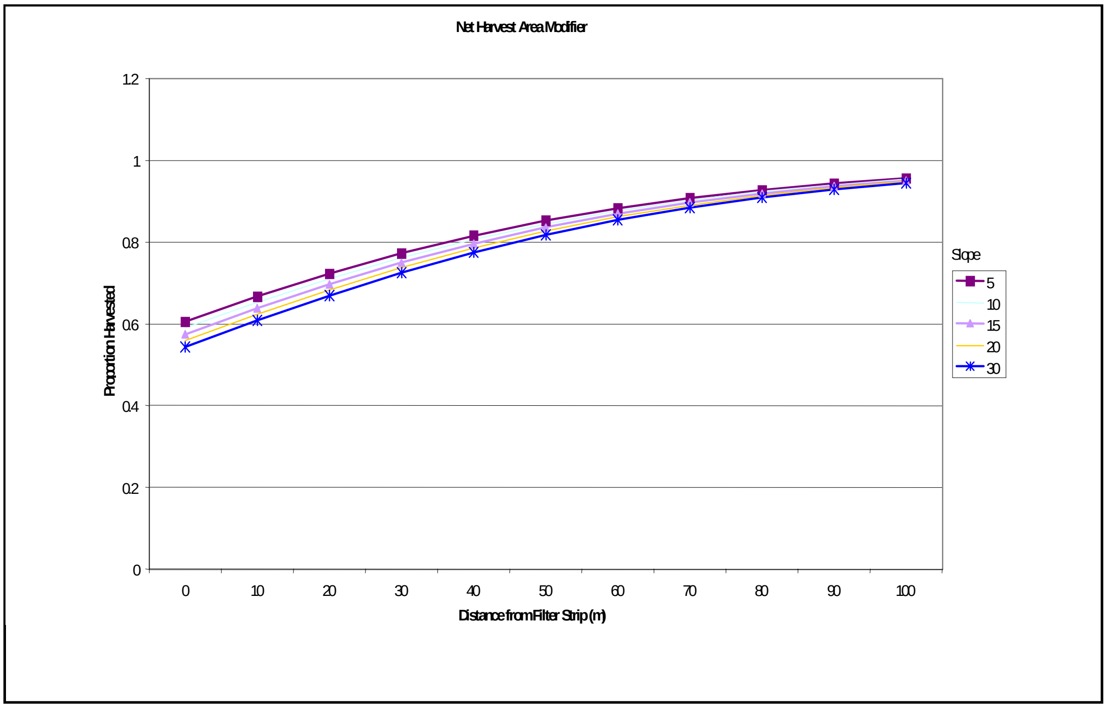
Harvest Code	UNE/LNE CRA Region				Southern CRA Region	
	Using LIC Drainage		Using Actual Drainage		Using LIC Drainage	
	Area (hectares)	% of total	Area (hectares)	% of total	Area (hectares)	% of total
Creek	936.1	20%	594.0	14%	601.6	18%
Creek/Steep	0.0	0%	0.0	0%	88.9	3%
Harvested	3,360.5	73%	3,311.0	77%	2624.3	79%
Inaccessible	25.8	1%	24.2	1%	0.0	0%
Inaccessible/ Creek	4.3	0%	2.9	0%	0.0	0%
Steep	110.6	2%	265.2	6%	13.5	0%
Steep/Creek	169.4	4%	111.6	3%	1.9	0%
Total	**4,606.7**	**100%**	**4,309.0**	**100%**	**3,612.9**	**100%**
Modifier	27%		23%		21%	

Filter strip exclusions have a comparable effect in UNE/LNE and Southern, although there is comparably less impact from slope in Southern even though the proportion of area by slope class is fairly similar for the two regions.

Slope Class	UNE/LNE - LIC Drainage	UNE/LNE - actual Drainage	Southern CRA Region - LIC drainage
0 -10	38.53%	36.51%	31.44%
11-20	34.36%	35.00%	42.71%
21-25	11.70%	12.07%	12.77%
26-30	8.12%	8.45%	7.22%
>31	7.28%	7.96%	4.52%

3.3 Modifier Trends

The proportion of an area that will be harvested is dependent on the combination of variables (soil erosivity, distance to filter strip and slope) that are present. This Figure shows the effect of distance to filter strip on the modifier equation. This figure also shows the minor influence of slope on the proportion of an area that is actually harvested.



The lowest possible value for the harvest proportion from the modifier indicates that the constant 15m filter strip width is moderately conservative. If the filter strip distance had been under-estimated (and the Net Loggable Area over-estimated) then a lower possible proportion of area harvested using the model would be expected as the Net Loggable Area would contain larger areas falling within filter strips.

4 References

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

Appendices

Appendix 1: Compartments used in the NHA Modifier Study

CRA Sub Region	State Forest	SF No.	Cpt No.	Comment
South Coast	Tallaganda	577	**2292**	Verfication Study Mapping 1998
South Coast	Tallaganda	577	**2450**	Verfication Study Mapping 1999
South Coast	Tallaganda	577	**2451**	Verfication Study Mapping 2000
South Coast	Tallaganda	577	**2464**	Verfication Study Mapping 2001
South Coast	Wingello	749	**4214**	Verfication Study Mapping 2002
South Coast	Wingello	749	**4217**	Verfication Study Mapping 2003
South Coast	Wingello	749	**4219**	Verfication Study Mapping 2004
South Coast	Wingello	749	**4220**	Verfication Study Mapping 2005
South Coast	Boyne	832	**96**	Verfication Study Mapping 2006
South Coast	Boyne	832	**102**	Verfication Study Mapping 2007
South Coast	Wandella	1008	**3290**	Verfication Study Mapping 2008
South Coast	Wandella	1008	**3291**	Verfication Study Mapping 2009
South Coast	Dampier	926	**3143**	Converted from Eden NHA Project
South Coast	Dampier	926	**3215**	Converted from Eden NHA Project
South Coast	Dampier	926	**3143**	Converted from Eden NHA Project
South Coast	Corunna	137	**3058**	Converted from Eden NHA Project
South Coast	Bodalla	606	**3044**	Converted from Eden NHA Project
South Coast	Bodalla	606	**3073**	Converted from Eden NHA Project
South Coast	Moruya	139	**3240**	Converted from Eden NHA Project
South Coast	Moruya	139	**3241**	Converted from Eden NHA Project
South Coast	Moruya	139	**3320**	Converted from Eden NHA Project
Tumut	Bago	560	**85**	Riverina NHA 1999
Tumut	Bago	560	**90**	Riverina NHA 1999
Tumut	Bago	560	**91**	Riverina NHA 1999

Appendix 2: Description of Tall/Not Tall Forest

The description of Tall/Not Tall forest is based on preliminary stratification.

Yield Association Description for Tumut Sub Region

Yield Association	Description (Forest types based on RN17)	Forest Height
1.	Ash forest (147 & 148) - Bago	Tall
2.	Ash forest (147 & 148) - Maragle	Tall
3.	HWD (151,154,155,159,164,111,131,140) Bago/Maragle	Not Tall
4.	Buccleuch (logged) (same types as HWD + 147 & 148)	Not Tall
5.	Buccleuch (unlogged) (same types as HWD + 147 & 148)	Not Tall

Yield Class Description for South Coast

Group Code	Description	Yield Associations	Forest Height
A	BBT/SBG	1, 2	Tall
B	SPG	3	Tall
C	STA (Silver top ash)	4	Not Tall
D	Stringybark-coastal grey box	5, 6	Not Tall
E	Brownbarrell/Messmate	9	Tall
F	Gum	10	Tall
G	Alpine Ash	8	Not Tall
N/C	Non-Commercial	7, 11, 12, 13, 14, 15, 16	Non Commercial