EVALUATION OF DATA AND METHODS FOR ESTIMATING THE SUSTAINABLE YIELD OF SAWLOGS IN VICTORIA

REPORT OF THE EXPERT DATA REFERENCE GROUP

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Executive Summary

This evaluation of data and methods used to estimate sustainable yields for each Forest Management Area (FMA) in Victoria has revealed that the Department of Natural Resources and Environment (NRE) now has the knowledge and procedures to provide reliable estimates of the extent and the nature of the forest resource, and of its capacity to produce sawlogs.

However, the evaluation has also revealed that other priorities have impinged on these resource estimation activities, with the result that the state of the forest within the production estate, and its ability to sustain timber harvesting can be reliably established for only a few FMAs. Initiatives (such as SFRI and IFPS) already under way will do much to redress these deficiencies, but cannot deliver within the timeframe required for the licence renewal process. It is little consolation that NRE is not unique in this regard, and that other forest services in Australia find themselves in similar situations. The standard expected is not arduous, and reflects the accepted best practice for State Forest Services.

Estimates of non-declining yields for most FMAs seem reasonable (Table 8, Page 50), but are underpinned with sound empirical data only in three FMAs (Benalla-Mansfield, Midlands and North-East). Estimates in other FMAs involve subjective inputs, that while not unreasonable, may be handled differently in subsequent reviews. A five-star rating (Table 5, Page 47) gauges the rigour of the estimates in terms of supporting empirical evidence and absence of subjective inputs.

Because of uncertainties in the yield estimates for many FMAs, NRE is not well placed to make long-term commitments to industry. Twenty-five specific recommendations offer guidance for sustainable forestry in Victoria. Many of these recommendations reaffirm the importance of work already in train. Some contain advice similar to that previously offered but not yet implemented, so innovative ways must be found to give stakeholders a vested interest in implementing these recommendations. There is a special need to foster broad support for establishing and monitoring the nature of the resource, and in making this work part of the core business of NRE. Specific suggestions to achieve such reform have been made throughout this report. Examples of possible actions include:

- Licensee entitlements could be debited with the predicted volumes rather than the actual out-turn, so that both NRE and licensees have a vested interest in accurate predictions and in reconciling predictions with out-turn.

- Estimates of the standing volume of timber could be published, and harvests planned so that the lower confidence limit does not decline; this would help to boost stakeholder confidence about the management of native forests.

This report delves into considerable technical detail in order to offer constructive suggestions to redress these issues (Chapters 3–7). Readers not interested in technicalities are referred to Chapters 1–2 and 8–9.

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1. Introduction

In March 2001, the Minister for Environment and Conservation announced a new framework to progress the renewal of native timber harvesting licences in Victoria. The Expert Data Reference Group is one of several groups providing input to the Peak Strategy Group to help identify and evaluate timber supply and licensing options. The process seeks to establish the reliability of resource data as a basis for long-term wood supply commitments, and in doing so, to alleviate concerns and gain stakeholder support for the licence renewal process.

In 1986, the Timber Industry Strategy established 15 Forest Management Areas (FMAs, Figure 1) to facilitate the proper planning, management, and administration of publicly owned native forest. It also established regional sustainable yield as the basis for harvesting of sawlogs from State Forest in Victoria, and determined these sustainable yields for each FMA. Resource security was provided by the introduction of fifteen-year licences.

The sustainable yield rates were enshrined in legislation (*Forests Act* 1958, Sch.3) in 1990, with a requirement that the sustainable yield be reviewed every five years from 1 July 1991 (*Forests Act*, s.52D).

Under the *Act* timber licences can be issued for any period up to 20 years. The Timber Industry Strategy led to the introduction in 1987 of 15-year licences. Other "evergreen" licences issued in 1992 were also for 15 years and, may be “rolled-over” after the fifth year, effectively ensuring holders of a known timber supply for at least ten years.

1.1 Terms of Reference

The Expert Data Reference Group is required to:

- Undertake an examination of the current data available in relation to volumes available for timber harvesting in various forest management areas across the State.
- Provide an assessment of the assumptions and methodologies proposed to establish realistic licence volumes; and
- Provide advice to the Peak Strategy Group regarding the validity of the current data assumptions and methodology to assist in the identification of appropriate options for licence renewal.

In undertaking this task the Expert Data Reference Group is required to:

- enlist the appropriate skills within the group to assist in the completion of the task;
- consult with the Licensing Working Group regarding the assumptions about the economic viability of available timber resources;
- consult with environment stakeholders, as determined via discussions with the Peak Strategy Group;
- seek direction from the Peak Strategy Group in identifying the work program of the Expert Data Reference Group particularly in relation to priority areas for examination.

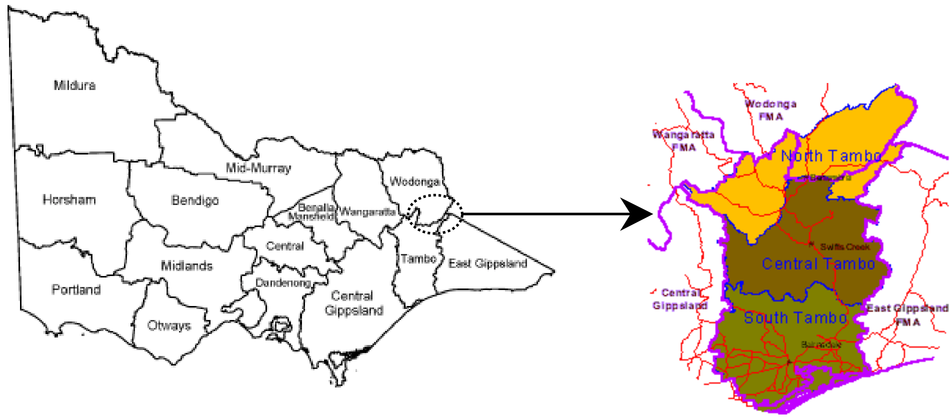

Figure 1. The 15 Forest Management Areas (FMAs) in Victoria (left). Part of Wodonga FMA is managed as if in the Tambo FMA (right). Wangaratta FMA and the remainder of Wodonga FMA are managed as one, and called the North-East FMA.

1.2 Approach

The Expert Data Reference Group conducted wide-ranging discussions with key NRE staff involved in resource estimates (see Annex 1), reviewed published and unpublished documents relating to forest resources in Victoria, sought responses to a detailed questionnaire about resource calculations, and examined metadata and partially-processed data. A number of stakeholders were also consulted (Annex 1). The *Timber Resource Assessment* and *Timber Harvesting Strategy* for each FMA was scrutinized, and calculations (particularly the simulation of the non-declining even flow scenario) were examined.

Particular attention was paid to the procedures and processes used to obtain and make inferences from data. It was not possible, and not appropriate to examine each datum (e.g., to determine whether or not a particular stand was 40 or 50 ha). Instead, emphasis was directed to ascertaining whether procedures and processes were comprehensive, able to be checked, and likely to give an unbiased estimate.

The *Forests Act* (Schedule 3) defines 15 FMAs that form the basis for sustainable yield estimates. However, eleven blocks (known as North-East Gippsland) within the Wodonga FMA have been managed as if they were within the Tambo FMA (Figure 1). Wangaratta and Wodonga (minus the 11 blocks) have been treated as a single FMA, the North-East. This informal redefinition of FMAs causes confusion, and hampers comparison of yields. Yield estimation and monitoring should be consistent with the FMAs defined in Schedule 3 of the *Act*, or the FMAs boundaries should be amended in accordance with the provisions of s.52F of the *Act*.

Recommendation 1: *Reconcile sustainable yield estimates and FMAs by calculating yields corresponding to the FMAs as defined in the* Forests Act *1958 (Sch. 3), or by adjusting the FMA boundaries in accordance with the provisions of s.52F of the* Act.

Bendigo has not been considered in the present analysis as no data have been presented for scrutiny. The Bendigo FMA has a legislated sustainable yield of 800 m^3/yr, but no current long-term sawlog licences.

Assessments of the data and methodology underpinning yield estimates for each FMA are given in Annex 2.

2. Overview of Resource Assessment

Resource estimation embraces many facets, ranging from establishing the area of the resource, through estimates of the current standing volume, to predictions of future volumes and wood flows that can be sustained. It is the latter, the sustainable wood flows, that are of primary interest in the present context.

There is a legislative requirement for NRE to "*consider what, in the circumstances (including the structure and condition of the forest) existing at the time of the review, are the appropriate sustainable yield rates having regard to the maximum volume of hardwood sawlog that could be harvested from the area under review without impairing the capacity of the area to sustain the harvesting of a similar quantity of hardwood sawlogs over each succeeding year*" (Forests Act, s. 52D).

At present, it is not practical to attempt to measure all the wood volume and its growth directly across the entire forest estate (though technology may soon make this possible). So timber yields are estimated indirectly by determining the area with accessible and productive forest, measuring the volumes on some of those areas, and observing the growth on some of the trees contributing to those volumes. This report considers how NRE procedures estimate these components and combine them to form yield forecasts. Special emphasis is placed on the efficiency and accuracy of these procedures.

2.1 General approach to Yield Prediction

Resource estimation specialists use a range of methods for yield forecasting, depending on the context, the nature of the forest, and the available data. However, a generalized view of resource forecasting can be portrayed as in Figure 2.

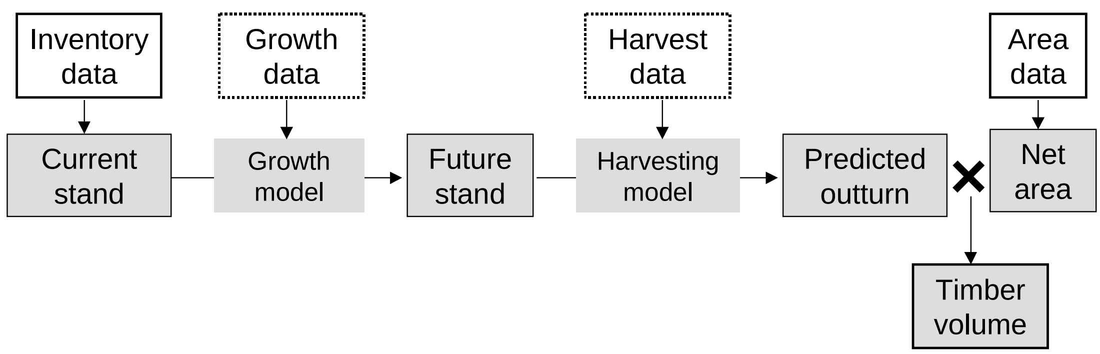

Figure 2. Overview of yield prediction showing components contributing to an estimate of future timber yields. White boxes (top row) indicate source data; grey boxes are derived information. Dotted lines (e.g., growth data) indicate inferences made from a small sample rather than estate-wide sampling. Boxes to the left of the × are on a per-hectare basis (i.e., everything except the area estimates and the timber volume).

This generalized approach requires inventory data to quantify the current stand, usually on a per-hectare basis. This may done using temporary plots to sample several strata (large areas with similar forest types and ages), or in some instances, to sample each management unit within the forest estate. A growth model may be used to update existing inventory data to reflect current stand conditions. The growth model is also used to anticipate the nature of the forest stand in the future, often by simulating the growth of (and mortality, etc. on) each individual plot. A harvesting model is used to predict which trees would be felled during a harvesting operation, to predict any felling damage, and to estimate resulting log volumes. Finally, the net area of the stand is used to estimate the total timber volume that would be obtained from harvesting the stand. Although shown as a single column at right, it is equally important in influencing the overall accuracy of yield estimates.

Yield prognoses usually involve repeating these calculations for each stand within the forest estate, and scheduling predicted harvesting operations to provide for a steady wood supply over time.

Special cases of these calculations include estimates of current merchantable volume (in which case there is no need to use the growth model to predict future stand condition) and clearfelling systems (which may assume that all trees will be felled, simplifying the harvesting model to a volume estimation procedure).

This description reflects the general approach, but many variations apply, and two variations are of interest in the present situation.

2.1.1 Yield Prediction in Even-aged forests

Much of the production forest in Victoria is even-aged, and managed under a clearfelling system, and this allows a number of efficiencies in resource estimation.

The yield table is the heart of all yield estimates for even-aged forests in Victoria. The yield table, which is often represented as an equation or curve (e.g., Figure 3), allows a user to look up the expected yield at any given age. Yield tables typically provide for a range of site

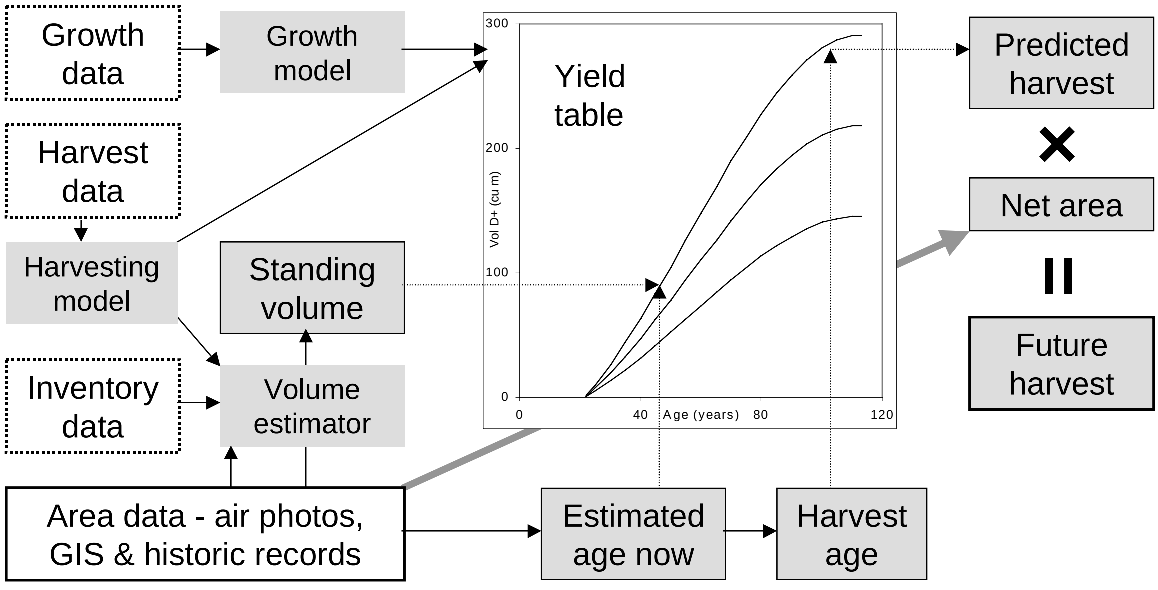

Figure 3. Overview of yield prediction methodology for even-aged forests in Victoria, using the same conventions as in Figure 1. The yield table plays a central role in this approach. Another element (not shown) is the scheduling of areas to be harvested.

productivity, so that both age and site quality are needed to look up the predicted volume of a stand. Conversely, the estimated current volume may be used in conjunction with stand age to select an appropriate yield curve for the stand in question. The estimate from the yield table is then multiplied by the anticipated net harvestable area, which is usually derived from a geographic information system (GIS).

Although this procedure for deriving a yield estimate differs from the generic one, the basic data requirements remain the same: growth and harvesting data to compile the yield table; inventory data to estimate the current standing volume, and area data denoting the extent of the resource available for harvesting. These components will be examined in more detail later.

2.1.2 Yield Prediction in Uneven-aged forests

Some of the forests in Victoria, especially in the north and west, are not even-aged and are not managed as even-aged forests. Thus they require a different approach to yield prediction. The generic approach illustrated in Figure 2 is eminently suited, but not presently used in these uneven-aged forests. Instead, anticipated harvest volumes are derived from the expected yields multiplied by the net harvestable area. The inferences about yields are based on historic harvests in the Mid-Murray and Mildura FMAs, and on the periodic annual increment (PAI, the growth observed over a given period) in Horsham FMA. These approaches may give reasonable estimates when the forest estate resembles a *normal forest* (i.e., when past harvesting has been both stable and sustainable, so that there is a near-equal area of each age class), but are likely to overestimate short-term yields if recent harvesting has exceeded the sustainable yield.

2.2 Key Components of the Yield Estimate

Figure 3 reveals that the key components of yield estimates for most Victorian forests are

- Estimates of the *net areas* available for harvesting;
- *Yield tables* (or growth rates of uneven-aged stands), including procedures to choose an appropriate entry point into these tables (or basis to initialize the growth model); and
- *Scheduling* the harvest in a realistic sequence, taking account of the ages, yields and geographic distribution of the stands in the forest estate.

One exception to these three key components is when the supply situation is “tight” with difficulties in satisfying timber demands in the short-term. In such situations (which are not uncommon in Victoria at present), estimates (and locations) of the present standing volume (i.e., inventory data) may be more important than estimates of growth (i.e., yield tables and growth models).

Factual underpinning of these components requires the following data:

- Area data, suitably stratified (e.g., by forest type, age, productivity), preferably into geo-referenced analysis units (i.e., spatially explicit) at or near the coupe scale, reflecting the net area worked over during harvesting;
- Inventory data collected on, or inferred for each analysis unit to
  - guide the choice of yield curve and entry point (e.g., species, age, site productivity), or
  - in the case of uneven-aged stands, to define current conditions consistent with model and volume estimation procedures, or
  - when short-term supplies are critical, to establish the current standing volumes;

- Growth data, usually summarized as a yield table or growth model for each forest type and productivity class;
- Harvest data indicating the volume out-turn achievable during operational harvesting (also, in the case of uneven-aged forests, the trees to be cut and to be retained);
- Tools to help schedule harvests in a realistic and attainable sequence (e.g., SYSS and IFPS).

2.2.1 Key Information requirements

In principle, estimates of net area and mean annual volume increment (MAI) can form the basis for an estimate of the long-term sustainable yield. However, such minimal information does not offer any insights into short-term availability, or into the characteristics of the harvest over time (e.g., species composition, average log volumes).

It has long been recognized that it is both possible and useful to provide more detailed information about the forest resources, for operational use and for monitoring and feedback. For instance, Reventlow's (1827) oak and beech yield tables discriminated first- and second-class trunks as well as branchwood volumes. Reineke's (1927) yield chart provided estimates of average dbh, number of trees and volume in several stand fractions (trees larger than 4 and 7 inches diameter, the dominants, and the entire stand). Vanclay and Preston's (1989; also in Vanclay 1994a; see Table 1 below) yield projections for Queensland rainforests reported not only yields, but also average stem volumes, size assortments and species composition.

Grosenbaugh (1955) advocated the recognition of homogeneous record-units as the sole unit for all mapping, sampling, forecasting and operational work. He also insisted that yield forecasting should recognize the actual order of working over the resource. This approach was tested in eucalypt forests by Phillis (1971) and has been used operationally in Queensland native forests since 1987 (Vanclay *et al* 1987). The analysis units used in IFPS simulations are defined on this basis.

Clearly, there is a well established precedent that predicted yields should be accompanied by detailed information on the location and timing of proposed harvests, and on the nature of these harvests in terms of species, and log dimensions and grades.

Table 1. Predicted harvests may include forecasts of yields (per ha), stem volumes, size distributions and species composition, as well as predictions of average basal areas (>20 cm dbh) and merchantable volumes (above girth limit) for the productive forest estate (Vanclay and Preston 1989). All these parameters offer insights into the sustainability of the timber harvest. Note that it may take 250 years for these trends to stabilize and thus for sustainability to be inferred.

Period beginning	Regional average		Average characteristics of simulated harvest			
	Basal area m^2/ha	Merch. volume m^3/ha	Harvest volume m^3/ha	Stem size m^3	Size dist. –60–100– cm dbh	Main species† in harvest %
1990	40	24	18.9	2.9	10:75:14	Y 21, M 13
2037	38	20	18.0	2.8	10:87: 3	S 22, M 14
2077	37	25	18.8	3.0	8:90: 2	S 21, M 16
2119	36	29	17.5	3.0	8:90: 2	S 20, M 17
2166	36	23	14.7	2.8	11:86: 3	M 17, N 17
2201	37	18	13.4	2.7	13:84: 2	M 21, N 16
2231	38	19	13.3	2.7	13:85: 1	M 22, Q 21
2253	39	21	14.4	2.8	13:86: 1	Q 22, M 19
2290	40	26	17.3	2.8	14:86: 1	Q 23, M 19

† M: maple silkwood (*Flindersia pimenteliana*), N: northern silky oak (*Cardwellia sublimis*), Q: Queensland maple (*Flindersia brayleyana*), S: silver ash (*Flindersia bourjotiana*), Y: yellow walnut (*Beilschmiedia bancroftii*).

2.2.2 Specific Requirements of NRE

The *Forests Act* (s. 52D) requires that "*The Minister must in each 5 years beginning from 1 July 1991 review the sustainable yield rates … of hardwood sawlog*", and in doing so, "*must consider … the structure and condition of the forest*". The appropriate sustainable yield rates should be established with "*regard to the maximum volume of hardwood sawlog that could be harvested from the area under review without impairing the capacity of the area to sustain the harvesting of a similar quantity of hardwood sawlogs over each succeeding year*."

The *Code of Forest Practices for Timber Production* (NRE 1996) requires NRE to prepare Wood Utilisation Plans (WUPs) each year. These specify the kind and quantity of wood to be produced over a three-year period with detailed specifications (i.e., volumes by grades and species) for the first year, consistent with sustainable yield strategies, silvicultural requirements, and operational arrangements of the timber industry. Presently, estimates presented in the WUPs are independent of estimates made in estimating the sustainable yield.

Current licences specify sawlog grade, may specify volumes by grades or by species (Table 2), and may be struck in terms of gross or net volume (about 20% of the volume is sold as gross volume). All resource calculations are based on net volumes, but may be converted to gross volumes using conversion factors in the range 0.84 to 0.97 (gross → net; based on data collected during 1988-90). The discrepancy between resource forecasting procedures (net D+ volumes by forest type) and licensing arrangements (by grade and species) makes it difficult to establish whether current commitments can realistically be achieved.

Table 2. Current commitments to supply sawlogs, by species and grade. Predictions should provide sufficient detail to assist in meeting these obligations.

Sawlog grade specified in licence	Species specified in licence (by volume, %)		
	Ash species	Other, or unspecified	Total
B+	12	5	17
C	20	38	58
D	4	20	24
Total	36	63	100

During the negotiation of the Regional Forest Agreements, Victoria undertook to complete the State-wide Forest Resource Inventory (SFRI) and to estimate sustainable yields using the Integrated Forest Planning System (IFPS) in all FMAs, in accordance with the timetable in Table 3. This agreement replaces earlier commitments made in the East Gippsland (1997, s.31), Central Highlands (1998, s.45e & 88.2) and North-East RFAs (1999, s.45c & 86.3).

Table 3. Commitment under RFA to complete SFRI and estimate sustainable yields with IFPS (Commonwealth of Australia and State of Victoria, 2000).

Forest Management Area	Date to complete SFRI and IFPS
Benalla/Mansfield	30 June 2001
Wangaratta & Wodonga (i.e., North-East)	31 December 2001
Tambo and Central Gippsland	31 December 2002
Midlands	31 December 2003
Central and Dandenong	31 December 2004
Otway	30 June 2005
East Gippsland	31 December 2005
Portland	30 June 2006

Clearly, NRE requires resource information for a wide range of management and reporting needs. Efficiencies may be gained by taking a service-wide view of these information requirements and of data gathering opportunities. There is much in common amongst the data required and information desired for sustainable yield estimation, licence renegotiations, WUP preparation, industry planning and forest planning and management. A yield forecasting system designed to address these common information needs can draw on more sources, can realize additional opportunities for checking predictions, and may reduce the effective cost by serving more clients and by eliminating unnecessary duplication.

2.3 Specific issues highlighted in previous reviews

During the last few years, several reviews have examined procedures relevant to resource estimation, and it is appropriate to reconsider their findings. Many of the issues raised have been addressed, and others have been overtaken by other events (such as the Regional Forest Agreements), but some findings remain relevant. Below are some issues selected from those reviews, chosen deliberately to highlight current issues that may warrant further attention.

2.3.1 Auditor General (1995)

In 1995, the Auditor General's review of progress achieved in implementing the 1986 Timber Industry Strategy highlighted several issues relating to resource estimation, including that:

> "… several important aspects of forest management still need to be addressed by the Department. In particular, it needs to (5.3): …
>
> - intensify timber resource assessments to improve the reliability of data used as a basis for calculating sustainable yields; …
> - develop a mechanism to assess the comparative values of forest areas for water catchment and timber production; ….
>
> "… methodology and data … were independently reviewed … identified that … (5.21):
>
> - The estimation of net areas available for timber production was largely based on untested allowances for unproductive areas …
>
> "To improve … the management of timber resources, there is a need for (10.3):
>
> - … greater integration of the significant number of information systems established by the Department and more effective utilisation of the systems for planning, reporting and decision-making purposes."
>
> The Auditor General's report concluded (1.3 Summary of major audit findings) …
>
> - "In order to improve the reliability of sustainable yield calculations, the Department needs to increase the extent of information maintained in relation to both timber and non-timber resources within the State's native forests (5.15-27). …
> - "The downgrading of logs … may impact on the ability of the Department to maintain harvesting within regional sustainable yields (6.45-48)."

2.3.2 Burgman (1995)

In 1993, Mark Burgman was contracted to review wildlife information and planning with respect to the forest planning system FORPLAN. His 1995 report offered an extensive list of recommendations, including

- "The use of empirical data rather than professional judgement whenever reasonably possible. Where judgement is used, its use should be clearly documented, and the sensitivity of models to this judgement should be explored.

- "… field programs (including long term monitoring sites) should be established with the aim of validating the predictions of the FORPLAN models …."

2.3.3 Turner (1995)

Brian Turner's (1995) report on yield estimates for the Midlands FMA expressed concern about the "estimation of future growth" and "the simplicity with which the development of the residual and regenerating stands are modelled in the so-called shelterwood cuts, and with the handling of site variation". It also recommended that "a clear mechanism for monitoring the yield predictions should be established so that actual removals and growth are routinely compared with predictions."

2.3.4 Turner & Ferguson (2000)

Brian Turner and Ian Ferguson's (2000) report on the Wombat State Forest concluded: "We strongly recommend that a more detailed analysis of the risks be conducted, perhaps after some sensitivity analysis to determine the impact of the various factors on the final sustainable yield rate. Of critical importance is that NRE establish a transparent and effective routine mechanism for feeding back the volumes removed in harvesting operations into the data used by the Integrated Forest Planning System for calculating sustainable yields."

2.3.5 Present situation

Recurring themes in these reviews included the reliability of data, the scope and integration of information systems, trade-offs between wood and non-wood values, and the need for sensitivity analyses, monitoring and feedback. These, and other issues raised by reviewers, have received attention by NRE, but a uniform result has not yet been achieved in all FMAs, in part because of the long lead-time involved with some initiatives. The State-wide Forest Resource Inventory (SFRI) was in part, a response to the Auditor General's review. Audit procedures were also established to monitor log grading, and have quantified the extent of grade slippage (c. 10%). Some attempts have been made to accommodate the value of water production into forest planning, but these efforts have not been sustained.

The Department made several specific undertakings in response to Burgman's (1995) report, including that the FORPLAN model would be used; that projections would be monitored; and that efforts would be made to provide data for developing and testing planning models. FORPLAN (or its successor Spectrum) has been made an integral part of NRE's state-of-the-art Integrated Forest Planning System (IFPS), but has been used to estimate sustainable yields in only two of the fifteen FMAs. New growth plots have been established, but data for constructing and testing yield tables are still limiting. Attempts have been made to monitor predicted yields and provide data for testing and feedback, but record-keeping needs to be refined. It appears that other priorities have hampered progress.

3. Present Resource

While long-term yields are influenced largely by area estimates and growth rates, short-term yields depend heavily on estimates of standing volumes on those areas. Reliable estimates of both net area and of standing volumes are fundamental to the reliability of the estimated annual harvest rates, particularly when the forest is not a normal forest with a long history of sustainable harvesting.

3.1 Sampling, Reliability and Scaling

At present, it is not feasible to measure every tree in a forest, so resource estimates are based on a sample. Sampling basically involves choosing a few small representative areas within the forest and measuring the trees on these areas. However, there are many ways that this approach can be varied to make it more robust or efficient. Because we have a sample rather than a census, we never know for sure what is the true volume (or other property) of the forest, but we can estimate the likelihood that the “truth” will lie within confidence intervals derived from our data. The width of these confidence intervals depends on the variability of the forest, the sample size, and the inferences made. The confidence interval can be reduced by taking more samples, or by making better inferences.

We seek an accurate estimate, which is both precise and free of bias (Figure 4). Precision reflects the extent to which an estimate is repeatable, and can be gauged by calculating the standard error of a sample with multiple observations. Bias is the discrepancy between the expected value of an estimate and the “true” (usually unknown) value. Bias can be difficult to

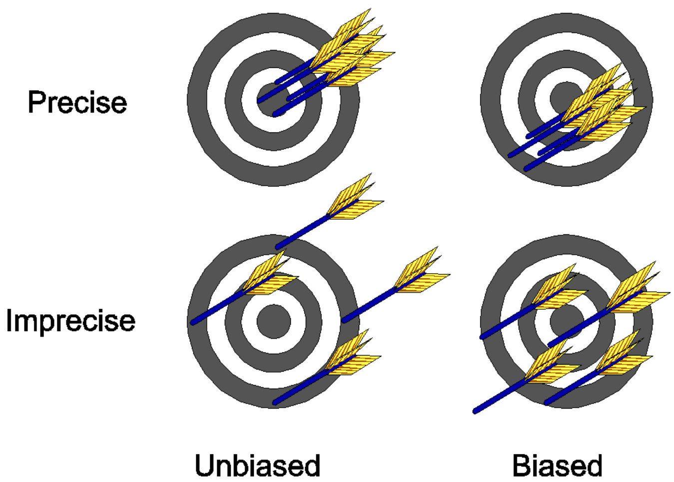

Figure 4. Bias and precision in sampling (Vanclay 1994b). Precision refers the extent to which independent samples are similar. Bias relates to the discrepancy between the expected value of a sample and the “true” value. Standard error is the customary measure of precision. Bias is more difficult to assess, as the “true” value is often unknown (imagine the arrows without the targets).

gauge, and sometimes may be deduced only through careful consideration of the issues and procedures involved. If the true value is known, the ratio of difference to the standard error indicates whether a discrepancy is likely to be "real" or simply due to chance. Student's t-test is a customary indication of the significance of any such discrepancy. In many cases, especially when there is a wide range of "true" values, it is appropriate to look for trends in the data, as a simple adjustment may not be appropriate.

We seek an estimate with the best possible precision and least possible bias. Generally, precision is improved by taking more samples (in some circumstances, better inferences can also lead to better precision). We can compensate for bias by calibrating estimates with other more reliable data that reveal the "true" values, if these are available. However, care needs to be taken in deriving calibration factors, firstly to ensure that the calibration data are in fact unbiased, and secondly that the calibration factors are correctly calculated. For instance, suppose we find that our estimated volume (Y) has the following relationship with the operational out-turn (X): $Y = 1.5 \times X$. In this case we would say that our prediction was a 50% over-estimate, and that a 33% (n.b., not 50%) scaling factor was required (viz. $X = 0.67 \times Y$). Note that the percentages relating to overestimation and scaling are not symmetrical, but have an inverse relationship. Thus care is required in calculating and reporting these adjustments.

Natural systems are variable, and any sample will encompass some of this natural variation. Any discrepancy that we find between predictions and observations (on areas logged, of volumes realized, etc.) may be due to bias in our estimate, to natural variation included in our sample, or other factors (e.g., book-keeping errors, etc.). It is customary to examine the nature of the sample in an attempt to attribute the discrepancy to bias or chance. If discrepancies in individual observations tend to be similar, bias should be suspected; if not, it may be attributed to chance variation. This is the basis of standard statistical tests, such as Student's t-test, customarily used to examine such discrepancies. The scientific principle of parsimony urges us to attribute discrepancies to chance unless there is statistical evidence to support an adjustment. Thus it is appropriate to test the statistical significance of discrepancies between areas predicted and worked-over, and between predicted and realized volumes.

3.2 Area Estimates

While technology has made it relatively easy to establish the total area of State Forest, anticipating the area that will actually be worked over during logging operations remains challenging. Estimating the latter (net harvestable area) may involve the use of a geographic information system (GIS) to integrate several determinants in a spatially explicit way:

- Tenure (e.g., State Forest)
- Management intention (e.g., General Management Zone, Special Management Zone)
- Exclusions under the Code and other guidelines (e.g., stream buffers, steep slopes)
- Economics (e.g., low-yielding stands, and mixed-species stands with a low proportion of commercial species may not be economically viable for a licensee)
- Operational considerations (e.g., "islands" too small to be commercially viable)
- Aesthetics (e.g., visual buffers)
- Wildlife considerations (e.g., "stepping stones")

While it may be straightforward to deal with any one of these components, the challenge is to find the intersection of all these components in a consistent way, notwithstanding diverse sources (e.g., cadastral and topographic data may be provided by different agencies, using different projections and scales).

To facilitate the calculation and reporting of area estimates, NRE have adopted the following definitions:

Available Area is the area of State Forest available for timber harvesting under the Code of Forest Practices, and excludes slopes greater than 30 degrees, stream buffers (generally 20 m), and rainforest. It may include areas within special management zones (SMZs) that are unavailable for timber harvesting. Available area is spatially explicit and can be determined from cadastral and topographic maps using a GIS.

Productive Area is the available area that is stocked with merchantable eucalypt species, attains a suitable stand height at maturity (generally >28 m), but excludes non-forest, bare ground, water bodies and areas unable to be mapped due to cloud cover on the aerial photography. Unlike available area, productive area requires resource estimates derived from remote sensing (e.g., aerial photos) or field inventory. Productive area is spatially explicit, and can be estimated with a GIS.

Net Harvestable Area is the area expected to be worked over during a logging operation. It is usually based on the productive area, but is adjusted to account for economic and operational considerations, including unmappable areas such as inaccessible terrain not apparent in resource mapping. Unlike the available and productive areas, the net harvestable area may not be mappable, because it may involve adjustments that are not spatially explicit. This area may change from time to time in response to circumstances that influence the economic and technical feasibility of harvesting marginal stands.

The exclusions contributing to the productive and net harvestable area estimates may be considerable, commonly comprising a large proportion of the forest estate, so that the net harvestable area may well be only 20% of the gazetted area of State Forest. Figure 5 illustrates some of these issues.

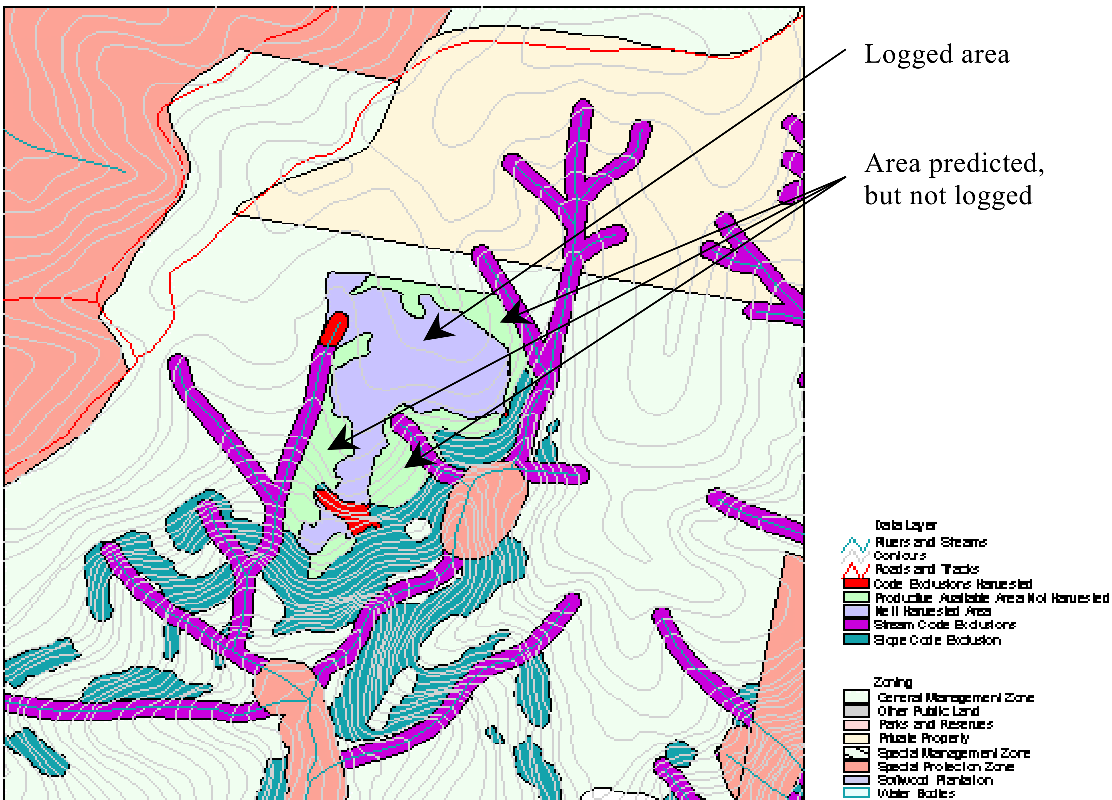

Figure 5. Part of a net area study in the Otway FMA, showing stream buffers, steep slopes, and other features. Note that only part of the predicted harvestable area was cut over during logging operations.

The primary system for managing area information is SFRI, the State-wide Forest Resource Inventory. However, the heritage systems HARIS and Forest25 warrant a mention. HARIS, the Hardwood Resource Information System, was developed in the 1970s, and was updated from time to time until the early 1990s. It was a database of resource attributes (forest type, productivity class, gross and net productive areas, stand age, sawlog and residual volumes), at the Compartment level. Subsequently, the detail was enhanced to reflect the stand level. HARIS was updated periodically (e.g., to reflect changes in area, composition or age due to harvesting, fire, etc.), but there was no systematic procedure to update and check HARIS entries. This haphazard approach to updating databases, coupled with a drift in standards over the 20-year period over which HARIS was compiled, contributed to inconsistencies in HARIS data. HARIS no longer contributes to sustainable yield estimates, but offers some important lessons about the need to maintain standards and manage updates.

In the early 1990s, the accessibility of GIS and need for better spatial data to support forest land use decisions lead to a precursor of SFRI, and contributed to several geospatial databases still in use today, including Forest25 and Rainfor100. Forest25 was based on block assessment maps captured at 1:25,000, and includes details of species, heights, stand origin and forest cover, but contains no volume estimates. Rainfor100 identifies areas mapped as rainforest communities in 1988 from aerial photographs interpreted as structurally mature stands using the 1987 rainforest definition contained in the publication “Victoria's Rainforests - An Overview”. Aerial photographs included 1:25 000 and 1:40 000 monochrome photographs (Gippsland, parts of Central Highlands), and 1:25 000 colour photographs (Otway, parts of Central Highlands). Rainforest areas were registered to 1:100 000 base features and may involve errors of 50m to 200m (Victorian Spatial Data Directory 2000).

3.2.1 SFRI – State-wide Forest Resource Inventory

In 1994, the State-wide Forest Resource Inventory (SFRI) set out to provide reliable and complete forest resource information for informed and consistent yield forecasting and land-use planning (Penny and Hamilton 1997). SFRI seeks to provide systematic coverage of Victoria’s natural eucalypt forests, using a consistent forest classification system, and tree measurement procedures independent of current forest product specifications. It also provides for the collection of some biodiversity information (e.g., number of hollows). The forest stand mapping phase of the SFRI program provides the digital data from which maps (at 1:25 000) and area statements are derived.

The primary source of data for the SFRI is aerial photographs covering the whole forest estate. Most are high quality, large format, 1:20,000 colour photographs, specially flown for the project, and colour balanced to optimize the identification of eucalypt species. Forest stands as small as 1 ha (average of 10 ha) are delineated and coded using standard procedures to describe dominant tree species present; crown cover; crown form (reflecting stages of maturity and development); and height of the most abundant crown form. Additional information relating to stand disturbance through harvesting, fire and disease, and year of origin is also recorded. Non-eucalypt areas are mapped in less detail. Interpreters verify their photo mapping by ground visits, and are audited by a separate team of specialist auditors.

The linework is either scanned or digitized for transfer to GIS. The mapwork is matched to existing digital 1:25,000 road and stream data, and collated with other digital resource data to provide the final product for forest management. The coding convention reflects these steps:

- SFRI-25VE (vegetation) is the digitized linework from the interpreted air photos;
- SFRI-25BM (benchmarked) includes age, origin and other data from a variety of sources;
- SFRI-25FS (forest stand) is the final refined and user friendly product.

SFRI-25FS is benchmarked (or date-stamped) to indicate that it is "all present and correct" at the nominated date. SFRI outputs have been published on CD and some have been made available for public scrutiny. Although the interim product varies by FMA according to the information available, the usual SFRI product includes

- Forest type and species composition
- Stand age and origin
- Stand height
- Growth stage
- Crown cover and width, and
- Estimated volumes.

These layers offer useful insights into the nature of the forest resource, and provide the basic information needed for resource estimation. The central requirement for resource estimation (Figure 3, Page 7) is information on forest type (species composition), site productivity (growth rates), stand origin (age), and stand density (i.e., is the stand "fully stocked" or was regeneration uneven?). Forest type and site productivity guide the selection of an appropriate yield curve, stand age provides the entry point to the yield table, and stand density indicates whether the resulting estimates should be further adjusted.

Many of the problems with SFRI were "teething" problems that have been resolved as work has progressed, and many procedures have been refined as a result of lessons learned. The State-wide, stand-level forest type mapping at a consistent standard provided by the SFRI is an important pre-requisite for yield prediction and sustainable forest management. However, further work is required on estate volume estimation procedures.

Recommendation 2: *Continue to provide and maintain up-to-date stand-level forest type mapping on a consistent basis over all forested crown lands in Victoria through the SFRI.*

It would also be useful to supplement SFRI on Crown lands with comparable coverage of other (private) lands likely to supply the hardwood industry in Victoria. Private forest inventory has commenced, and should be completed.

3.2.2 Estimating Net Area – Mappable areas

Estimates of sustainable yield rely on estimates of the net area available for harvesting (net harvestable area), which may be only a fraction of the total area of State Forest (and any other lands zoned for logging). The gross area can be established easily with geographic information systems (GIS), and can be reconciled against the gazetted area of State Forest, but it is more difficult to establish the net area that will actually be operated during a harvesting operation. The gross area needs to be reduced to take into account legal restrictions (e.g., *Code of Forest Practices*), management zoning provisions (e.g., Special Protection Zones), technical limitations (e.g., areas that are unworkable because of topography), and operational considerations (e.g., areas with volumes too low to be commercial, including "islands" where the area involved is too small for commercial interest).

The SFRI charter is to provide information on State Forest lands, especially those areas net of restrictions imposed by the Code of Forest Practices (i.e., buffers along streams and around rainforest, slope exclusions). The net areas reported by SFRI represent the theoretical maximum, but in the context of yield prediction, may be seen as systematic overestimates because they do not allow for operational considerations. SFRI computes productive areas by excluding tenures excluded from harvesting (National Parks, Special Protection Zones, etc.), slopes exceeding 30 degrees, buffers within 20 metres of digitized streams, and areas where the canopy height is less than 28 metres (or other threshold considered economically marginal). While this may approximate the theoretical net area available for harvesting, there are many practical limitations that contribute to a net harvestable area much less than the SFRI productive area. For instance, SFRI makes no allowance for the width of the saturated zone of streams, or for the additional areas that remain unlogged to ensure that trees do not fall into buffers. And while the Code of Forest Practice may preclude logging on slopes over 30 degrees, in practice, slopes over 25 degrees are often excluded if they are contiguous with steeper (>30°) slopes. Thus the estimated net harvestable area for use in SYSS and IFPS analyses may be substantially less than the published SFRI productive area.

Some information sources also pose some additional concerns that stem from the nature and scale of the data. For instance, productive areas exclude a 40 metre buffer about any rainforest from Rainfor100, or where available, Rainforest25 (not State-wide). Other information may also involve distortions (e.g., because of different scales and projections) that require some personal judgement on the part of the GIS specialist to adjust to the standard base mapping.

NRE recognizes that the SFRI net areas are optimistic, and alternative algorithms have been developed to accommodate stream width and operational restrictions that keep buffers free of logging debris. The algorithm assigns a buffer to each side of the stream independently, and bases the width of the buffer on the nature of the topography (steeper slopes have wider buffers) and on the estimated stand height (from SFRI). The algorithm appears to give more realistic (and conservative) area estimates. Preliminary analysis of 170 samples in the North-East FMA suggests that the algorithm performs satisfactorily, but a formal evaluation has not yet been completed. This algorithm has been used only for a two FMAs (Benalla-Mansfield and North-East). Case studies suggest that in some FMAs, 30 metre stream buffers may create a similar area reduction (but not the same distribution of area), and may offer a convenient first approximation. The reliability of this approximation may depend on the topographic complexity within FMAs.

Operational harvesting requires a certain critical mass, and small isolated stands may not be operated if they are distant from other timber resources, or if they contain a small volume and are completely surrounded by forest not to be logged. In the Benalla-Mansfield FMA, such "islands" were identified (and excluded from the net harvestable area) on the basis of the volume involved (800 m^3), but most FMAs adopted the simpler alternative of discriminating such islands on the basis of area (usually 5-15 ha). A minor but unresolved issue is how to efficiently discriminate a "string of beads" that could be viable to harvest.

Visual buffers may also be considered along roads (and along the forest boundary with private lands). GIS may also be used to model "visual catchments" to withhold highly-visible stands from harvesting, but a preferable approach may be to use IFPS to schedule harvests in a way that minimizes visual impact, rather than by excluding land from the productive estate.

Whilst SFRI provides an important and reliable basis for estimating areas, the available and productive areas do not account for operational considerations. The procedures used to model variable-width buffers appear to offer more reliable estimates of net harvestable area and should be further developed, tested, and documented. Other GIS procedures to estimate the net mappable area appear to be reasonable approximations, but are nonetheless unrefined and untested. NRE should further develop and test these algorithms, then document and make them available as standard routines to allow a consistent approach to be followed where appropriate.

Recommendation 3: *Test, document and make available as standard routines the GIS-based procedures for estimating net mappable areas to facilitate consistent area estimates.*

3.2.3 Estimating Net Areas – non-spatial adjustments

Some factors cannot be determined spatially and modelled directly with a GIS. Trees may be omitted from a harvest because rocky outcrops or other unmapped features make them inaccessible, and it is usual to apply a non-spatial adjustment to deal with these issues. The nature of this adjustment may be gauged from field surveys, or by contrasting predicted areas versus areas actually worked over in logging. The latter comparison is non-trivial, as there may be many reasons why the area actually worked over may not equate exactly with the area that could (and should) be harvested. External factors may motivate a contractor to quit a coupe early, and measurement or book-keeping errors may contribute to a poor estimate of the area actually harvested. Nonetheless, these logged-over areas offer a useful insight into the area that one can reasonably expect to be logged. Thus it is important to consider carefully the coupes used to calibrate net area estimation procedures, especially if abnormal externalities may have influenced the area operated.

Coupes should not be excluded from the computation of such an adjustment lightly. All coupes should be considered, unless the unlogged area is adjacent to another similar stand in a such a way that it is likely to be logged as part of the adjacent stand, or unless the abnormal externality is highly unlikely to re-occur. Unlogged margins that cannot be harvested before the next rotation (e.g., unlogged areas adjacent to stream buffers in Figure 5, Page 15) should be included when determining an adjustment, as they effectively reduce the net harvestable area during the rotation. It may be appropriate to include contractor identity in the analysis as a qualitative variable, so the adjustment can be based on the "best" contractor (if differences between contractors are evident), and thus reflect best practice.

Calibration for any observed discrepancy between predicted and worked-over area should not be automatic, as the mean discrepancy is not informative. Some analysis of the discrepancy is warranted to establish the nature and significance of the difference. Student's t-test may offer some insight as to whether the discrepancy is statistically significant, but is only valid if the differences exhibit a normal distribution. With the long-tailed distributions common in forestry, it may be more appropriate to regress predicted on operated areas and to test whether the slope of the relationship differs from unity. This approach may also offer insights into the pattern of harvesting (and any discrepancies) which may vary with topography, standing volumes, etc. Graphical analyses may offer useful insights as to the nature of this relationship (e.g., Vanclay and Skovsgaard 1997). It is also appropriate to plot the discrepancy against time (year harvested) to help detect any coupe selection bias (i.e., the tendency to harvest the most desirable coupes first). If no statistically significant discrepancy (slope not unity) or trend (with environmental or temporal variables) can be detected, it may be inappropriate to calibrate, as any apparent discrepancy may be merely due to chance.

Some of these issues may be solved with remote sensing. Laser altimetry may help to improve mapping of streams, steep slopes and rocky outcrops, and multispectral scanning may allow better detection of non-forested areas and of the saturated areas of watercourses (e.g., using the normalized difference of wet- and dry-season data). These (and other) approaches warrant further investigation.

Recommendation 4: *Test and document procedures to calibrate estimates of net harvestable area against areas logged-over operationally*.

3.3 Volume Estimation

Forest resource estimates deal with a range of volume estimates: log volumes, tree volumes, stand volumes, and estate volumes. These volumes may be gross or net of defects such as pipe (hollow centre), knots, gum veins, etc. Sustainable yield estimates and most licence agreements are based on volumes net of defect, but some licence agreements specify gross volumes (Table 2, Page 10). Conversion factors ranging between 0.85 and 0.97 are used to convert gross to net volumes. These factors were derived from studies undertaken during 1988-90, and conversion rates have not been monitored during the past decade. If NRE are to provide estimates of both gross and net volumes, it is timely to review conversion rates.

Log volumes are usually determined by directly measuring the centre girth and length of logs as they lie on the ground. NRE usually determined log volume using Huber's formula (length times cross-sectional area at the mid-point of the log, Husch *et al*. 1982). Adjustments for defect, if warranted, usually involve deducting the volume of a rectangular prism enclosing the defect. Measurements of log volumes may be correlated with stem diameter (dbh) and other tree and stand parameters to provide volume equations. It is customary to construct "one-way" volume equations as $V = a + b \times D^2$, but other volume equations may also be appropriate (Husch *et al*. 1982).

Log measurements can only be taken in this way when the tree is felled. Estimates of the volume in standing trees are usually obtained using the TREEMAP and VOLCALC procedures.

3.3.1 Tree volumes

TREEMAP is a standardized procedure to gather mensurational data from individual trees so that volumes can be estimated to different specified standards. A variable-radius plot is established at each sampling location, and tree species, dbh, merchantable height, crown form, and tree hollows are recorded. A sub-sample of trees is selected using list sampling based on the merchantable heights of plot trees. TREEMAP stem profiling (Irvine 2001) guides the collection of multiple diameters (at 0.5 m, merchantable height, and centroid) and data on type, size and position of defects (Figure 6). The TREEMAP trees on a sub-sample of the inventory plots are later felled to allow direct measurement of tree stem information (such

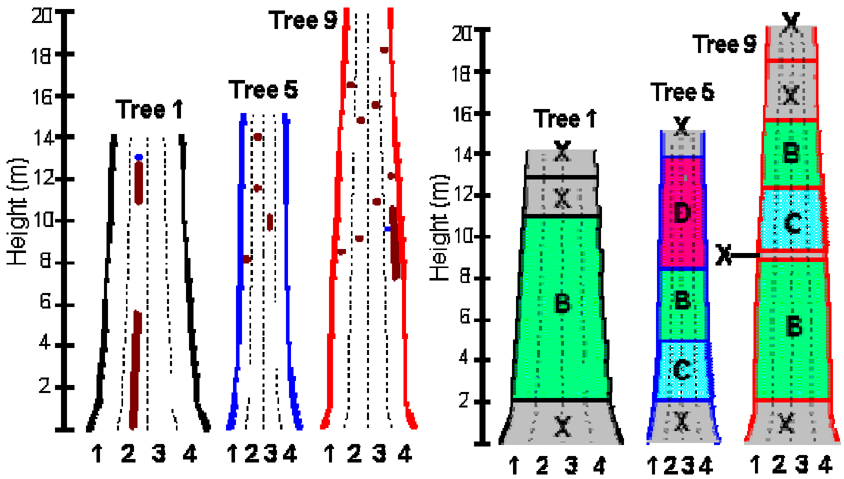

Figure 6. An illustration of defect mapping with TREEMAP (left) and the out-turn by log grade predicted by VOLCALC (right). TREEMAP is a procedure to record stem defects, and VOLCALC is an algorithm to compute expected log grades given optimal bucking. The numbers on the X-axis refer to the four quadrants of the tree's circumference (cf. N, S, E, W).

as upper-stem bark thickness), and to enable estimation of losses due to internal defect and felling damage.

VOLCALC is a computer program that uses data from each TREEMAP tree to estimate its volume. Merchantable volumes of felled trees are calculated from tree diameter and height. The location, type and size of external defects are used to determine the distribution of defective wood in conjunction with parameters associated with internal defect. VOLCALC then compares the predicted distribution of defect against the log grading rules, and estimates the optimal yield of timber products from the tree (Hamilton *et al*. 1999). In theory, D+, C+, or any other log grading standards can be applied. However, only D+ grades are used in calculating sustainable yields. The approach predicts optimal bucking (i.e., the merchandising of stems into logs), which may not always be achieved in practice. For instance, it is an open question as to whether the grades predicted in Figure 6 would be achieved, or whether field workers would simply cut a single 12 m D-grade log in the case of Tree 5, and a single residual log in the case of Tree 9. In some FMAs where there is no market for residual logs, volume estimates are reduced by 20% to account for trees with single short logs that are not felled. The Tambo-Central Gippsland study revealed that VOLCALC may overestimate volumes by 40-50% before calibration against felling plot data, and underestimate by 8% after calibration. This suggests that further development and testing of VOLCALC may be warranted. A formal error budget may be the best way to establish the source of this bias, and should reveal directions for further refinement of the method.

For those FMAs where the SFRI program has not yet introduced TREEMAP and VOLCALC, volumes are estimated using existing volume equations. Volume equations used vary from FMA to FMA, but may include STANDSIM's two-way volume equations (gross bole volume from tree height and diameter, developed for regrowth ash during the 1970-80s, Incoll 1983), EVTAB (Eucalypt Volume Table, a State-wide table developed during the 1970s), and locally developed one-way volume equations (e.g., $V = 0.0418 \times D - 1.58$ for Horsham FMA). The only reported test of these volume estimation procedures was for the Horsham equation (33% over-estimate, but no test of significance).

Tree volumes are fundamental to forest resource estimation, and the accuracy of these estimates directly influences the quality of overall resource estimates and forecasts. Adjustments may compensate for bias, but cannot compensate for imprecision in volume estimates. Greater emphasis should be placed on basic mensuration, and on evaluating the adequacy of existing equations.

The VOLCALC approach makes it possible to predict volumes by log size and grade, but current procedures predict only D+ sawlog volumes. Because of licence commitments (Table 2, Page 10) and the price differential between log grades and sizes, it is important to predict not only D+ volumes, but also the proportion of the volume in large (>45 cm) and C+ logs.

Recommendation 5: *Refine yield prediction procedures to predict not merely D+ volumes, but also the breakdown of volume by size and grade.*

3.3.2 Stand Volumes

Tree volumes are only a means to an end, that of estimating the volume in a stand of trees or in a coupe to be felled. In many situations, inventory provides a representative list of trees per unit area, and this can be used with tree volume equations to estimate stand or coupe volumes. However, in many FMAs, stand volumes are estimated using the TREEMAP approach.

The TREEMAP approach uses a two-stage sampling procedure. Stand volumes can be reconstructed by weighting tree volume estimates to account for each trees' contribution to the stand basal area and merchantable height, using the formula

$$V = \sum_i \frac{v_i}{p_i} w_i \quad = \quad \sum_i v_i \frac{\sum t}{t_i} \frac{BAF}{b_i}$$

where V is stand volume (m^3/ha), v_i is the volume (m^3) of tree i, p_i is the probability of tree i being selected in the second stage sample, and w_i is the weighting, or number of stems per hectare represented by tree i. *BAF* is the basal area factor (a measure of sampling intensity), b_i is the basal area of tree i, t_i is the merchantable height of tree i, and Σt is the sum of merchantable heights in the second stage sample. The effect of this equation is to greatly magnify (e.g., 100-fold) the tree volumes, consistent with (and inversely to) the small proportion of the stand they represent as a result of the two-stage sampling. This further underscores the importance of accurate estimates of tree volume.

As no formal error budget has been prepared, it is not possible to evaluate the source and magnitude of any discrepancies in volume estimates. However, three possible sources of error warrant investigation in a formal error budget:

- Area estimates: Comparisons between predicted and realized volumes must be based on the same area, the area actually worked over during harvesting. If volumes realized from a coupe are expressed per unit area predicted (e.g., the area listed on the WUP) rather than per unit area actually harvested, then a bias is introduced, and there is a danger of a double adjustment (viz. adjusting for the same discrepancy in both area estimates and volume estimates).

- TREEMAP: Any oversight in mapping defects on trees will contribute towards over-optimistic estimates. Established audit procedures (Irvine 2001) should allow any such bias to be quantified.

- VOLCALC estimates the volumes that may be obtained with optimal bucking and nominal felling damage. These estimates are calibrated with data from felling plots, but the extent to which the felling plots reflect the conditions and pressures of harvesting operations remains contentious. This is relevant, because VOLCALC should not estimate total volume, but the volume that can be realized during “best practice” operations that may not be conducive to optimal bucking.

A formal error budget (see Section 7.3, Page 43) may be the only way to reliably indicate the performance and limitations of these volume estimation procedures. It may also be appropriate to re-examine whether a larger plot size (or a smaller basal area factor in angle gauge sampling) could help to reduce the high within-stand variance associated with estimates (e.g., samples of 129, 277 and 349 m^3/ha within a single ash stand in Central Gippsland).

3.3.3 Estate volumes

Resource estimates are required for the whole forest estate, but it is impractical to measure every stand, so we need a means to extrapolate from a few samples to the estate. There are many ways to do this (e.g., Schreuder *et al*. 1993); they differ substantially in the effort (especially travel time) and assumptions involved. In the past, the conventional approach would be to use systematic sampling, or stratified random sampling where prior data existed. The opposing trends of increasing labour and decreasing computer costs encourage the use of fewer data and more inference. This has led to the approach that Hamilton and Brack (1999) call “model-based” sampling. However, this approach is effectively a variant of stratified sampling in which strata are defined within the data-space rather than on a geographic basis[1]. The only suggestion of an underlying model is the choice of four variables used to divide the data-space (species, crown cover, crown form, height class; cf. stand parameters used in conventional stratification). Inventory plots were randomly assigned to these (potentially 96) classes. An improvement to this approach would be to estimate the variance in each class (using prior data) and sample proportional to the variance.

Plots were established on a 500 m grid that excluded areas unavailable or uneconomic to harvest, and areas within 50 m or further than 1 km from a road. The exclusion of these areas may have been unwise, because it raises the spectre of bias, and may have excluded extreme points that could have helped to establish relationships. In addition, procedures were established to relocate plots if they fell within 35 m of the stand edge, to avoid possible complications of dealing with large trees within the plot, but outside the stratum of interest. SFRI uses a 3 m^2/ha gauge in establishing point samples, so a tree of 120 cm dbh at a distance of 35 m will lie just outside the plot. This provision to avoid trees within the plot but outside the stand should be considered in conjunction with the observation that the average stand size mapped with SFRI is 10 ha. For a hypothetical square 10-ha stand, 40% of the stand will be ineligible to host the plot centre. This means that big trees (e.g., >120 cm dbh) will be sampled throughout the stand, but that smaller trees will be sampled only in the stand's interior (e.g., trees of 40 cm dbh will remain unsampled on 25% of the area near the margins). These proportions (40% and 25%) increase as stands become smaller in size or more irregular in shape. Of course, this is of no consequence if stands are homogeneous without edge-effects, so that conditions near the stand margins are the same as those in the interior – but this may not be the case, as there is often a relationship between tree size, density, and position in a stand (e.g., Jacobs 1955, para 175). Given the importance of these data to sustainable yield estimates, it is critical that these and other possible sources of bias be investigated.

Recommendation 6: *Establish the extent of any bias in SFRI volume estimates, particularly with regard to stand edges*.

The North-East pilot study sought to fit a model to these observations, so that stand volumes could be estimated directly from parameters held in the SFRI GIS. Candidate variables included those used to design the inventory (species, crown cover, crown form, and height class), as well as other variables available from the GIS (e.g., elevation, latitude). The 271 observations in the North-East pilot has been supplemented with a further 261 observations from the Tambo FMA. A 9-parameter model (involving crown cover, dominant height, elevation, latitude and binary variables for pure ash and mountain ash) was fitted to the pooled data (n = 532). Stand age is not included in the model, presumably because it was not readily available from the SFRI GIS. However, standing volumes are obviously well correlated with stand age in regrowth forests, and it would seem to be a good candidate for future efforts of this kind. Forest management records should be able to support the estimation of stand age for the bulk of the managed forest estate. It appears that a few data were particularly influential in the fitting of the model, and it may be appropriate to use Cook's distance to guide the selection of variables and indicate the need for additional sampling.

New models for mixed species and ash forest types were developed for the Tambo-Central Gippsland study. The equation for the mixed species forest types was

$$V = 1677 + 2.1 \times H + 0.14 \times E - 0.074 \times E^2 - 30 \times L + 35 \times R$$

[1] To appreciate this nuance, consider how the inclusion of latitude and longitude (i.e., AMG reference) in the sampling strategy would have made it effectively equivalent to conventional stratified sampling.

where *V* is D+ sawlog (m^3/ha), *H* is stand height (m), *E* is elevation, *L* is latitude (AMG northing), and *R* is a binary variable that takes the value 1 for 1926-44 regrowth and 0 otherwise. The equation for ash was somewhat more complex, involving 9 parameters (involving crown cover, dominant height, elevation, latitude and binary variables). A comparison with operational out-turn from 132 coupes (2300 ha) in the Tambo FMA revealed that the equations predicted 90% of the ash out-turn and 88% of the out-turn from mixed species forests, but no tests of statistical significance were attempted. This discrepancy may be due to coupe selection bias, but warrants further examination, and if confirmed, indicates a need for re-calibration. There is evidence of coupe selection bias in East Gippsland (P=0.01, see Page 76), and it appears to amount to about 10% (i.e., yields from coupes harvested in recent years have been declining, apparently converging to about 10% less than recent harvests). Similar tests for bias have not been made for other FMAs.

The GIS-based approach illustrated in the Tambo-Central Gippsland study offers an efficient way to provide stand volume estimates for the SFRI in the absence of any other data, but it does not pave the way for fully utilising existing data from other sources. Forest services generally have lots of data relating to forests (inventories, surveys, logging and fire histories, remote sensing, etc.). Most of these data are durable, and changes slowly in predictable ways. Efficient resource estimation techniques should draw on this material to provide the best composite resource estimates for a range of end-uses. Forest services generally have substantial on-going inventory (both formal and informal, e.g., to prepare WUPs), and efficiency demands that resource estimation recognizes these information needs, and the possibilities created by the new data generated in this way. This theme is further developed in Section 7.1 (Page 40).

4. Yield Tables and Growth Estimates

Most yield forecasts in Victoria rely on estimates drawn from yield tables, making yield tables one of the three key components of the yield prognosis. Yield estimates in some FMAs were derived from yield tables calibrated with empirical data, while others relied on subjective judgements expressed as yield tables or as average growth rates (i.e., MAI or PAI). Subjective estimates should be used with caution, even when offered by experts, because history suggests that such estimates are often over-optimistic.

4.1 Yield Tables

Yield tables are a well-established concept, apparently first applied in the *Lung Ch'uan* codes in China in the early 1600s (Vuokila 1965), and developed independently in Europe in the 1800s (e.g., Reventlow 1827). Many variations on this theme exist, but the basic concept remains unchanged (Figure 7). Unfortunately, no reliable short-cuts for yield table construction have been devised, and site-specific temporal data are required to construct yield tables and take adequate account of local growth patterns, defect levels, and commercial considerations. There is no biological basis for a sawlog yield curve; it reflects not only biology (i.e., net primary productivity, decay), but also technology and economics.

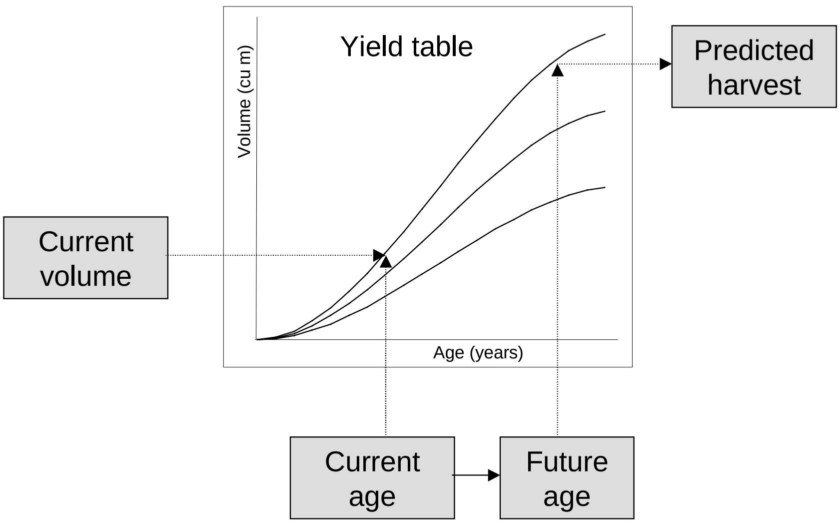

Figure 7. Yield tables like this are used to predict the sawlog volume available at a given stand age. Yield tables may involve several yield curves (3 in this case) corresponding to different sites and species composition; the shapes of these curves may be quite different. Current volume and age are used to choose a yield curve, from which the yield at any future age can be estimated. See Figure 3 (Page 6) for the broader context.

It is worth re-iterating that different localities may cause different growth patterns, which in turn, lead to yield curves of different shapes. This means that data used to construct yield tables should span a range of ages, so that some insights are gained into the shape of the curve. Particular care must be taken when attempting to calibrate a yield curve to locations with different soils or climatic conditions and to stands with different species compositions.

4.1.1 Establishing a guide curve

In Victoria, estimates of standing volume are often used to calibrate a generic yield table to a particular site. With this approach, the absolute level of the generic yield table is immaterial, but the shape of the curve and the way it is scaled are critical for the accuracy of predictions. The role of growth data in this context is to help define a suitable generic yield curve, and to indicate how it can best be scaled to customize it to a particular site. Ideally, data for developing the generic yield curve should be derived from growth plots remeasured several times over a long period (preferably through a full rotation), so that the temporal development of stands can be investigated. However, in the absence of such plots, useful inferences may be drawn from a series of temporary plots spanning comparable stands on similar sites with a range of ages. The reliability of curves developed in this way from temporary plots depends on the ability of researchers to satisfactorily denote comparable sites and stands.

When long-term growth plots are unavailable, useful insights may also be gained from short-term plots that indicate current stand age, and periodic annual (volume) increment (PAI). Such (age and PAI) data for several stands can form the basis of a “vector field” (Figure 8) that can be used to compile a yield table. Stem analyses may also offer some insights into the temporal development of stands, but suffer two limitations: growth rings may not always be annual rings, and such analyses can normally be undertaken only on surviving trees, so no insights of mortality can be gained.

4.1.2 Scaling the guide curve

Another issue critical to the reliability of a yield curve is the way in which it is calibrated to a new situation. There are several ways a yield curve can be calibrated; three possibilities are

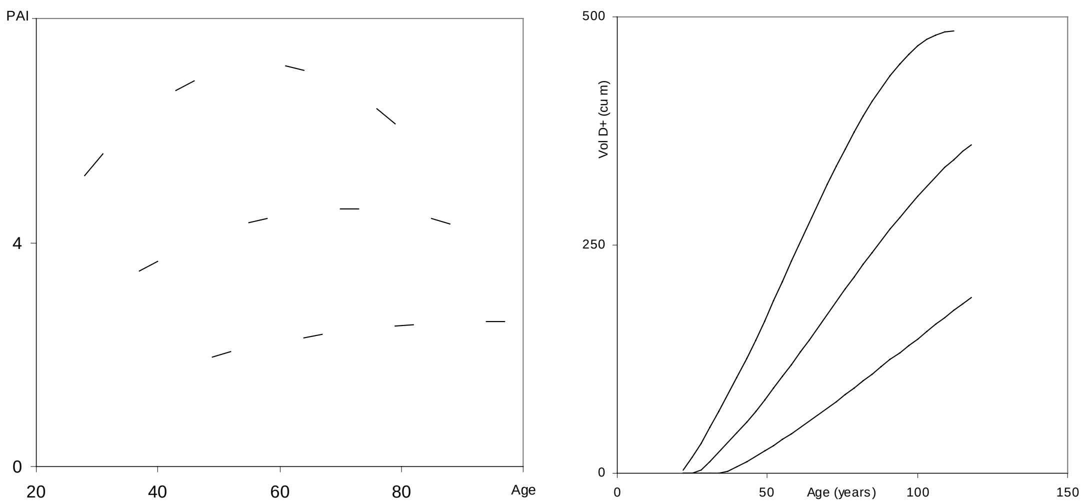

Figure 8. Vector field (left) showing periodic annual volume increment versus age for three site types. Each vector or line segment represents three years growth observed on a newly-established growth plot or derived from stem analyses. Equations can readily be fitted to data such as these, and can be integrated to provide conventional yield curves (right).

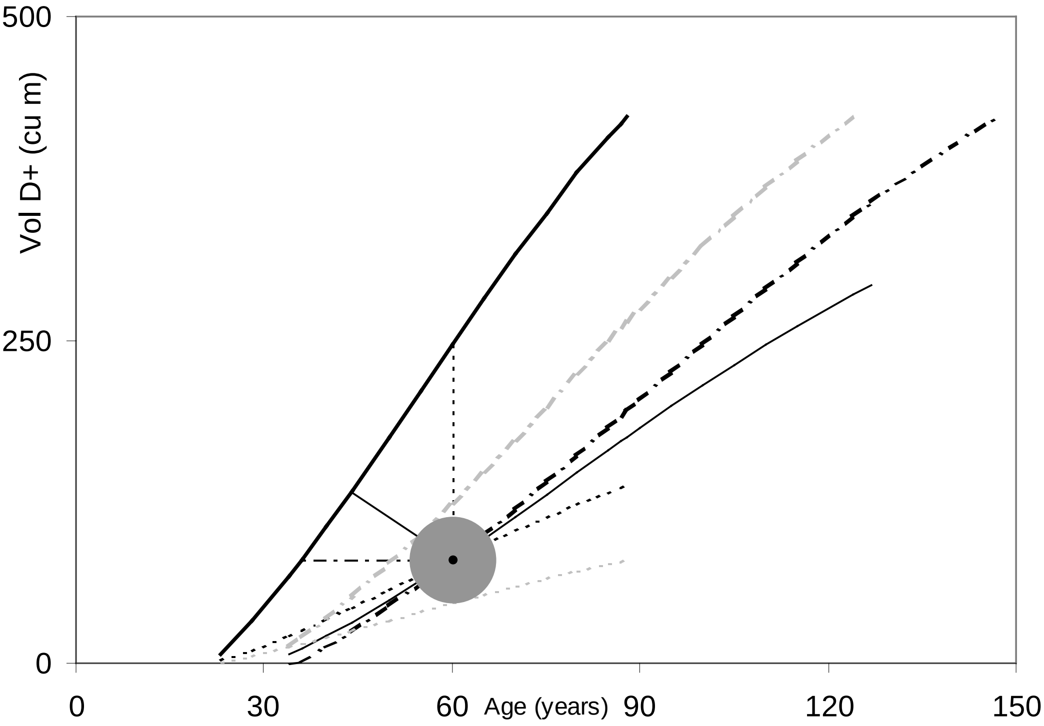

Figure 9. Different ways to scale a yield curve (here for ash in Benalla-Mansfield) to make predictions for a stand thought to be 60 years old, with a volume of about 80 m^3/ha (grey blot). Scaling may transform the Y-axis (dotted line), the X-axis (dashed line), or both axes (solid line). Lines end where the maximum MAI is attained.

warrant consideration. One possibility is to scale only the yields (i.e., the Y-axis, illustrated with the dotted line in Figure 9), effectively assuming that growth is age-dependent (so that it has the same optimal rotation age, but a different asymptotic yield). The other extreme is to scale only the stand ages (i.e., the X-axis, illustrated with the dashed line), effectively assuming that growth is stage-dependent rather than age-dependent (so that it has a different optimal rotation age, but the same asymptotic yield). Alternatively, both axes can be scaled, equally or otherwise. The decision has considerable implications for predictions of future yields and optimal rotation ages, especially when one also considers the variance associated with the reference stand (grey lines in Figure 9). Insights into the appropriate scaling method may be gained by examining growth trends from a series of permanent plots to establish the appropriate procedure for those plots, and assume that the same tendency holds for all stands and sites. An alternative is to use the PAI (estimated from stem cores if necessary) at each calibration site to signal the appropriate direction of stand development (i.e., PAI shows the recent growth trajectory of the stand in question).

The question remains whether scaling a guide curve is the best approach for estimating future yields, or whether an alternative approach may be more appropriate. NRE's current approach is likely to deliver the best results for short-term prognoses, but the uncertainty surrounding scaling means that alternative approaches may provide more reliable long-term predictions. One commonly used approach is to select one of a series of pre-defined yield tables, on the basis of site-specific variables (e.g., height, ecological indicators). Given the central role of the yield table in estimating sustainable yields, further research into these issues is warranted.

Recommendation 7: *Establish whether scaling of a guide curve on the basis of estimated volume is the most reliable way to predict future yields, and if so, what is the most reliable way to scale such a guide curve.*

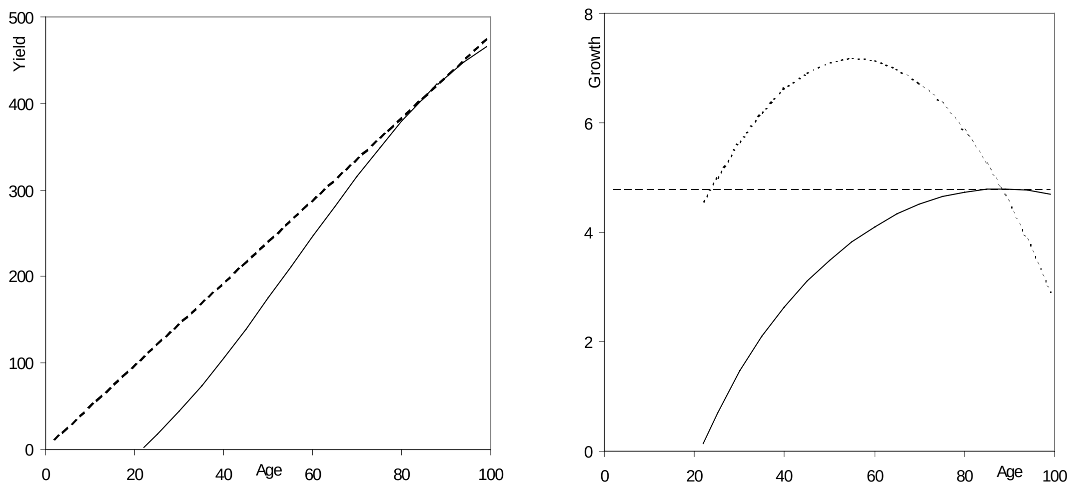

Figure 10. Benalla-Mansfield ash yield curve (solid line, left) contrasted with the line representing average MAI at maturity (dashed line). The volume growth (right) assumed is the same only at culmination (88 years); at other ages, the average MAI (dashed) underestimates current growth (dotted) and overestimates the actual MAI (solid line). If the stand is not harvested at the optimum rotation age, the yield may be overestimated (left).

4.2 Mean Annual Increment – MAI

In preliminary calculations for some FMAs, interim yield tables simply reflected the MAI at maturity, and assumed that this MAI would be attained throughout the life of a stand. These yield tables have since been amended by scaling a guide curve to achieve the desired MAI. The guide curve approach is more satisfactory because it reduces the potential for bias. Figure 10 illustrates how the application of MAI at maturity throughout the life of a stand may overestimate yields, especially if stands are harvested before the optimal rotation age. The MAI approach is satisfactory in the case of a normal forest, in which stands are harvested at the nominal rotation age, but may create a substantial overestimate if harvesting occurs at other ages. The use of guide curves scaled to the desired MAI is more appropriate.

4.3 Growth models - STANDSIM

Some of the generic yield tables in Victoria have been compiled using the STANDSIM growth model rather than the raw data from permanent plots. A forest growth model is an abstraction of the natural dynamics of a forest stand, encompassing tree growth and death, and other changes in stand composition and structure. Common usage of the term “growth model” generally refers to a system of equations to predict the growth and yield of a forest stand under a wide range of conditions (Vanclay 1994b). The only dynamic growth model currently used in yield prediction is STANDSIM, a model constructed by Opie in 1972, subsequently enhanced by others (e.g., Campbell *et al.* 1979, Incoll 1983), and recently evaluated by Wang (1999).

STANDSIM comprises some 16 functional relationships that describe the growth of tree height, stand basal area, the height-diameter relationship, and the maximum stand density. The source data for the model are not documented, and parts of the model were established using “graphical analysis” rather than conventional statistical analyses (Campbell *et al.* 1979). Nonetheless, the model seems to give reliable predictions.

Opie (1972) observed that 300-year simulations of seedling stands provided predictions similar to virgin stands, and concluded that cumulative bias was presumably not serious. Campbell *et al*. (1979) found that most STANDSIM growth predictions were reliable, but that basal area growth tended to be overestimated in dense stands (>50 m^2/ha). They concluded that although their results were encouraging, the size of the standard errors indicated scope for considerable improvement of the model. Wang (1999) found that predictions initiated at stand ages ≥15 years yielded errors within ±1% per year for stand density, within ±0.5% per year for stand basal areas, and within ±0.25% per year for sawlog volumes. Thus a 15-year-old regrowth stand, when extrapolated to clearfall age (say 75 years), could have an error of ±15% in sawlog volume. These errors are greater for simulations initiated with stands younger than 15 years.

These evaluations of STANDSIM devote considerable attention to potential bias. However, the dominant use of STANDSIM is to construct the guide curve for a yield table. This guide curve is subsequently scaled with local empirical data to customize the curve for a particular location. Thus the concern should not be for bias in STANDSIM predictions, but rather whether it generates a reliable guide curve – one with an appropriate shape. Care is required to ensure that the shape of any such curve is a result of the data used to calibrate the model, and not a consequence of the assumptions made in building the model. It is appropriate to use independent data to establish the reliability of the shape of such a generic yield curve, by establishing the temporal pattern of residuals from individual plots, rather than by establishing the absence of any overall bias. No tests of this aspect of STANDSIM performance have been published, but graphs by Wang (1999) suggest that simulated basal area development exhibits no obvious anomalous trends, offering some basis for the assumption that volume growth trends might also be adequate for the purposes of yield table development. Further testing of this aspect of STANDSIM is warranted.

Recommendation 8: *Establish the circumstances under which STANDSIM can be relied upon to provide suitable guide curves for yield tables for both ash and mixed species stands*.

The thinning of selected stands to boost future timber yields has been proposed for some FMAs (e.g., East Gippsland). Because thinnings are sold as pulp- rather than saw-logs, the effect of thinning in yield simulations is merely to increase growth rates and shorten rotations. Thinning can be accommodated within the yield table and by the scheduler (i.e., SYSS or IFPS), but a major obstacle is the lack of reliable data to calibrate anticipations. Some East Gippsland simulations assume a 70% growth response to thinning (i.e., a stand thinned at age 40 will have 70% more D+ sawlog volume at age 55 than its unthinned control), but offer no empirical data to support this contention. Horne and Robinson's (1990) study of the 33-year growth response after thinning in 28-year-old alpine ash revealed no such growth stimulus. They found that thinned stands contained bigger trees, but that the total merchantable volume (>40 cm dbh) actually decreased as a result of thinning. West (1991) reported a 40% stimulus in mountain ash. In the absence of plot-based data, it would seem prudent to use STANDSIM to explore the likely response to thinning.

Recommendation 9: *Ensure empirical data substantiate any assumption that thinning can resolve a short-term hiatus in sawlog supply.*

There is no equivalent to STANDSIM for the mixed species forests, which comprise some 70% of the State Forest available for timber harvesting (Hamilton *et al*. 1999). Furthermore, there are few data that could provide a basis for the development of such a model. Until such data are obtained, there is no real alternative to the continued use of the forecasting methods presently in use.

Recommendation 10: *Develop growth models for mixed species forests to enable more reliable yield predictions for these forests*.

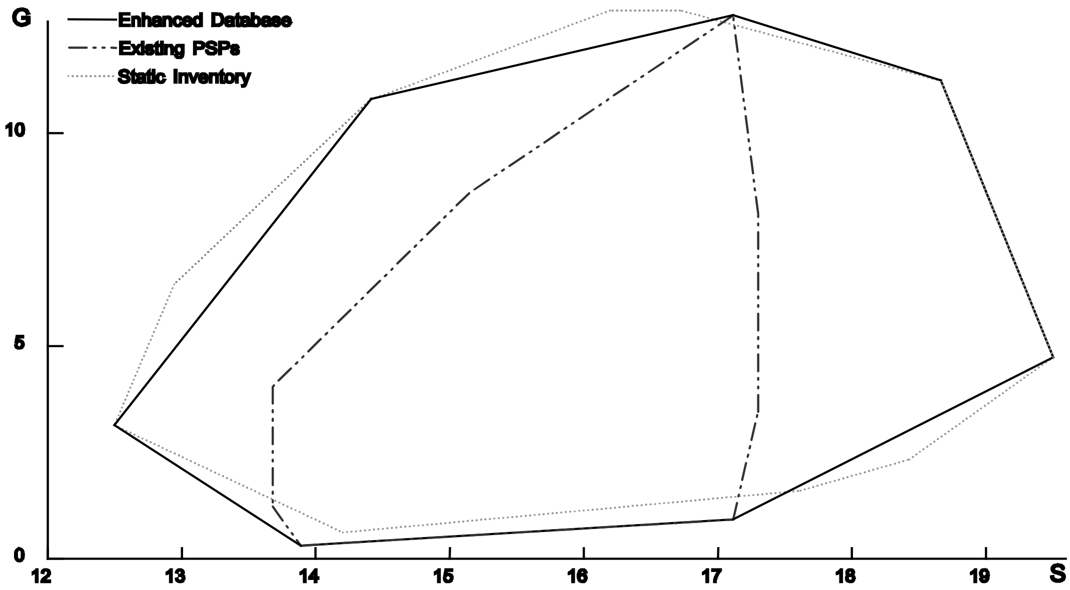

Figure 11. Comparing the convex hull enclosing data from a permanent sample plot (PSP) system (solid line) with that from the managed forest estate (dotted line), on the basis of site quality (S) and stand basal area (G). Reproduced from a study (Beetson *et al*. 1992) to supplement a PSP database to better support forest management decision-making. Comparable axes for NRE could be stand height and stand volumes. Ideally axes should be orthogonal rather than correlated.

4.4 Growth data

Growth models and yield tables are underpinned by data, and good model performance requires a good database. Ideally, the database should be such that management applications of the model interpolate rather than extrapolate the data. This means that plot data used for developing growth and yield models should extend beyond the range of data normally found in the managed forest. More specifically, the convex hull of the data used in model development should enclose the corresponding data from the managed forest estate (Figure 11, Beetson *et al*. 1992; Vanclay 1994b). This requires not only passive monitoring plots (e.g., continuous forest inventory), but also experimental plots where extremes of stand density (e.g., heavily thinned and unthinned stands) are explored.

NRE has an extensive network of permanent plots, and it is appropriate that the scope of this database is contrasted against the production estate in this way (cf. Beetson *et al*. 1992), and used more effectively in support of yield prediction and forest management activities.

Recommendation 11: *Contrast the characteristics of the growth plots with those of the production forest estate to investigate the extent to which yield estimates extrapolate (rather than interpolate) the growth plot data and to indicate where additional growth plots may be required.*

5. Scheduling the Wood Flows

The third of the key components in resource prognoses is resource scheduling (the other two being net areas and yield tables). Scheduling is unnecessary in the case of an unexploited estate in which all parts of the forest carry the same timber volume, and is trivial in a normal forest. However, in most other situations, especially where there is a history of past over-cutting, scheduling is a critical part of the yield prognosis, because the sequence and timing of the harvest will influence the volume of timber available in the short-term, and possibly in the longer term (Figure 12).

NRE uses two tools for yield scheduling, the Sustainable Yield Spread Sheet (SYSS) package which facilitates simplified heuristic simulation, and the Integrated Forest Planning System (IFPS) which is a sophisticated mathematical programming package. Yield calculations for some north-western FMAs were estimated using cutting cycle analysis, and in Horsham FMA simple broad-area averages were used.

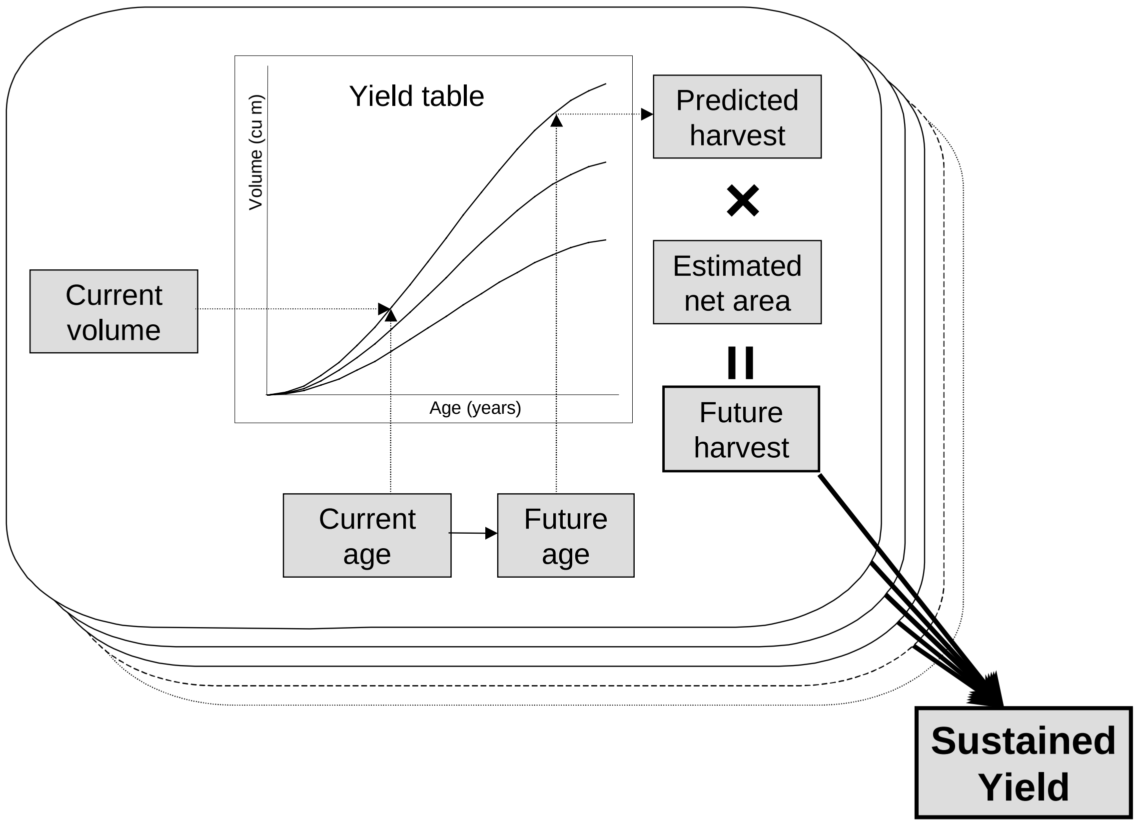

Figure 12. Schematic illustration showing how scheduling of yields is required to estimate sustainable yields. The challenge is to find the sequence of coupes (here illustrated as cards) that delivers the highest yields while observing operational constraints (log sizes, yields per hectare, coupe sizes, etc). The sequence and duration of cutting on initial coupes influences the harvesting age, and thus the volumes realized in subsequent coupes.

5.1 Cutting cycle analysis

Cutting cycle analysis is a traditional way to explore timber yields over time, and has been used extensively for yield forecasting in uneven-aged forests. Its wide use may be because it is easy to use and is the most reliable technique that can be performed without computers. The basic method (Leuschner 1984, Vanclay 1994b) is to nominate a cutting cycle length, construct a representative stand table for each stratum, project the stand to the mid-point of the cutting cycle, and apply a harvesting rule to estimate the out-turn. As the actual time of harvesting may not be known, the mid-point of the cutting cycle is used as a compromise. The annual yield is determined by dividing the predicted out-turn by the cutting cycle length.

Cutting cycle analysis offers several advantages over alternatives such as area control (i.e., harvesting an equal area each year). The usual method employs the current stand table and a harvesting rule that approximates field practice, to predict yields available for harvesting. Continuing the analysis for several cycles indicates the long-term yield, and the viability of the nominal cutting cycle length and harvesting rule (Vanclay 1996). The method poses some questions which require subjective decisions and which may have a substantial impact on forecasts: What if the yields derived from successive cycles differ – should the nominal cutting cycle length be altered, or should the harvesting rule be changed? Is the "typical" stand employed representative?

The method can be improved by stratifying by site productivity and standing volume, and by simulating individual plots rather than stratum averages. Other deficiencies include the assumption of a fixed cutting cycle for all stands in the stratum, the assumption of harvesting at mid-cycle, and the implicit assumption that all stands will be cut in the same sequence in subsequent cutting cycles. Cutting cycle analysis has largely been displaced by more realistic approaches such as heuristic simulation and mathematical programming, both of which overcome some of the restrictive assumptions in cutting cycle analysis (e.g., fixed length cycles with harvesting only at mid-cycle).

The approach adopted in the Mid-Murray and Mildura FMAs departs from this usual approach by simply assuming that the usual harvest volume (e.g., typical of harvests during last ten years; in some cases, with reductions for second and subsequent harvests) would be available each cycle. This assumption simplifies calculations, but detract from the method. The conventional method simulates both growth and harvesting, reveals whetherthe simulated harvests can be sustained with the assumed growth rates and cutting cycles. The modified approach used in the Mid-Murray and Mildura FMAs offers no check on the interaction between growth, harvesting and assumed cycle length. The modified method may give reliable predictions if the cycle length and the nature of the harvest are appropriate and consistent with growth rates, but the method will not reveal any inconsistencies. The onus is on the user to ensure the that the harvest and the length of the cycle are appropriate.

5.2 SYSS – Sustainable Yield Spread Sheet

The Sustainable Yield Spread Sheet (SYSS) is an MicroSoft-Excel-based system that facilitates manual scheduling of wood flows. SYSS requires users to define the forest estate, tabulating net areas by forest types and age classes, and stipulating the silvicultural regime for each of these type/age categories. Yield tables must be provided for each forest type, and modifiers can be specified for particular silvicultural regimes. Once SYSS has been set up in this way, the user can manually schedule yields heuristically (i.e., by trial and error). However, the yields obtained depend to a considerable degree on the skill and inclination of the operator.

v6.1.33a Prepared 27-Nov-00

Input Information for AVAILABLE forest (Net Productive Area)

FMA	East Gippsland
Product	D + Sawlog net
Base Year	2000

Period	Length
1	5
2	5
3	5
4	5
5	5
6	5
7	10
8	10
9	10
10	10
11	10
12	10
13	10
14	10
15	10
16	10
17	10
18	10
19	10
20	10

Forest Resource Information	Forest Type (full name)	Forest Type (abbrev.)	Regrowth MAI (m3/ha/yr)	Rotation Length (yrs)	Minimum Harv Age (yrs)	Fire risk %	Error in data %	LTSY (m3/yr)
	Alpine Ash	AA	2.75	80	65			12,600
	Mount Ash & Shining Gun	MA&SG	3.30	80	65			7,700
	Mountain Mixed Species	MMS	2.40	80	65			194,300
	Foothill Mixed Species	FMS	1.80	80	65			259,500
	Coastal Alpine Mixed Spp	CAMS	0.60	120	85			64,800
	Thinning	Thin	2.18	55	55			9,900
							TOTAL	548,800

Net Productive Area	Stratum	Year of Origin	Net Productive Area (ha) AA	MA&SG	MMS	FMS	CAMS	Thin	Total (ha)
	All	1800	598	531	38,199	85,822	69,700		194,850
	All	1915			38				38
	All	1925	52	30	556	1,210			1,848
	All	1935	395	7	2,082	1,388	41		3,913
	All	1945	42		459	29	38		568
	All	1955			1,450	2,623	746		4,819
	All	1965	122	128	4,129	7,517	11,026	1850	24,772
	All	1975	1,663	750	6,900	7,205	7,378	2700	26,596
	All	1985	1,283	558	13,612	18,943	12,841		47,237
	All	1995	432	334	13,534	19,437	6,158		39,895
		Total	4,587	2,338	80,959	144,174	107,928	4,550	344,536

Regime	Stratum	Year of Origin	Regime AA	MA&SG	MMS	FMS	CAMS	Thin
	All	1851	CLEAR-AA	CLEAR-MA	CLEAR-MMS	CLEAR-FMS	CLEAR-CAMS	CLEAR-THIN
	All	1915			CLEAR-MMS			
	All	1925	CLEAR-AA	CLEAR-MA	CLEAR-MMS	CLEAR-FMS		
	All	1935	CLEAR-AA	CLEAR-MA	CLEAR-MMS	CLEAR-FMS	CLEAR-CAMS	
	All	1945	CLEAR-AA		CLEAR-MMS	CLEAR-FMS	CLEAR-CAMS	
	All	1955			CLEAR-MMS	CLEAR-FMS	CLEAR-CAMS	
	All	1965	CLEAR-AA	CLEAR-MA	CLEAR-MMS	CLEAR-FMS	CLEAR-CAMS	CLEAR-THIN
	All	1975	CLEAR-AA	CLEAR-MA	CLEAR-MMS	CLEAR-FMS	CLEAR-CAMS	CLEAR-THIN
	All	1985	CLEAR-AA	CLEAR-MA	CLEAR-MMS	CLEAR-FMS	CLEAR-CAMS	
	All	1995	CLEAR-AA	CLEAR-MA	CLEAR-MMS	CLEAR-FMS	CLEAR-CAMS	
		Subsequent Rotations	CLEAR-AA	CLEAR-MA	CLEAR-MMS	CLEAR-FMS	CLEAR-CAMS	CLEAR-THIN

Figure 13. The "Information Input" sheet from a SYSS analysis for East Gippsland. Grey fields that require user inputs include time intervals for each of the 20 steps (top right), forest types with MAIs and rotation ages (top), areas by ages for each type (centre), and regimes for each stratum (bottom; these are species-specific, but they may vary with stand origin). The version number is at the top left.

SYSS encourages users to stratify the forest by forest type and age class (Figure 13), but does not reach the same degree of spatial explicitness attained within IFPS. SYSS offers a useful first approximation, but does not approach the operational considerations that can be accommodated in IFPS, and as a result, SYSS may tend to overestimate yields. A comparison of SYSS versus IFPS predictions based on the same data would offer useful insights into the extent to which SYSS overestimates. Turner and Church (1995) found that "under a maximum timber objective, the same results from SYSS and FORPLAN have been achieved. FORPLAN can add to and refine the process significantly though, as it does not use aggregated data and is spatial in nature". However, the operational realities introduced by this spatial modelling tend to reduce the estimated sustainable yields, and it is important to gauge the extent of these discrepancies. In the Benalla-Mansfield FMA, strategic-level simulations analogous to the SYSS approach (but simulated with IFPS without operational constraints) were examined, suggest yields of about 35% higher than the standard IFPS scenario, largely because of assumptions relating to available areas. It is intended that IFPS will be used in preference to SYSS in future, but this comparison is timely as many of the current estimates were derived with SYSS. The fact that SYSS was used in several FMAs where the supply situation is "tight" makes this comparison particularly important.

Recommendation 12: *Conduct a parallel run with SYSS and IFPS on an identical data set to establish whether, and to what extent, SYSS may overestimate sustainable yields.*

Some enhancements to SYSS would be beneficial, even if SYSS has a short life beyond the current licence renewal process. In their enthusiasm to find a good solution, users may overcommit timber towards the end of a simulation, or conversely, may allow stands to remain well beyond the optimum rotation age. It would be useful to offer users an index summarising the general state of the forest. Simply reporting the average age and total standing volume during each simulation period would provide users with useful reference points (cf. estate average basal area and merchantable volume in Table 1, Page 1).

The minimum rotation age solicited by SYSS acts as an ending condition in many SYSS situations, and realistic estimates are required. SYSS also solicits estimates of MAI from users; this is unnecessary and undesirable, as it can lead to an estimated long-term sustainable yield ("Total LTSY" in Figure 13) that is inconsistent with information implicit in the yield tables also provided in SYSS. It is possible and preferable for the MAI (and optimum rotation ages) to be computed directly from the yield tables in SYSS. Finally, there are already many different versions of SYSS in circulation (see version number at top left of Figure 13), and careful management of these is required, especially to ensure that all users are aware of updates, enhancements and bug fixes.

Recommendation 13: *Modify SYSS to report performance indicators such as the estate-wide mean age and mean standing volume during each simulation period, and to automatically calculate the maximum MAI and optimum rotation age from the yield tables supplied*.

5.3 IFPS – Integrated Forest Planning System

The Integrated Forest Planning System (IFPS) is an extension of SPECTRUM, the successor to FORPLAN, a linear programming model developed by the US Forest Service. Linear programming (LP) is an efficient way to sort through a matrix of many alternatives to reveal the strategy that best fulfils the stated objective while observing all the stated constraints. IFPS is state-of-the-art, and reveals the optimal sustainable yield that can be achieved within a defined scenario.

One limitation of IFPS is the set-up time: the time taken to check and correct basic data (including corporate map libraries), to manipulate data to form analysis units, to test models, check assumptions with field staff. These are critical steps in the process, as for instance, the number and boundaries of analysis units can have a significant effect on prognoses. However, once basic preparations have been completed, evaluation of alternative scenarios is greatly facilitated, and IFPS simulations generally can be completed within an hour.

Barber and Rodman (1990), prominent critics of the use of FORPLAN in the USA, argue that most shortcomings of FORPLAN are not technical, but are problems arising from the lack of analytical rigour and the frequent use of "professional judgment" in place of scientific data. This is partly due to the great many parameters required by FORPLAN and SPECTRUM when they are used in their full capacity to optimize the use of several resources simultaneously (e.g., timber, water, grazing, etc.).

Important parameters required for IFPS include those that define the objective function, any constraints, and suitable ending conditions. The objective function defines what we are trying to achieve, but in our case it is non-trivial. One way to establish the sustainable yield is find the greatest sawlog volume that can be cut in the first period, subject to the constraint (among others) that the volume cut in any period should not be less than the volume in the preceding period ($v_{i+1} \geq v_i$). This is the non-declining even-flow constraint as mandated by the *Forests Act*. However, this may not lead to the most efficient timber production, so it may be appropriate to consider the *value* of timber production, subject to the same constraint ($v_{i+1} \geq v_i$). We may also consider the total or discounted value of sawlogs produced over time, the value of royalties received, or the value that the timber processing industry expects to recover from the sawlogs.

Some IFPS runs have explored the use of discounted revenue (to NRE) as the objective, but the inability to predict log grade, species and size severely limited the ability to do so reliably. Since there may be a ten-fold difference in royalty between a small D-grade and a large A-grade log, the inability to quantify this difference begs the question whether an alternative objective function may offer better insights. These alternatives may lead to different solutions, and the "best" outcome may be a matter of opinion.

A common mistake amongst SPECTRUM users is to over-constrain the problem. Generally the best results are obtained by minimizing constraints to a few essential restrictions. It is often possible to relax constraints by transferring the intent to the objective function (e.g., by adding the value of water, grazing, recreation, etc., or by deducting a penalty for under-performance).

The end condition is a special constraint that warrants some careful consideration and experimentation, as LP is sufficiently "cunning" that it may clearfell the entire forest in the final period under consideration unless constrained otherwise. It may be appropriate to stipulate that a normal forest should be achieved by the final period, or to establish other constraints to ensure that the forest is left in a "good" condition at the end of the simulation. One of the constraints in the Benalla-Mansfield and Otway analyses demanded that the volume cut in any period should not be less than 95% or more than 110% of the volume in the preceding period ($0.95 \times v_i \leq v_{i+1} \leq 1.1 \times v_i$). This appears an unnecessarily restrictive way of satisfying the requirement for a non-declining even flow, and it seems appropriate to explore alternatives (e.g., such as $v_{i+1} \geq v_i$).

5.4 Important assumptions in yield scheduling

While tools such as SYSS and IFPS can offer important prognoses of wood flows, they are only as good as the assumptions upon which they are based. Several assumptions may be critical: the time step, planning horizon, minimum rotation age and the ending condition.

The influence of the time step on yield prognoses depends to some extent on other assumptions: principally whether yields are estimated at the beginning or middle of each time period, and whether the yield table is implemented as a continuous curve or as a look-up table with discrete steps. If the time step is large, bias may be introduced if yields anticipated at the middle of a time step are marked for commitments at the start of a period. One way to test for such bias is simply to adjust the time step. The time step (and any associated assumption) is probably reasonable if doubling or halving the time step has no significant effect on yield prognoses.

A related issue is the planning horizon: for how long should we simulate yields to assert sustainability? The echo of an adverse impact can linger for a long time in the age structure of the forest, so if it is necessary to demonstrate sustainability, it may be appropriate to simulate wood flows for two rotations or until a normal forest is approximated. This can be achieved routinely with IFPS, but warrants specific attention in SYSS simulations.

Will our estimate of sustainable yield change if the horizon is increased? With a good model and a sound ending condition, no change should be evident. Sensitivity testing of the planning horizon (i.e., by comparing with results obtained when the horizon is set to a more distant date) is a convincing way to demonstrate the adequacy of the planning horizon.

The ending condition is another important issue that may influence estimates. It is important because without a suitable ending condition, the optimizer may determine that yields can be maximized by arranging harvests so that everything is clearfelled in the last time step. If our planning horizon is a thousand years, this may have no discernible effect on short-term yields, but it will clearly lead to an overestimate if the planning horizon is ten years. An efficient compromise is to schedule yields for 100-200 years, and set an ending condition to ensure the forest is left in a reasonable condition at the end of the simulation. Ending conditions may be explicit (e.g., a normal forest to be achieved at the planning horizon), or implicit (e.g., by setting minimum rotation ages). As with the planning horizon, a good test of the adequacy of the ending condition is to alter the planning horizon and re-run the model. If the planning horizon and ending condition are adequate, the effect on estimated yields should be negligible. The usual IFPS simulation involves thirty 5-year periods, a total of 150 years. One run with forty 5-year periods (200 years) demonstrated yields that were very similar (discrepancies <¼%) during the first 25 periods (i.e., >100 years), and became substantially different (>5%) only during the last period of the standard run (145-150 years). This demonstration confirms that yields simulated with IFPS can be sustained in the long term.

The ending condition should also be considered for SYSS simulations, even though SYSS requires no formal ending condition. Newer versions of SYSS show a “green band” to encourage users to harvest stands near the optimal rotation age and prevent cutting before the minimum rotation age, but no explicit indicator of the condition of the forest estate is provided. It would be useful to modify SYSS to report the estate-average stand age and overall standing volume, and to draw any decline in these two indicators to the attention of users.

At present, the prime purpose of the minimum rotation age is as a proxy ending condition in SYSS. However, estimates appear to be quite subjective (e.g., rotation ages specified in SYSS simulations for THS vary from half to twice the age of maximum MAI). If a minimum rotation age is to be specified as a constraint in SYSS or IFPS analyses, it is appropriate to carefully establish a meaningful minimum rotation age. Industry should contribute to this decision, as it is not merely about wood volumes, but also about log sizes and wood properties.

Rotation age warrants particular attention because reducing the rotation age is a “one way street”. For instance, suppose past cutting has created a resource approximating an 80-year normal forest, and there are now moves to convert it to a 60-year normal forest. The change from an 80-year to a 60-year rotation leads to a 33% increase in the area harvested each year, and “frees up” some 40% of the standing volume which can be cut over a few years. Conversely, the change from a 60- to an 80-year cycle means a 25% reduction in the annual area harvested, all of which will be well below the optimal size and volume for many years. The effect on timber yields is further magnified, because harvesting early (i.e., at 60 rather than 80 years) will depress the MAI below its optimum. Thus, because it is easy to shorten, but hard to lengthen rotations, the decision to shorten a rotation should not be taken lightly.

Recommendation 14: *Maintain rotations near the ages nominated in the Timber Industry Strategy unless there is explicit stakeholder agreement and acceptance of the consequences, including the characteristics of the wood produced.*

It is necessary to better establish an appropriate time step, planning horizon, ending condition, and minimum and target rotation ages. Sensitivity analyses to test the suitability of the adopted values are simple to do, but are important because the consequences of inappropriate values are considerable. These analyses may be required for only two or three FMAs representative of the range of forest types in Victoria, as results are likely to be generally applicable. Initiating IFPS (i.e., including the formation of analysis units) is a complex specialist task, so it is appropriate to examine to what extent this can be automated (and what trade-offs this may imply for the accuracy of prognoses), and whether LP remains the appropriate optimisation technique (cf. integer programming and simulated annealing).

Recommendation 15: *Conduct sensitivity testing of IFPS procedures, to establish and document appropriate approaches, including the consideration of alternative objective functions, ending conditions, constraints, and optimization techniques*.

An effective way to approach Recommendation 15 (and other Recommendations, including 6–8 and 10–12) may be to offer scholarships for staff or students to research these specific topics as part of an MSc or PhD programme.

6. Environmental Considerations

Yield prognoses considered during the current review have considered only the wood flows. This is all that SYSS was designed to do, but IFPS was designed for, and is capable of doing much more, notably of maximizing the total value of all forest goods and services to the community at large. At present, we have examined the simple question: *How much timber can the forest supply?* We have neglected the question: *What is the appropriate volume to supply to deliver the greatest benefits to industry?* It may be that a focus on added-value production rather than on roundwood volumes leads to a different production strategy. This issue cannot be explored without industry cooperation to establish sawn recovery and value-adding potential. A more important question is yet to be addressed: *What is the appropriate level of timber to supply while maximizing all the benefits of the forest to the community at large*? While this question tends to be addressed in other ways (e.g., zoning), it is appropriate to consider the impact of possible alternatives and any trade-offs on the sustainable yield. Both production (e.g., sawlog, roundwood, water, grazing, honey, etc.) and non-consumptive (e.g., recreation, conservation, etc.) benefits can be considered in this regard. These questions should not be divorced from other aspects of estimating sustainable yield, because they may influence timber yields by provoking adjustments to rotation ages, silvicultural regimes, scheduling of harvests, etc.

6.1 Optimizing for multiple benefits

The present approach to conservation, reaffirmed through Regional Forest Agreements (RFAs) relies on largely zoning rather than on integrated management, with protection in National Parks and Special Protection Zones (SPZs), and production in General Management Zones (GMZs). It is only the Special Management Zones (SMZs) that are managed for both production and protection objectives. It is possible that a different emphasis on non-wood goods and services in GMZ may lead to a different sustainable yield. IFPS provides the capability to optimize for multiple goods and services, and it behoves NRE to look beyond mere timber scheduling, if for no other reason than to examine possible trade-offs.

Water production is important in some catchments, and some stakeholders seek a modified silviculture to improve water yields. The current approach is to restrict the extent of harvesting (i.e., maximum coupe size and total area harvested per year) within a catchment, but other approaches could be examined with IFPS.

In other areas, the aesthetic value of, and recreation opportunities within the forest adds value to the tourist industry. Elsewhere, the value of grazing and honey production are easily quantified, and could easily be factored into IFPS analyses. Other environmental services (e.g., existence value, maintaining habitat, controlling salinity) are more difficult to quantify, but could be taken into account, even if in an elementary and approximate way. Protection of selected plant and animal species can also be taken into account, either as constraints or through optimisation, if the habitat requirements can be defined explicitly, and in the case of optimisation, if the abundance of individuals or suitability of habitat can be valued. Further work on these issues is warranted (cf. Burgman 1995).

Recommendation 16: *Acknowledge two components of* sustainable *yield: the maximum timber yield that can be sustained (as a non-declining even-flow, as required by the Forests Act), and the optimal harvesting rate that delivers the greatest benefit to stakeholders*.

6.2 Special Management Zones

In most FMAs, SMZs are considered to be "conditionally available" for timber production, and the present practice is to include a proportion of the area of these SMZs in the net harvestable area. This approach is probably an appropriate approximation where the area involved is small, and resulting wood volumes are not scheduled during a short-term supply hiatus. However, a preferable approach is to model the special characteristics of the stands in question, and ensure that the wood scheduler simulates the harvest of these stands at an appropriate time, and in an appropriate way.

In the Midlands, a prescription currently under trial provides for unlogged islands of habitat (within GMZ) that fauna can use as stepping stones between larger areas of reserved forest. While this appears to be a good initiative, the impact of this initiative has not yet been satisfactorily quantified; the Timber Harvesting Strategy (THS) assumes that this will entail a reduction of 0.75% of the net harvestable area, but the basis for this estimate is weak.

An assumption in several FMAs is that new obligations to protect species or sites will cause no net loss of area, as land will be swapped from existing SPZs. While this assumption is yet to be tested, it is an appropriate assumption. Yield estimates should establish the optimal non-declining yield under current objectives and constraints. If new information leads to a change in the resource base, the yield estimates should be revisited at that time. The *Forests Act* s.52D(2) makes specific provision for such eventualities: "*If … there has been a significant variation in the hardwood sawlog resources in any State forest available to be exploited commercially, the Minister must as soon as possible review the sustainable yield rates for the forest management areas concerned*."

7. Monitoring and Review

The *Forests Act* (s.52D(1)) requires that sustainable yields be reviewed each 5 years beginning from 1 July 1991. Although SFRI activity has been sustained during the past five years, other components contributing to resource estimates have not been prepared in advance of the 5-year deadline. This last-minute approach has the potential to overwhelm technical support units, compromise the rigour of re-appraisals, and to frustrate stakeholders. It would seem appropriate to stagger reviews, so that for instance, three FMAs were reviewed each year during the 5-year period. The commitments made during the RFA process (Section 2.2.2 above and Table 3, Page 10) offer one possible basis for such a rolling program of sustainable yield review.

Recommendation 17: *Stagger completion dates for the review of sustainable yields, so that two or three FMAs are scheduled for completion each year*.

7.1 Gathering and managing resource data

At present, the preparation of sustainable yield estimates is largely a stand-alone activity that is not well integrated with other forest assessment activities. It is not the only activity that involves estimating the nature of the forest (e.g., WUPs also require resource estimates). There is considerable scope to combine these and other forest intelligence activities to serve more than one purpose. In doing so, it should be possible to reduce overall costs, increase utility, and increase the scope for checking predictions.

Inventory supports many forestry activities – surveys attest to the adequacy of regeneration, volume estimates form the basis of harvest plans, inspections are made on completion of a sale, assessments are made of fire and storm damage, and so on. Although gathered for other purposes, these data can be useful for yield forecasting. Much information conveyed in these data is durable, and can be used to improve the accuracy of subsequent yield estimates (e.g., logging history). Other data may change, but slowly (e.g., species composition), or in predictable ways (e.g., standing volumes), so they may still contribute usefully to resource estimates. Thus it is important to take a holistic view of information requirements for natural resource management. Efficiencies can be gained by seeking, and capitalising on complementarities, particularly since a large part of the cost of field inventory is the travel cost to get to the field site.

There are two issues to be addressed: one is planning for, and collecting information in a way that enables multiple- rather than single-use; the other is maintaining the information in a way that it is accessible to others. The latter "librarian" function should not be neglected. It is important to identify a data custodian who can assist others to interpret and correctly use prior information wisely. Although there are costs associated with data management in this way, it is likely that the benefits outweigh the costs. Data mismanagement may lead to unnecessary and inefficient inventory, and inferior resource estimates, all of which are costly and easily avoided.

Yield predictions may be improved by including additional data from sources other than those designed for yield prediction (e.g., SFRI). Forest resources change slowly, in predictable ways (except for wildfire and other catastrophic disturbance). This makes forest resource data durable, and means that they can be updated with a growth model or yield table. Thus forest resource data can serve in the estimation of more than one round of sustainable yield estimation, provided that the data are reliable and well documented.

The preparation of WUPs offers scope for further efficiencies in resource estimation. IFPS outputs could form the basis of a list of candidate coupes for a WUP. Obviously, these stands are, and should be re-appraised in the field before they are included on a WUP. Much of the cost of such appraisal is travel time, and the cost formal inventory data is only marginally higher than the cost of an “eyeball estimate” once an officer has arrived in the field. Thus such appraisals should include formal inventory that can serve as feedback to refine yield estimates, to update the GIS-based equation for stand volume estimates, and to influence subsequent lists of candidate coupes for the WUP. This simply requires that WUP assessment procedures are consistent with other resource estimation procedures contributing to SFRI and IFPS estimates.

Recommendation 18: *Examine the feasibility of harmonising SFRI and WUP assessment procedures, so that both can contribute to IFPS estimates, and that IFPS can contribute lists of candidate coupes for WUPs*.

Attempts to calibrate predicted areas and volumes against operational performance have been frustrated by inadequate and inaccessible coupe data. A Coupe Management System was proposed in 1991 and some efforts were made to develop such a system during 1992-95 (Jamie 1992, Deed 1995), but it did not meet user expectations and was never completed (Turner and Brack 1997). Instead, staff in some FMAs developed their own Coupe Recording Systems to satisfy local needs.

Checking predictions against performance is central to good management, and the first step in this process is good record keeping. A coupe information system is needed, and should embrace procedures and a database to maintain (and make available) records of predictions (IFPS, WUP, and any other predictions), inventory (CFI, IFPS, WUP, regeneration surveys and any other formal or informal observations), harvests (yields, purchasers, contractors, commencement and completion dates, residue assessment, etc.), health (fire history, pest outbreaks) and other details that may help managers and researchers better understand past and future performance of the site. Is some ways, “the history of a coupe … ends when … successfully regenerated” (Turner and Brack 1997), but a coupe information system should maintain the details of each intervention beyond the full rotation of the regenerating stand.

Obviously, designers of the system should consult with potential stakeholders to establish needs and access points and pathways. The focus of the system should be to document wood-related matters in a spatially and temporally specific way. This will enable systems concerning other issues (e.g., fauna) to remain independent, while linking effectively to entries in the coupe information system.

Recommendation 19: *Establish a coupe information system to maintain details of wood-related matters at the coupe level in a spatially and temporally explicit way*.

7.2 Checking Predictions and Providing Feedback

Several reviewers (Auditor General 1995, Burgman 1995, Turner 1995, Turner and Ferguson 2000) have previously observed the need to check predictions, and to use the findings as the basis to improve future estimates. No system has been instituted to ensure that these checks are done, and that adjustments are made as a result of these checks. Such checks are important; the only way to gauge the quality of predictions is to make such checks. Furthermore, efficient feedback relaxes the requirement for sophisticated growth models.

"Closing the feedback loop" is such an important concept that it warrants an everyday analogy. Consider two alternative ways to control a room air-conditioner. One way is to build a model of potential heat sources and their radiance, to periodically calibrate this model (by assessing the number of people and appliances present in the room), and to pump in warm or cold air accordingly. An alternative is to build a simple model – a thermostat based on a bimetallic strip – that instantaneously assesses whether the room is too hot, too cold, or "about right", and to control the fan and compressor directly from the thermostat. The latter approach is likely to make frequent small (almost imperceptible) adjustments, but may well deliver better performance than the former approach which cannot cope with the unexpected. The analogy with forest management is obvious: a system of continual monitoring to guide small annual adjustments (as needed) may be more cost-effective and reliable, and less disruptive to both industry and ecosystems, than the present approach of infrequent but large swings in supply.

There is no question that a system should be instituted to close the feedback loop, by taking the results of routine comparisons between predictions and out-turn and ensuring that prediction and monitoring systems, yield estimates and licences are modified in response to the findings. It appears that the only way to ensure this happens is to make such checks part of core business, by building them into the sales system. There are a number of ways this could be done; one alternative is to deduct the predicted volume (rather than out-turn) from a purchaser's entitlement – this would provide an incentive for both buyer and seller to take an interest in the accuracy of predictions, and in reconciling out-turn against predictions.

Recommendation 20: *Institute procedures that facilitate routine comparison of predicted versus realized yields and a feedback system that enables the sawlog entitlements of licensees to be adjusted annually in response to any discrepancies between predicted and realized yields*.

Another issue that warrants further mention is grade creep, when logs are downgraded from sawlogs to the status of residual logs. This is significant not only because of the loss of revenue, but because it diverts wood from the category of sawlog (i.e., that predicted as part of sustainable yield calculations) to another category which is not regulated to the same extent. Any such leakage of sawlogs out of the D+ category may lead to over-cutting, because purchasers will generally seek to have the resulting shortfall in D+ logs made up, by scheduling the next sale earlier than otherwise. Thus it is important that grading practices are monitored and that grade creep is kept to a minimum.

7.3 Error budget

At present it remains impossible to fully census a forest, so estimates of sustainable yield remain estimates based on sampling. Thus, these estimates are not known with absolute certainty, but have an associated standard error. In a composite estimate such as the sustainable yield estimate, it is non-trivial to estimate the standard error, but it is worthwhile

Table 4. Components of an error budget designed to offer insights into possible sources of error in yield estimates. No such error budget has yet been compiled.

Estimating coupe area	Area logged (ha)	Area not logged (ha)
Gross area in the vicinity of the sale		
Area in SFRI 20m/30º buffers		
Area not zoned for logging (not GMZ or SMZ)		
Area in “enhanced” buffers		
Area in “islands” below threshold size/volume		
Any other exclusions …		
Net area predicted as loggable		

Estimating volume within coupes	Predicted (IFPS/SYSS)	Predicted WUP	True Value (± std err)	Operational out-turn	SFRI estimate (± pred int)
Stand age					
Gross log volumes					
Net log volumes					

Checks on yield tables	Yield Table (as scaled)	True Value (± std err)	SFRI estimate (± range or pred int)
At entry point: Age Volume PAI			
At harvest: Age Volume PAI			

Tree volumes		Dbh	Volume out-turn	TREEMAP-VOLCALC estimate
Site 1 … … Site *n*	Tree 1 Tree 2 … Tree *m*			

to attempt an approximation, to reveal the precision of the estimate. This can be presented as an error budget, in which standard errors and biases are determined for each component of the yield calculation (Table 4). Such an error budget can reveal where research and development effort can most efficiently be directed to improve the overall quality of the estimate.

The error budget should compare volume estimates derived via the processes used to estimate the sustainable yield with the actual out-turn achieved in practice. An attempt should also be made to estimate the “true” volume to gauge whether the resource is being used efficiently. The “true” volume may differ from both the out-turn and the predicted yield, so logging operations may need to be followed by a residue assessment (of wood remaining in standing trees and in logs remaining on the ground), or preceded by a detailed independent estimate of the “true” standing volume. A rigorous comparison requires predictions and out-turns specific to each coupe, and requires these data for several coupes. IFPS predictions may enable stronger tests because SYSS does not offer spatially-explicit predictions at the coupe scale.

The error budget should explicitly examine area and yield estimates (Table 4). Any discrepancies must be attributable to net area estimates or estimates of yield/ha (or both).

Volume comparisons should be made on an equivalent basis, with the realized out-turn converted to per-hectare yields on the area actually worked over. Any discrepancy in the per-hectare yields must be attributable to the yield curve, the entry point to the yield curve, or to the gross-net conversion factor. Given the use of volumes to scale yield curves, the yield curve cannot contribute much error in cases where harvesting occurred soon after the base year for the simulation. However, it may be an important source of error when predictions span long periods (Figure 9, Page 27). In many of the cases available for scrutiny, the entry point may be a greater source of error than the yield curve itself, because harvesting will have occurred close to the base year of the analysis.

7.3.1 Evaluating the yield curve

An attempt should be made to establish the "true" yield curve through a full rotation by contrasting each coupe with long-term growth plots similar to the stand in question. Where no growth plots are available, it may be sufficient to determine the current coordinates (age and volume), and periodic annual (volume) increment (PAI) of the stand in question. Such (age and PAI) data can form the basis of a "vector field" (Figure 8, Page 26) that can help to evaluate a yield table. In some species, it may be possible to establish the PAI through stem analysis. As a minimum, it should be possible to establish stand age, volume at time of harvesting, and PAI, and thus establish one vector near which the yield curve should pass.

In establishing the validity of a yield curve, there are two issues to be pursued – the reliability of the original guide curve, and the validity of any scaling of the curve. In many cases, the guide curve is scaled so that it passes through the entry point, so that the issue of scaling is intertwined with issues surrounding the assumed entry point. However, there are several ways in which a guide curve may be scaled, so some scaling issues remain. Since the scaled yield curve may pass exactly through the entry point (age, volume) of the stand in question, the PAI (i.e., the vector showing the current growth trajectory of the stand in question) may be the only reliable gauge of the adequacy of the yield curve. Incorrect data (age and current volume estimates) may lead to forecasts starting from a point inappropriate for the stand in question. This could happen if the estimated age was wrong, or if there was error in the predicted standing volume at the base year for the analysis. Thus it is important to establish the "true" stand age at the base year of the calculation.

7.3.2 Evaluating volume estimation procedures

Discrepancies observed in estimates derived from a GIS-based volume equation may be attributed to weaknesses in the model, or to errors in the predictor variables. Any discrepancies in the true and assumed values of each of the predictor variables (cover, height, elevation, composition, crown, and latitude) should be established. If the predictor variables appear sufficiently accurate, the error may be attributed to the equation, which in turn, may be attributed to inadequacies in the form of the equation (re-examine residuals about the original data), or to weaknesses in the development database. The adequacy of the development database can be appraised by examining the extent of extrapolation (e.g., see Beetson *et al* 1992, Vanclay *et al* 1995). The overall performance of the equation can be tested with independent data (e.g., Vanclay and Skovsgaard 1997).

The volume estimation procedures used to prepare data for GIS-based sampling should also be examined for possible error contributions. There are several aspects that should be examined. It may be that the optimal merchandising modelled in the TREEMAP-VOLCALC system predicts a higher volume per tree than that achieved in practice. There may be discrepancies between predicted and observed internal defects. It may be that the TREEMAP-VOLCALC approach leads to reliable estimates for certain categories of trees, but performs less well for others. Individual tree data for a range of sites should shed light on these issues.

At least some of these data should be independent of data used to develop and calibrate the VOLCALC system. The immediate requirement is to obtain this data in respect of D+ volume; however, it would be prudent to record numbers and volumes of logs by grades.

Collectively, the data requirements set out in Table 4 (Page 43) will provide a suitable basis for an objective appraisal of the quality of data.

Recommendation 21: *Compile a comprehensive error budget for selected FMAs to establish the accuracy of the various components of sustainable yield estimates*.

7.4 Contingencies and Uncertainty

Box 1 illustrates some arguments promoted in support of contingency allowances to account for uncertainties in resource estimates. Proponents argue that there are many factors not yet taken into account that could influence forecasts, but that remain difficult to quantify. They suggest that a general contingency allowance is the most efficient way to address these issues, particularly in the context of long-term commitments (Box 1).

Some of these issues may tend to reduce predicted yields (e.g., SYSS inability to account for operational feasibility); others will simply make yields more variable (e.g, spatial discrepancies in SFRI stand mapping). The view of the Expert Data Reference group is that if these factors can be substantiated, they should be properly quantified and a specific scaling factor developed. If they cannot be substantiated in a statistically robust way, any contingency proposed lacks a technical basis, and is best viewed in the political arena, which may have a better purview of social issues.

It is appropriate to draw attention to these and other possible contingencies in the documentation supporting yield estimates. However, it is not appropriate to conceal a general contingency allowance within the yield calculation. Any adjustment proposed for unsubstantiated contingencies should be conspicuous, and should be implemented as a discount to the final rigorous estimate.

- Maps may not reveal streams and steep slopes masked by the tree canopy; this may contribute towards overestimates of net areas;
- GIS-based estimates of net area have not been adequately tested in rugged areas;
- Recent harvesting may not be representative of the remaining resource, and this may bias attempts to calibrate areas and volumes;
- Few data are available to calibrate yield estimates for selectively-harvested mixed species stands, and for ash stands without a market for residual logs;
- Selective harvesting of mixed species stands is not easily accommodated in the yield table approach, which may provide inferior predictions;
- Ability to assess the threshold of economic yield has not been tested;
- SFRI estimates standing volume, and makes no allowance for sawlog volumes retained as habitat or seed trees, and yield tables make no allowance for overwood suppressing regrowth;
- SYSS uses simplified and aggregate data, and may not reflect operational feasibility;
- Analyses make no allowance for delayed or incomplete regeneration, and assume that productivity will be maintained or increased in subsequent rotations;
- Some FMAs assume increased yields from future thinning operations, and make no allowance for stem damage or wood quality;
- IFPS modelling assumes an optimal result which may not occur because of operational factors.

Box 1. Arguments promoted in support to contingency allowances to compensate for possible deficiencies in yield prognoses for some FMAs.

There is no doubt that it is risky to enter into an inflexible long-term agreement to supply wood without maintaining something in reserve. However, it is important to maintain a clear separation between the rigorous and defensible technical aspect of predicting the sustainable yield (a technical resource estimation activity), and the setting of the annual harvest rate (which requires social and economic factors to be considered, consistent with the *Forests Act s.*52B). It is appropriate to allow for contingencies, but that allowance should recognize not only uncertainties in resource estimates, but also the rigour of feedback loops, the flexibility within the supply commitment, and the duration of the supply contract.

In some circumstances, deficiencies in yield estimates may tend to bias estimates towards overestimates, but this is not always the case. Some deficiencies tend towards underestimates, and many contribute to greater variability in yield estimates. The appropriate response to uncertainties and suspected deficiencies in yield estimates is not to introduce arbitrary contingencies, but to institute a rigorous monitoring and feedback system.

The sustainable yield generally represents about 2% of the standing volume, but may reach 5% in forests where standing volume has been reduced by harvesting and fires in the past. Even if the estimate of the sustainable yield is seriously biased (towards an overestimate), it should be possible to detect and remedy such a discrepancy before any further draw-down of standing volume reaches 10%, provided that a reasonable monitoring system is in place. As long as field operations adhere to best practice (minimizing erosion, ensuring regeneration, etc.), a temporary 10% draw-down of an otherwise 80-year normal forest is of little ecological consequence, and can easily be recovered.

Thus if we suspect, but lack evidence of, an inflated estimate of sustainable yield, the appropriate response should be rigorous monitoring rather than arbitrary reductions in the estimate. Monitoring should allow early detection of any discrepancies, and can confirm or allay suspicions. If confirmed, estimates can be adjusted and licences reduced with minimal draw-down of the standing volume. If allayed, substantial social and economic dislocation may have been avoided.

Recommendation 22: *Calibrate scaling factors empirically and demonstrate their significance with standard statistical tests. Avoid unsubstantiated contingencies in estimates of sustainable yield*.

8. Management implications

Table 5 gives an overview of the data quality and methodological rigour associated with current yield estimates for each FMA. The derivation of this Table and the basis for assigning stars are discussed in Annex 2 (Page 67).

The overall reliability of an estimate of sustainable yield is dominated by three factors: the nett area estimates, the yield tables, and the scheduling of timber harvests. The indicative overall reliability is assumed to correspond to the worst of these three elements. This is appropriate, because for example a 10% bias in the yield table will result in a 10% bias in overall estimates even though other components may be "perfect". Where more than one component is biased, there is a chance that errors may compensate, but standard statistical procedures assume that errors accumulate as the "root sum squares", so the simplistic assumption of worst case is a reasonable approximation.

It is clear (from the "Best composite" in Table 5) that NRE has the capability to prepare state-of-the-art yield estimates, but it is also apparent that a lack of emphasis and resources has been devoted to this work. The result is that there is no single FMA in which resource assessments and yield forecasts can really be considered reliable, and there are only four FMAs where estimates can be considered reasonable. This has implications for forest management.

Table 5. Overview of data quality and methodological rigor (* = inadequate; ***** = excellent). The overall score is the weakest of the three categories (Areas, Yields, Scheduling). Annex 2 (Page 66) gives the basis for assigning stars.

FMA	Areas	Yields	Scheduling	Overall
Benalla-Mansfield	****	***	****	***
Central	**	**	***	**
Central Gippsland	***	**	***	**
Dandenong	***	*	***	*
East Gippsland	***	*	***	*
Horsham	**	**	*	*
Midlands	***	****	***	***
Mid-Murray	**	*	**	*
Mildura	*	*	**	*
North-East	****	***	***	***
Otway	**	*	****	*
Portland	**	*	**	*
Tambo	***	**	***	**
Best composite	****	****	****	****

8.1 Recognising Risks

Standard texts (e.g., Covello and Merkhofer 1993) identify the following sources of risk:

- inaccurate data processing;
- inappropriate assumptions for extrapolation;
- fitting models to sparse data; aggregating data; using surrogate data;
- relying on experts who are underqualified or who do not represent a full range of scientific opinion;
- using discrete approximations of continuous decision variables;
- using models that are based on poor data, inadequate theory, or that are incomplete.

Powell (1999) suggested that when some of these sources are present, the solution is to use an iterative approach (i.e., close the feedback loop), and to fully disclose sources of uncertainty to avoid a false sense of accuracy.

It is clear that some of the issues identified by Covello and Merkhofer (1993) are present in the NRE yield calculations. It is also evident that the resource assessments and yield forecasts for many FMAs have deficiencies that need to be redressed. Renewed emphasis must be placed on inventory and yield forecasting work, and resource estimates should be revisited as additional data become available. Unfortunately, deficiencies in current estimates mean that future estimates may differ substantially from the current estimates. The star-rating in Table 5 may be used as a guide to gauge the likelihood of such differences.

If the current sustainable yield estimates are accepted, they may lead to substantial consequences, and require considerable reductions in harvesting in some FMAs (Table 6). However, weaknesses in current yield estimates mean that further revisions may differ again.

Table 6. Volumes currently licensed, estimated sustainable yields, and reductions in harvesting that may be required.

FMA	Licensed Volume (m^3/yr net)	Estimated sustainable yield (m^3/yr)	Reduction required (m^3/yr)	Reduction (%)
Benalla-Mansfield	15,108	12,660	2,448	16%
Central	129,085	121,000	8,085	6%
Central Gippsland	180,832	89,970	90,862	50%
Dandenong	40,200	31,000	9,200	23%
East Gippsland	249,367	138,600	110,767	44%
Horsham	920	880	40	4%
Midlands	49,100	8,576	40,524	83%
Mid-Murray	5,904	2,600	3,304	56%
Mildura	700	290	410	59%
North-East	44,357†	37,300	7,057	16%
Otway	28,700	25,900	2,800	10%
Portland	9,350	7,500	1,850	20%
Tambo	71,869‡	64,800	7,069	10%
Total	825,492	541,076	284,416	34%

† The licenced volume for North East includes the 11 blocks considered elsewhere as part of Tambo.
‡ The licenced volume for Tambo excludes these 11 blocks.

8.2 Avoiding Risk

There is no cost-free way to avoid the risks associated with inferior yield estimates. Additional contingency allowances have been proposed as one way to compensate for a number of issues that cannot as yet be adequately quantified (Box 1, Page 45). However, this is not a risk-free approach, as it will result in lower estimates of sustainable yield, and thus may increase social and economic dislocation. Similarly, the risks cannot be avoided by deferring a decision until better data are available, because such indecision may involve continued over-cutting and continued uncertainty for business and workers. The solution is to make the best possible decision despite any limitations in the information presently available, to monitor performance and compare it against predictions, and to make regular adjustments on the basis of these comparisons. In short, to manage the risks by closing the feedback loop.

8.3 Managing Risk

Significant risks exist (Table 7) and they cannot be avoided – they must be managed to minimize the consequences. There are a number of ways that these risks can be mitigated: through fast feedback, regular reviews, shorter supply periods, shared responsibility for efficient utilisation, and so on.

8.3.1 Feedback

There is a considerable likelihood that revised yield estimates may differ from the present estimates, but it is through the yield estimates that we find the best avenue to manage the risk of unnecessary hardship. The simplest way is simply to monitor operational out-turn and compare it against current predictions to warn of any possible bias. Some of these

Table 7. Risk of unnecessary social or ecological disruption because of unwarranted changes in the licensed sawlog volume.

Likelihood (revised estimate will differ)	**Consequence** (of current estimate, i.e., reduction in harvest)				
	Insignificant (<500 m³/yr)	*Minor (<5,000 m³/yr)*	*Moderate (<10,000 m³/yr)*	*Major (>40,000 m³/y)*	*Catas-trophic*
Almost certain (*)	Horsham Mildura	Mid-Murray Otway Portland	**Dandenong**	**East Gippsland**	
Likely (**)			Central Tambo	**Central Gippsland**	
Moderate (***)		Benalla-Mansfield	North-East	Midlands	
Unlikely (****)					
Rare (*****)					

Risk (unnecessary social or ecological disruption)
High
Significant
Moderate
Low

comparisons should attempt a formal error budget as illustrated in Table 4 (Page 43). Comparisons should be collated, and reviewed at least annually (e.g., in conjunction with the review of s.52B of the *Forests Act*), until adequate resource forecasts can be concluded.

Some may question the efficacy of this approach. However, calibration of biased estimates is a standard statistical technique, commonly used in preparing yield estimates. It is used operationally in many aspects of daily life. For instance, a thermostat is a simple bimetallic strip, that switches heating (or cooling) on or off. Provided that it reacts quickly enough, we don't notice fluctuations in room temperature. The secret to this approach is fast feedback – recall how difficult it can be to adjust shower temperature if the taps are a long way from the shower head. We can use monitoring and feedback in the same way to adjust yield estimates and compensate for inadequacies in current yield estimates.

It is unreasonable to expect that yield estimates will be correct for any individual coupe (simply because of natural variation). However, the running average of the difference between predicted and realized yields for several coupes should be near zero – if it is not, it signals the need for an adjustment to be made to licence levels.

The need for systematic monitoring and review has previously been identified, but to date it has not been implemented. One way to bring about such monitoring and review is to make it part of core business. The system must give all stakeholders a vested interest in accuracy of practices, in conduct of monitoring, closing the feedback loop, and achieving continuous improvement. One way to do this may be to debit the licensee's entitlement with predicted volume rather than out-turn (Royalties could still be invoiced on the out-turn). This should create an incentive for the purchaser to improve utilisation, and for both the purchaser and NRE to monitor out-turn and contrast it with predictions. Summaries of both the predicted and realized yields should be published to allow scrutiny by interested stakeholders.

8.3.2 Independent yardsticks

Sustainable yield estimates for the thirteen FMAs have drawn on the best available data and local knowledge, but are not without limitations (Table 7). Since some estimates lack statistical rigour and involve subjective input, it is important to find an alternative yardstick to gauge their credibility. One way to do this is to compare the estimates of sustainable yield when expressed per unit area (on net harvestable area), and as a percentage of standing volume. These comparisons can be made more effective if the data are arranged according to geography (Table 8, cf. map of Victoria), rather than as a conventional table. These estimates vary in a logical way, and appear reasonable. Benchmarks for these rough rules-of-thumb are 1 m^3/ha/yr (more in the Central Highlands, less in the north-west) and 2.5% (for an 80-year normal forest, less for longer rotations).

Central FMA has the highest yield (1.7 m^3/ha/yr, see Table 8.b), which is rather high. This is an estate-wide average, derived mainly from ash forests which comprise only 40% of the area. The implied expectation is that the ash yields will exceed 4 m^3/ha/yr estate-wide (approaching 4.7 m^3/ha/yr when the low-yielding Matlock areas are excluded), close to the peak MAI assumed for the best ash (4.9 m^3/ha/yr at 90 years). This can be achieved if the forest is maintained in a state close to the optimal normal forest. Nonetheless, it would seem prudent to re-examine sustainable yield estimates for Central FMA using IFPS when the SFRI is completed.

Dandenong and Central Gippsland FMAs have yields that represent a high proportion of the standing volume (3.6 and 4.2% respectively, Table 8.c). This presumably reflects past fires and harvesting, because the expected yields per unit area are reasonable (1.3 and 1.0 m^3/ha/yr respectively). However, these high percentages in Table 8.c indicate that the scheduling of yields may be critical in the short term.

Table 8. "Rule-of-thumb" comparisons of expected growth rates (8.b and 8.c) and area estimates (8.d) for all FMAs. These tables are laid out like a map (cf. Figure 1, Page 4) to facilitate geographically-based comparisons (i.e., expect adjacent entries to be similar, to the extent that soil, rainfall and topography are similar).

8.a Key to FMAs

Mildura	Mid-Murray	Benalla-Mansfield			
Horsham	Midlands	Central	North-East		
Portland	Otway	Dandenong	Central Gippsland	Tambo	East Gippsland

8.b Yields per unit net harvestable area (m^3/ha/yr)

0.07	0.06	0.5			
0.2	0.3	**1.7**	1.0		
0.4	0.6	1.3	1.0	0.8	0.7

8.c Yields as a percentage of standing volume (%)

0.2	0.7	1.2			
0.7	1.8	2.1	2.8		
1.1	2.1	**3.6**	**4.2**	1.7	1.9

8.d Net harvestable areas as a percentage of gross area of State Forest (%)

1	**75**	14			
4	24	35	7		
18	**47**	41	17	20	33

These yield-based yardsticks (yield per unit area and per unit growing stock) both depend on the net harvestable area, and thus effectively check only the yield table. Another useful yardstick that sheds some light on area estimation is the net harvestable area expressed as a percentage of the gross area of State Forest (Table 8.d). There is no benchmark for this rule-of-thumb, but experience indicates that values in the range 20-30% are common (lower in rugged terrain, higher where the topography is easier). Table 8.d suggests that estimates of net harvestable areas for Mildura (1%), Mid-Murray (75%) and Otway (47%) warrant re-examination.

Table 8 explores two of the key components of sustainable yield estimates, namely areas and yields, but does not examine the scheduling of timber harvests. The standard of scheduling can be gauged by examining how closely harvests approach the optimum (e.g., by comparing the MAI achieved at time of harvest with the maximum MAI attainable) and assessing what proportion of the stand is over-mature (i.e., older than the age at which MAI is maximized). Figure 14 illustrates these criteria for the Wombat forest (part of the Midlands FMA). It shows (solid, upper line) that in the short-term (2000-50), stands in the Wombat forest are proposed for harvesting despite having achieved only half the maximum MAI anticipated in the yield table. While this may be attributed partly to the stand structure resulting from past harvesting and fires, there is scope for improvement because 15% of the net harvestable area has over-mature forest during this period (Figure 14, dotted lower line). In the longer term (i.e., near 2100), scheduling approaches the optimum, with minimal over-mature forest (within the net harvestable area) and a realized MAI 85% of that theoretically possible. The 15% shortfall is largely due to allowances for contingencies (10% plus 0.2% for fire), but also because the target rotation is 100 years, shorter than the 120-year optimum implied in the yield tables.

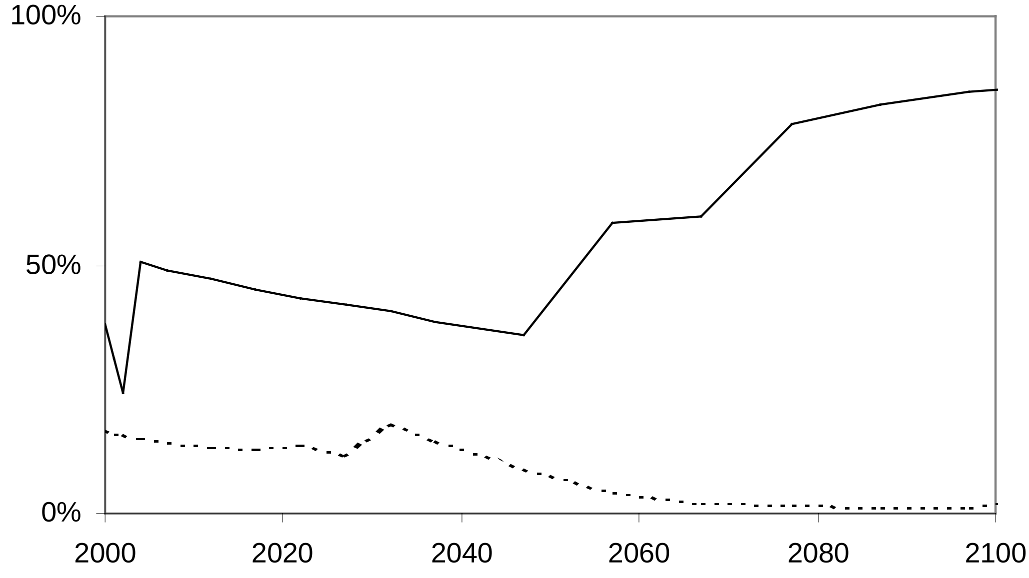

Figure 14. Quality of harvest scheduling in Wombat forest. The upper, solid line reveals the extent to which harvested stands attain the maximum MAI possible for that regime. The lower, dotted line indicates the area with over-mature forest. Optimal scheduling should result in 100% of the maximum MAI and no over-mature forest within the net harvestable area.

Figure 14 offers a useful way to gain an insight into the standard of harvest scheduling: the solid line shows the extent to which scheduling achieves the maximum MAI possible for a given regime, and the dotted line indicates the extent to which improvements are possible. If over-mature forest (dotted line) is present, it is possible that alternative harvesting schedules can deliver higher yields. In contrast, if there is no over-mature forest, the only option to improve yields may be to delay harvests by foregoing consumption in the short term to allow the growing stock to build up. Figure 14 can be compiled easily from data available within SYSS. Accordingly, SYSS should be modified to produce performance indicators like Figure 14 routinely (cf. Recommendation 13, Page 34). The LP solver in IFPS ensures optimal scheduling within the constraints specified, but a figure of this kind could still offer useful insights into the impacts of these constraints (e.g., operational limitations).

It is likely that many critics of NRE may not fully understand the yield prediction system, and will have lost confidence in it because of the large variation in yield estimates over the years. One way to restore community confidence is to offer yet another, simpler yardstick. One possibility is to publish annually, the lower 95% confidence interval of the estate-wide standing sawlog volume. This would provide community groups with a benchmark they can easily grasp, offer industry confidence in sawlog reserves, and provide focus for NRE staff. It emphasizes the need for inventory to be attuned to management intensity, demanding more detailed inventory where forest management is intensive (or after wildfire, etc.), and allowing sparse inventory where forest management is extensive.

Recommendation 23: *Publish annually an estimate of the current standing volume of sawlog resources within the net harvestable area of each FMA, with a statistically rigorous estimate of the 95% confidence interval. Production forests should be managed, and inventory devised so that the lower 95% confidence limit does not decline over time.*

8.3.3 Timely commitments

There is little point monitoring performance (predictions versus out-turn, as well as other yardsticks), unless there is scope to vary both the legislated sustainable yields and the licensed volumes during the timber supply period. The current timber supply period is fifteen years (*Forests Act* s.3(1)). This is a long time in terms of politics, community expectations, and ecological impact. There is no easy formula to derive an optimum timber supply period, but an examination of potential impacts on the growing stock offers some guidelines. However, even this relatively rigorous approach requires judgements about rotation length, uncertainty in estimates, and how much unintentional "draw-down" of growing stock is considered acceptable. If any draw-down should not exceed 20%, then timber supply commitments should not exceed 5 years in FMAs where there is a one-star rating, or ten years where there is a two-star rating. This is consistent with the need for a five-yearly review of sustainable yield estimates (*Forests Act* s.52D), but indicates that ecologically sustainable management requires more flexibility in licensing arrangements. This could be achieved either through shorter timber supply periods (for at least part of the licensed volume), or through a mechanism to adjust licensed volumes mid-term.

8.3.4 Shared responsibility

Efficient and consistent utilization of the timber resource is not simply an economic issue; it influences our ability to make reliable estimates of sustained yield and is thus a prerequisite for sustainable forest management. There are two issues: harvesting all the designated trees within a coupe, and making best use of all the wood in each tree. We have already mentioned the need for a system that gives all stakeholders a vested interest in accuracy of practices, in conduct of monitoring, closing the feedback loop, and achieving continuous improvement.

It may be useful to offer a stronger incentive for the purchasers to ensure better utilisation of sawlog material. Under the existing system, any abuse of resources has no consequences until the next generation. However, IFPS can predict yields at or near the coupe scale, facilitating comparisons of predictions against out-turn. Predicted yields will never match out-turn exactly, but the running average of several coupes offers a basis for comparisons that could be made annually (or on completion of a coupe) and could lead to regular adjustments to the annual harvest rate. If licences were expressed as a percentage of the annual harvest rate (rather than fixed volumes), as is common in fisheries, any adjustments would quickly be felt by all purchasers in a FMA, fostering self-regulation by peer pressure within industry.

It is also appropriate to ensure strong incentives for the field workers who often take the decision about log grades – the workers who buck logs after felling. Many options are foreclosed at this stage at the stump, so it is important that these workers also have the right incentives, not just to maximize throughput, but to maximize options for downstream value-adding. Anecdotes suggest that significant distortions include pay cycles (fortnightly for pulp; monthly for sawlogs) and marginal returns for the effort of optimal merchandising (e.g., cutters get minimal return for cross-cutting a long pulp log to make two shorter D-grade and residual logs).

Recommendation 24: *Explore appropriate incentives to encourage best practice by all field workers, and especially to encourage fellers to strive for better bucking.*

8.3.5 Alternative estimates

Present sustainable yield estimates are based on the "falling ceiling" approach: they begin by assuming that all the wood in all State Forests is potentially available, and arrive at the yield estimate by systematically deducting land that is unavailable or unproductive, defective or unmerchantable parts of trees, and so on. The danger with this approach is that any oversight will tend to bias yields towards overestimates. The converse is the "rising floor" approach: assume that nothing is available, and build up an estimate from evidence of available areas and realizable volumes. The evidence needed to support such an approach could include data from previous harvests – former coupes, areas previously operated, and previous yields. At present, these data are not available, so a rigorous rising floor estimate is not possible. However, such estimates could be prepared in the future, and could be facilitated by the coupe management system. Independent yield estimates, based on alternative approaches, could provide upper and lower bounds on sustainable yield estimates, and could offer useful insights into possible oversights and errors. The coupe management system (Recommendation 19, Page 41) should provide for this eventuality.

8.4 Legislation

The *Forests Act* (s.52A(2)) requires that the supply of sawlogs be within "*2% above or below the total of the sustainable yield rates for that area*". This is inconsistent with the principle of ecologically sustainable management, and should be amended so that the sustainable yield reflects the maximum amount of sawlog that can be supplied.

It may be that the community is best served by foregoing some timber production in order to increase the production of other forest goods and services. In the same vein, it may be in the best interests of the timber industry not to focus on the volume of sawlogs, but rather on the value of the end products. Such a focus may indicate the need to reduce sawlog volumes in an attempt to increase sawlog size, quality or other properties. This has already been raised in Recommendation 16 (Page 39). The current legislation does not appear to offer NRE that flexibility.

The *Forests Act* (s. 52D(1)) requires that "*The Minister must in each 5 years beginning from 1 July 1991 review the sustainable yield rates … of hardwood sawlog*". S.52E of the *Act* provides for changes to the sustainable yield rates, but there is no mechanism to change the licensed volume. Procedures must be established to facilitate adjustments to the licensed volume, otherwise it is pointless to review the estimates of sustainable yield.

Recommendation 25: *Amend the Forests Act to recognize that ecologically sustainable management requires that the harvest should not exceed the sustainable yield (s.52A(2)), to acknowledge that the optimal sustainable yield may be less than the maximum volume that can be sustained (s.52D(4)), and to establish procedures to allow adjustments to the licensed volume during a timber supply period.*

9. Synthesis and Recommendations

This evaluation has revealed that NRE has the knowledge and procedures to provide reliable estimates of the extent and the nature of the forest resource, and of its capacity to produce sawlogs. SFRI and IFPS have demonstrated the capacity to provide robust information for forest management and planning, including estimates of sustainable yields. Nonetheless, there is scope for improvement in both these systems, and suggestions for improvements have been offered (e.g., Recommendations 3-7 and 15 respectively).

Other priorities appear to have impinged on the work required to prepare estimates of sustainable yields, with the result that reliable estimates are available only for a few FMAs. The situation is exacerbated because it appears that a substantial reduction in harvesting is required in several FMAs. There are several contributing factors:

- Current legislation provides for yield estimates to be reviewed every five years, but offers no mechanism to adjust licences within the 15-year timber supply period (Recommendation 25).
- SFRI provides a reliable basis for area estimates (and thus for estimating sustainable yields), but is not yet completed for all FMAs (Recommendations 2–4).
- Reliable estimates of standing volumes from SFRI requires additional data and further research to establish appropriate methods (Recommendations 5–6, 18).
- Yield tables used in IFPS and SYSS are the weakest component of yield estimates for many FMAs, and warrant further research (Recommendations 7–11, 14).
- IFPS is a state-of-the-art approach for simulating future wood flows, but further work is required to enable it to incorporate aspects additional to the maximum wood volume (Recommendations 15–16).
- Current procedures for comparing predictions against areas logged and volumes realized are too informal and subjective, and more rigorous procedures should be established (Recommendations 19–22).

NRE has the capability to prepare state-of-the-art predictions, but to date, has been able to deliver reasonable assessments for only a few of the FMAs. As a result, NRE is not well placed to make long-term commitments to industry. Many of the recommendations below reaffirm the importance of work already in train:

Recommendation 1: *Reconcile sustainable yield estimates and FMAs by calculating yields corresponding to the FMAs as defined in the* Forests Act *1958 (Sch. 3), or by adjusting the FMA boundaries in accordance with the provisions of s.52F of the* Act.. (Page 5).

Recommendation 2: *Continue to provide and maintain up-to-date stand-level forest type mapping on a consistent basis over all forested crown lands in Victoria through the SFRI.* (Page 17).

Recommendation 3: *Test, document and make available as standard routines the GIS-based procedures for estimating net mappable areas to facilitate consistent area estimates*. (Page 18).

Recommendation 4: *Test and document procedures to calibrate estimates of net harvestable area against areas logged-over operationally*. (Page 19).

Recommendation 5: *Refine* yield *prediction procedures to predict not merely D+ volumes, but also the breakdown of volume by size and grade*. (Page 21).

Recommendation 6: *Establish the extent of any bias in SFRI volume estimates, particularly with regard to stand edges*. (Page 23).

Recommendation 7: *Establish whether scaling of a guide curve on the basis of estimated volume is the most reliable way to predict future yields, and if so, what is the most reliable way to scale such a guide curve*. (Page 27).

Recommendation 8: *Establish the circumstances under which STANDSIM can be relied upon to provide suitable guide curves for yield tables for both ash and mixed species stands*. (Page 29).

Recommendation 9: *Ensure empirical data substantiate any assumption that thinning can resolve a short-term hiatus in sawlog supply.* (Page 29).

Recommendation 10: *Develop growth models for mixed species forests to enable more reliable yield predictions for these forests*. (Page 29).

Recommendation 11: *Contrast the characteristics of the growth plots with those of the production forest estate to investigate the extent to which yield estimates extrapolate (rather than interpolate) the growth plot data and to indicate where additional growth plots may be required*. (Page 30).

Recommendation 12: *Conduct a parallel run with SYSS and IFPS on an identical data set to establish whether, and to what extent, SYSS may overestimate sustainable yields*. (Page 33).

Recommendation 13: *Modify SYSS to report performance indicators such as the estate-wide mean age and mean standing volume during each simulation period, and to automatically calculate the maximum MAI and optimum rotation age from the yield tables supplied*. (Page 34).

Recommendation 14: *Maintain rotations near the ages nominated in the Timber Industry Strategy unless there is explicit stakeholder agreement and acceptance of the consequences, including the characteristics of the wood produced*. (Page 36).

Recommendation 15: *Conduct sensitivity testing of IFPS procedures, to establish and document appropriate approaches, including the consideration of alternative objective functions, ending conditions, constraints, and optimization techniques*. (Page 37).

Recommendation 16: *Acknowledge two components of* sustainable *yield: the maximum timber yield that can be sustained (as a non-declining even-flow, as required by the Forests Act), and the optimal harvesting rate that delivers the greatest benefit to stakeholders*. (Page 39).

Recommendation 17: *Stagger* completion *dates for the review of sustainable yields, so that two or three FMAs are scheduled for completion each year*. (Page 40).

Recommendation 18: *Examine the feasibility of harmonising SFRI and WUP assessment procedures, so that both can contribute to IFPS estimates, and that IFPS can contribute lists of candidate coupes for WUPs*. (Page 41).

Recommendation 19: *Establish a coupe information system to maintain details of wood-related matters at the coupe level in a spatially and temporally explicit way*. (Page 41).

Recommendation 20: *Institute procedures that facilitate routine comparison of predicted versus realized yields and a feedback system that enables the sawlog entitlements of licensees to be adjusted annually in response to any discrepancies between predicted and realized yields*. (Page 42).

Recommendation 21: *Compile a comprehensive error budget for selected FMAs to establish the accuracy of the various components of sustainable yield estimates*. (Page 45).

Recommendation 22: *Calibrate scaling factors empirically and demonstrate their significance with standard statistical tests. Avoid unsubstantiated contingencies in estimates of sustainable yield*. (Page 46).

Recommendation 23: *Publish annually an estimate of the current standing volume of sawlog resources within the net harvestable area of each FMA, with a statistically rigorous estimate of the 95% confidence interval. Production forests should be managed, and inventory devised so that the lower 95% confidence limit does not decline over time*. (Page 52).

Recommendation 24: *Explore appropriate incentives to encourage best practice by all field workers, and especially to encourage fellers to strive for better bucking*. (Page 53).

Recommendation 25: *Amend the Forests Act to recognize that ecologically sustainable management requires that the harvest should not exceed the sustainable yield (s.52A(2)), to acknowledge that the optimal sustainable yield may be less than the maximum volume that can be sustained (s.52D(4)), and to establish procedures to allow adjustments to the licensed volume during a timber supply period*. (Page 54).

These recommendations should contribute towards better yield estimates in the future. Some of these recommendations contain advice similar to that previously offered but not yet implemented, so innovative ways must be found to give stakeholders a vested interest in implementing these recommendations. It is unproductive to apportion blame for this failure to address these deficiencies; it is preferable to create an environment that gives all stakeholders a vested interest in moving forward. There is a special need to foster broad support for establishing and monitoring the nature of the resource, and in making this work part of the core business of NRE (Recommendation 20 and 23).

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Annex 1

Glossary

Bucking – cross-cutting the felled tree into logs. Ideally, this should be done with a view to achieving the “best” assortment logs rather than mechanically cutting logs of standard length.

Clearfelling – silvicultural system in which trees are grown as an even-aged stand until maturity, when all the trees are harvested, and the stand is regenerated.

Coupe – “an area of forest of variable size, shape and orientation from which logs for sawmilling or industrial processing are harvested” (*Code of Practices for Timber Production*)

Diameter breast high over bark (dbh) – standard measurement of tree size, usually determined by measuring the tree’s girth at 1.3 metres above the ground with a tape calibrated in π centimetres so that an estimate of diameter can be read directly from the tape.

Geographic Information System (GIS) – a computerized atlas that allows map-based information from various sources to be collated and interrogated, that simplifies the computation of areas, and facilitates analyses such as slope calculations, stream buffers, etc.

Growth model – a procedure, usually implemented as a computer program, that offers objective and repeatable forecasts of the growth of a forest, and which can thus be used to anticipate future yields and wood flows.

Mean Annual Increment (MAI) – the whole-of-life average growth rate attained by a tree or a stand of trees. Usually refers to stand volume, but may also refer to diameters of individual trees. Because trees tend to grow (in volume) rather slowly when small, most rapidly in middle-age, and slowly when old, MAI tends to follow a bell-shaped when plotted against age. The maximum MAI refers to the apex of this bell-shaped curve, and indicates the greatest production that can be sustained under best management practices.

Merchantable volume – only some of the wood volume in a tree is saleable; some parts are too small or too crooked (e.g., branches), and some parts contain too much defect (i.e., hollows, knots, gum rings, etc). Merchantable volume may refer to gross (i.e., including any “pipe” or hollows in the log) or net log volume, excluding bark.

Net harvestable area – the area expected to be worked over during a logging operation, net of any unloggable areas such as inaccessible terrain not apparent in resource mapping.

Net mappable area – the spatially explicit component of the net harvestable area, determined from a GIS. It approximates, but overestimates the net harvestable area, because it does not account for unmapped areas such as inaccessible terrain.

Normal forest – a forest estate in which there is an equal area of each age class, and which can thus sustain a non-declining harvest in which $1/n^{th}$ of the estate, containing *n*-year old trees, is harvested and regenerated each year. The concept is an ancient one, mentioned in Evelyn’s (1662) *Silva* “the Kings Commissioners divide the Woods, and Forests, into eighty partitions; every year felling one of the divisions; so as no Wood is fell'd in less then fourscore years" (XXXII:13).

Periodic Annual Increment (PAI) – the average growth rate attained by a tree or a stand of trees over a period of years (usually 3-7 years). Usually refers to stand volume, but may also refer to diameters of individual trees.

Site productivity – The potential of a site to sustain the production of wood volume. An empirical way to quantify the combined effect of soil depth, nutrient status, rainfall, etc.

Stand – a group of trees with similar characteristics (e.g., age, size, and species), treated as an entity for management purposes.

Stratum – an area of forest considered to be relatively homogeneous (i.e., uniform with respect to the parameters of interest), and used as the basis for sampling.

Timber supply period – "each successive period of 15 years, the first period beginning on 1 July 1991" (*Forests Act* s.3(1)).

Yield table – table, graph, curve or equation that shows the expected volume of a stand at a given age.

NRE staff consulted

Dionesio Battad, Peter Black, Adrian Bloch, Matt Brookhouse, Fred Cumming, Gary Featherston, Anne Geary, Fiona Hamilton, Hamish Hurley, Mike Irvine, Catherine Jewel, Alex Lau, Peter Keppel, Evan Lewis, Ian Miles, Joe Miles, Gerard O'Neill, Bill Paul, Paul Pearson, Ross Penny, Jan Radic, Ross Runnalls, Owen Salkin , Caitlin Sheehan, Ian Shurvell, Ian Siebire, Michael Sutton, Willem Vandenberg, Grimaldo Villanveva, Yue Wang, Gary White, Kylie White, Mark Woodman

Other experts consulted

Cris Brack (Consultant to SFRI, Australian National University), Ian Ferguson (Professor, University of Melbourne), Bill Incoll (Consultant, co-developer of STANDSIM), Eric Keady (Queensland DPI Forest Service)

Stakeholders consulted

During the conduct of this review, several stakeholders indicated their desire to put their views to the Group. Stakeholder consultations were held with the following representatives. A brief indication of some of the issues is shown:

Australian Conservation Foundation (Lindsay Hesketh): Sustainable yield as a ceiling, not a target (cf. Recommendation 25).

Concerned Residents of East Gippsland (Jill Redwood): Downgrading of logs (cf. Recommendation 24); WUP procedures (cf. Recommendation 18); stream buffers, and the Code of Forest Practices (cf. Recommendations 4 and 21).

Environment Victoria Inc (Darren Gladman, Geraldine Ryan): Log grading (cf. Recommendation 24).

Environment Victoria Inc (Dean Haywood): Data management (cf. Recommendation 19), area definitions (cf. Recommendations 3 & 4), SFRI procedures (cf. Recommendations 6, & 20).

Geelong Community Forum (Cameron Steele): Trade-offs between water and wood production (cf. Recommendations 15 & 16).

Lawyers for Forests (Catherine Bourne): Legislated sustainable yields (cf. Recommendation 25).

Otway Ranges Environment Network (Simon Birell): Non-wood forest goods and services (ecotourism, water, scenic values; cf. Recommendations 16 & 25).

The Wilderness Society (Gavan McFadzean): Exchanging areas when new conservation values are found (cf. Recommendation 17).

Victorian National Parks and Wildlife Association (Jason Doyle): Bendigo FMA.

Wellsford Watch (John Bardsley, Stuart Fraser, Wendy Redford, Jenny Shield): Non-wood values of forests (cf. Recommendations 16 & 25).

Wombat Forest Society (Tim Anderson, Loris Duclos): WUP and harvesting data (cf. Recommendations 16, 18, 20, 24 and 25).

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Annex 2 - Assessments of data and methods by FMA

Introduction to the Assessments for each FMA

These assessments attempt to provide a concise summary of the key factors influencing the reliability of yield forecasts for each FMA. Substantiation of claims, explanation of acronyms, and discussion of alternatives is minimal; these issues are dealt with more fully in the main report.

The assessments draw on a range of information, but draw heavily from the Estimate of Sawlog Resource (ESR), the Timber Harvesting Strategy (THS), and the SYSS files (or equivalent cutting cycle analysis spreadsheet and IFPS summary output files) for each FMA. In some cases, the Timber Resource Assessment (TRA) has also provided pertinent information. Most of these documents have evolved throughout the conduct of our review, and the documents made available for assessment may not have been the final versions, so the version numbers and dates of the documents consulted are provided for each FMA.

Each assessment begins with a bald statement of the reliability of the data and of their utility to support licence renewal negotiations. This is followed by a brief review of issues contributing to each of the following components of yield estimates, arranged under the following headings:

Area estimates: a summary of the source and reliability of nett area estimates;
Inventory data: an overview of inventory data contributing to yield estimates;
Volume estimation: brief insights into volume estimation procedures;
Yield tables and growth estimates: comments on growth estimates and yield tables;
Wood flows: comments on the anticipated sequence of timber harvesting;
Contingencies and scaling factors: any contingencies included in the calculations.

The assessment concludes by summarizing the ***implications for licence renewal***. This paragraph attempts to summarize what reliance may be placed on resource estimates in contemplating long-term commitments to the timber industry.

The overall reliability of an estimate of sustainable yield is dominated by three factors: the nett area estimates, the growth estimates or yield tables (and the way they are used), and the scheduling of timber harvests. The indicative overall reliability is assumed to correspond to the worst of these three elements. This is appropriate, because for example a 10% bias in the yield table will result in a 10% bias in overall estimates even though other components may be "perfect". Where more than one component is biased, there is a chance that errors may compensate, but standard statistical procedures assume that errors accumulate as the "root sum squares", so the simplistic assumption of worst case is a reasonable approximation.

There are 15 FMAs under consideration (Figure 1, Page 5). Wangaratta and Wodonga (except the eleven blocks known as North-East Gippsland which are treated as part of Tambo FMA) have been treated as a single FMA, the North-East. Bendigo has not been considered in the present analysis as no data have been presented for scrutiny.

The data and methods used in preparing sustainable yield estimates for each FMA were assessed on the basis of the empirical evidence underpinning data and procedures, and the absence of subjective inputs. A 5-star rating was used. Five stars indicate that the estimate is rigorous, repeatable, and unlikely to change greatly when subsequently revised. In contrast, a

Table A.1. Overview of data quality (* = inadequate; ***** = excellent)

FMA	Areas	Yields	Scheduling	Overall score
Benalla-Mansfield	****	***	****	***
Central	**	**	***	**
Central Gippsland	***	**	***	**
Dandenong	***	*	***	*
East Gippsland	***	*	***	*
Horsham	**	**	*	*
Midlands	***	****	***	***
Mid-Murray	**	*	**	*
Mildura	*	*	**	*
North-East	****	***	***	***
Otway	**	*	****	*
Portland	**	*	**	*
Tambo	***	**	***	**

1- or 2-star rating lacks empirical underpinning and relies on subjective input. Such an estimate may be a good approximation, but this cannot be gauged without empirical evidence. The assessments are summarized in Table A.1. The scoring system is based on:

Area estimates

- * subjective estimates
- ** SFRI without benchmark; Forest25
- *** SFRI benchmarked, with standard 20/30 buffering
- **** SFRI with complete benchmark and variable-width buffers
- ***** full SFRI, variable-width buffers substantiated with ground checks

Yield tables

- * guess; expert opinion.
- ** local broad-area averages derived from measured data; subjectively selected yield tables calibrated for yield but not shape.
- *** generic state-wide or adjacent FMA tables calibrated for yield but not shape.
- **** FMA-specific yield table entered with age and site productivity; generic table re-calibrated for yield and shape with local data.
- ***** specific yield table entered with age and site productivity, locally validated.

Scheduling

- * none, broad-area averages
- ** assumed normal forest, formula-based estimates
- *** SYSS with 10-year age classes and 10-year time steps
- **** IFPS with wood-only objective and 5-year time steps
- ***** IFPS accommodating multiple values, with validation of early schedules

The **overall score** is the weakest of the three categories (areas, yields, scheduling). We considered discounting the star-rating for unsubstantiated adjustments, but this had no effect on the final ranking. The rationale for this discounting was that an estimate should be considered excellent, despite three 5-star ratings, if it contained unsubstantiated adjustments exceeding 20%. However, since it had no effect on the outcome, this element has been omitted from the star-rating system.

Implications for long-term timber harvesting commitments

- * inadequate
- ** weak
- *** reasonable
- **** reliable
- ***** excellent

Benalla-Mansfield FMA

This assessment is based on the ERS (V1, 19-10-01), THS (kw rev PS, 13-7-01), and IFPS files (Run 133, 28-9-01).

Yield estimates for the Benalla-Mansfield FMA are based on SFRI and IFPS, and provide a *reasonable* basis for renewing licence commitments.

Area estimates

Area estimates are derived from SFRI-25FS benchmarked to June 1997. Net area estimates are based on variable width buffering (25-60 m) of streams, and excluded steep slopes (>25-30º), small "islands" (yielding <800 m3/ha/yr, typically <1.5 ha in ash and <10 ha in mixed forest), and stands dominated by species currently considered unmerchantable. No specific adjustment was made for unloggable areas unable to be mapped. It is assumed that fauna and flora are protected adequately within the SPZ and SMZ provided by North-East RFA.

Inventory data

Some 271 inventory plots (81 in ash, 190 in mixed species forest) were established as part of the North East SFRI project in the Benalla-Mansfield and North-East FMAs. Data from these plots were used to develop an equation to predict standing volumes from attributes recorded in the GIS. Although the inventory was designed to achieve an overall precision within 15%, it performed below expectations (e.g., regrowth ash overestimated by 25%). Standing volumes (D+ sawlog in net harvestable areas of State Forest) are estimated at 1.1 million m^3, sufficient to satisfy anticipated harvests for about 90 years.

Volume estimation

Volumes were estimated using the TREEMAP-VOLCALC approach. A 20% reduction was applied to account for trees with single short (<3 m) logs unlikely to be harvested. Volumes in mixed species forests with previous selection harvesting were overestimated, so a further reduction of 31% (44% in Strathbogies timber catchment) was applied. These adjustments were based operational out-turn at the coupe level, but are not statistically significant. New volume estimation procedures tested in this FMA did not meet expectations, and enhanced procedures were subsequently developed elsewhere. The new equations developed for the North-East FMA could be used to check the Benalla-Mansfield estimates.

Yield tables and growth estimates

Ash yield tables were derived from STANDSIM simulations of 34 regrowth plots from the North-East FMA. Yield tables were adjusted with 27 scaling factors (a simple transformation of the Y-axis) to represent strata based on age, height and stand type. While the underlying ash yield table is sound, predicted yields are compromised by the volume estimates used to enter and scale the guide curve.

Yield tables for mixed species forests were based on a generalized yield curve calibrated with local tree ring data, adjusted with 44 scaling factors. It was assumed that mature and early mature stands would continue to grow, in some cases almost doubling their volume by 2030. No further growth was assumed for stands assessed as late mature, senescent or uneven-aged.

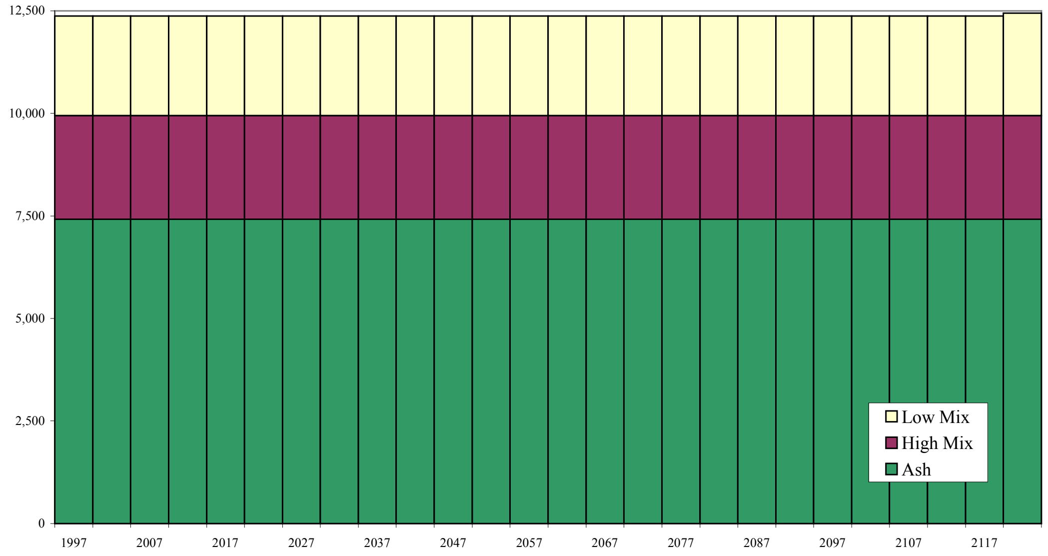

Figure A.1. Predicted wood flows from the non-declining scenario, showing the contribution from ash, and high- and low-quality mixed-species forest types. Note that more than half the volume comes from ash forests, which comprise less than 20% of the net area.

Wood flows

Wood flows were derived with IFPS using 2224 analysis units in 7 timber catchments, 30 intervals of 5 years, and operational constraints. Maximizing sawlog volumes led to a sustainable yield of 12,400 m^3/yr (Figure A.1). This represents about 1.1% of the standing volume, and 0.5 m^3/ha/yr from the net harvestable estate, both of which are conservative values. About half of the area involved is characterized by relative (regrowth, mature, etc.) rather than actual (decade) age estimates, and assumptions used to enter yield tables may have a significant impact on short-term wood supplies.

Strategic-level estimates without operational constraints analogous to the SYSS approach (but simulated with IFPS) suggest yields of about 16,800 m^3/yr. The difference (35%) is largely due assumptions relating to available areas (23,800 ha versus 35,000 ha). The former estimate is preferred; the difference offers an insight into the importance of taking full account of operational considerations.

Contingencies and scaling factors

Contingency allowances include 1.3% for wildfire; 20% for single small logs; 31% (44% in Strathbogies) for volume calibration (attributed largely to internal defect), and 13% for other unspecified contingencies. These total 54%. The 15% adjustment is not supported by empirical evidence, and the 31% (or 44%) calibration is not statistically significant (applies only in mixed species forests).

Implications for licence renewal

The analysis provides a reasonable basis for assessing the options surrounding licence renewal, but is hampered by inferior volume estimation procedures. Scaling factors and contingencies are excessive, are not statistically substantiated, and amount to a large proportion of the primary estimate.

Central FMA

This assessment is based on the ERS (V3rr, 24-10-01), THS (Draft 3, 15-8-01), and SYSS files (v6.1.38, 14-8-01).

Yield estimates for the Central FMA are based on interim SFRI (no benchmark, supplemented with stand ages from Forest25) and SYSS, and provide a *weak* basis for renewing licence commitments.

Area estimates

Area estimates were derived from interim SFRI data (no benchmark), which does not fully account for harvesting since the aerial photos were obtained. Local logging history records and older GIS data (Forest25) provided information on harvesting history and estimates of stand ages. Net area estimates are based partly on standard (SFRI) buffering of streams (20 m), and exclusion of steep slopes (>30º), and partly on a non-spatial adjustments (20% in ash; 10% in mixed species forests, based on 1000 ha harvested during 1998-99). A further 2% adjustment was made for small areas too small to operate efficiently (based on a case study of islands <7 ha). In addition to the SPZ and SMZ created by the Central Highlands RFA, a further 7,615 ha of potential habitat for Leadbeaters possum was excluded from the net harvestable area.

Inventory data

Some 357 inventory plots have been established in the FMA since the early 1980s, but were not used in the present study. Instead, yields were inferred from yield tables (and stand ages).

Volume estimation

Volume estimates derived from SFRI data and from log measurements during recent harvesting operations guided the selection of a yield table.

Yield tables and growth estimates

Ash yield tables were adopted from the Central Highlands Forest Management Plan, deliberately chosen to match operational out-turn from recent harvesting in the FMA, or to match estimates from SFRI volume plots. Comparisons revealed a 20% underestimate in alpine ash, and a 6% overestimate in mountain ash (based on 1996-2000 data); this was attributed to coupe selection bias, so no re-calibration was done. No evidence was presented establish that coupe selection bias had in fact occurred. Yield curves were further scaled by 7–25% where psyllid damage was evident.

Yield tables for mixed species forests are derived from similar curves used in preparing the Central Gippsland THS. Mature stands are assumed to exhibit no further growth, and yields are based on recent harvesting out-turn.

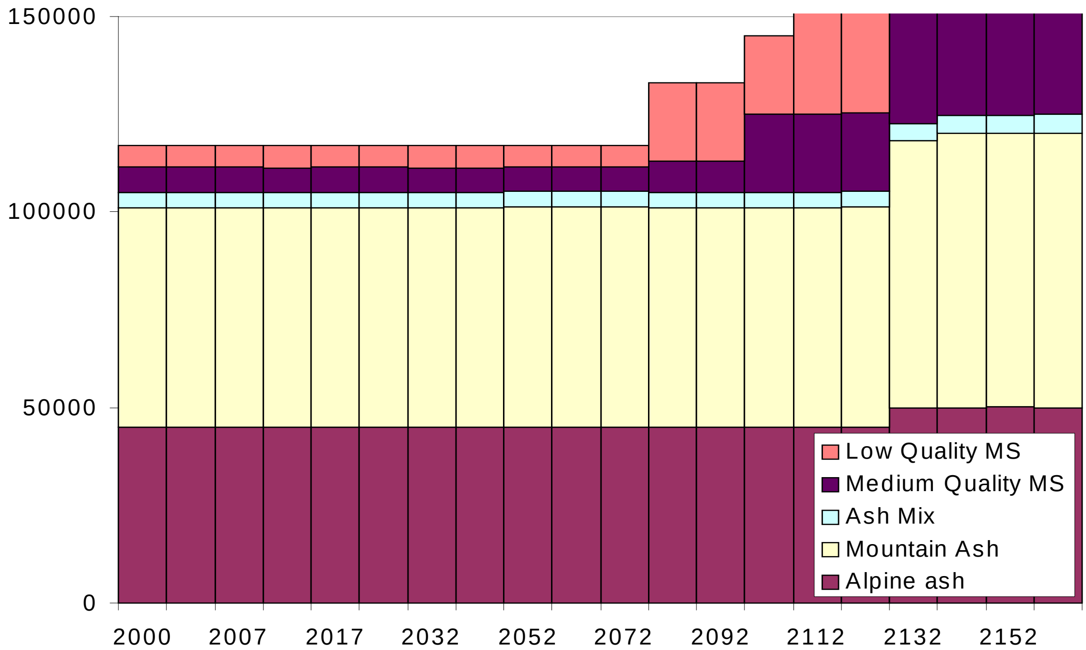

Figure A.2. Wood flows predicted with SYSS for the non-declining scenario. Note that the intervals shown may represent two, five or ten years.

Wood flows

Wood flows were simulated with SYSS, using five 5-year and fourteen 10-year periods for analysis, demonstrating predicted yields for 165 years. The non-declining yield represents 1.7 m^3/yr from each hectare of the net harvestable estate. This is the highest sustained productivity predicted in Victoria. This is an estate-wide average, derived mainly from ash yields (Figure A.2) drawn from only 40% of the area, implying that ash needs to maintain an average yield exceeding 4 m^3/ha/yr. If the low-yielding Matlock areas are excluded, the yield on the remaining ash estate needs to approach 4.7 m^3/ha/yr, close to the peak MAI assumed for the best ash (4.9 m^3/ha/yr at 90 years). It can be attained, but only if the forest is maintained in a state close to the optimal normal forest. It would seem prudent to revisit these estimates with IFPS to explore operational considerations in more detail.

Contingencies and scaling factors

In addition to the area reductions (2% for small “islands” plus 10 – 20% based on comparison of predicted versus operated areas), a further contingency of 8-13% (ash and mixed species stands respectively) was applied for habitat trees and uncertainties in modelling. There is also a 10-25% calibration for net harvestable areas, and a fire risk factor of 1.3%. These total 40% in ash and 33% in mixed species forests. Few of these adjustments are adequately substantiated.

Implications for licence renewal

The underlying data provide a weak basis for establishing long-term commitments. Yield estimates should be revisited using IFPS when SFRI benchmarking is completed. Better yield tables are also required.

Central Gippsland FMA

This assessment is based on the ERS (V7, 23-10-01), THS (21-8-01), and SYSS files (v6.1.38, 19-9-01).

Yield estimates for the Central Gippsland FMA are based on SYSS and SFRI area statements. They provide a *weak* basis for renewing licence commitments. New inventory data are available, but have not yet been used to explore sustainable yield implications.

Area estimates

Area estimates in the THS were based SFRI-25FS benchmarked to June 2000. Estimates of net harvestable area were based on standard stream buffers (20 m) and slope exclusions (30 degrees), and adjustments based on case studies in recently harvested stands and GIS analysis of stream buffers and slopes. Small "islands" (<7 ha) were excluded, as were stands dominated by species currently considered unmerchantable. In addition to the SPZ and SMZ provided by the Gippsland RFA, 924 ha (mainly alpine ash) has been excluded from the net harvestable area to provide better protection of the Baw Baw frog.

Inventory data

Some 599 plots have been established in the Central Gippsland FMA as part of the SFRI, but these data were not used in estimating the annual harvest rate. Instead, actual out-turns from recent harvesting operations were extrapolated to comparable stands.

Estimates of standing volumes suggest that the present standing volume of D+ sawlogs within the net harvestable estate is around 2 million cubic metres, sufficient to sustain projected harvests for 23 years.

Volume estimation

Volume estimates derive from direct log measurements in recent harvesting operations. They were not accompanied by audits of log grading or by an assessment of forest residue.

Yield tables and growth estimates

Separate yield curves were used for alpine ash, mountain ash and mixed species forests. Ash yield tables were based on alpine ash curve for the North-East FMA, and calibrated using local harvesting records. The yield curve for mixed species forests was based on the curve used in the 1996 review, calibrated using local harvesting records.

Wood flows

Wood flows were simulated with SYSS, using six 5-year and twelve 10-year periods to project yields for 150 years. The expected sustainable yield represents 4.2% of the standing volume, a rather high proportion. However, it corresponds to 1.0 m^3/ha/yr which is conservative, suggesting that the high proportion of the standing volume is a reflection of past overcutting.

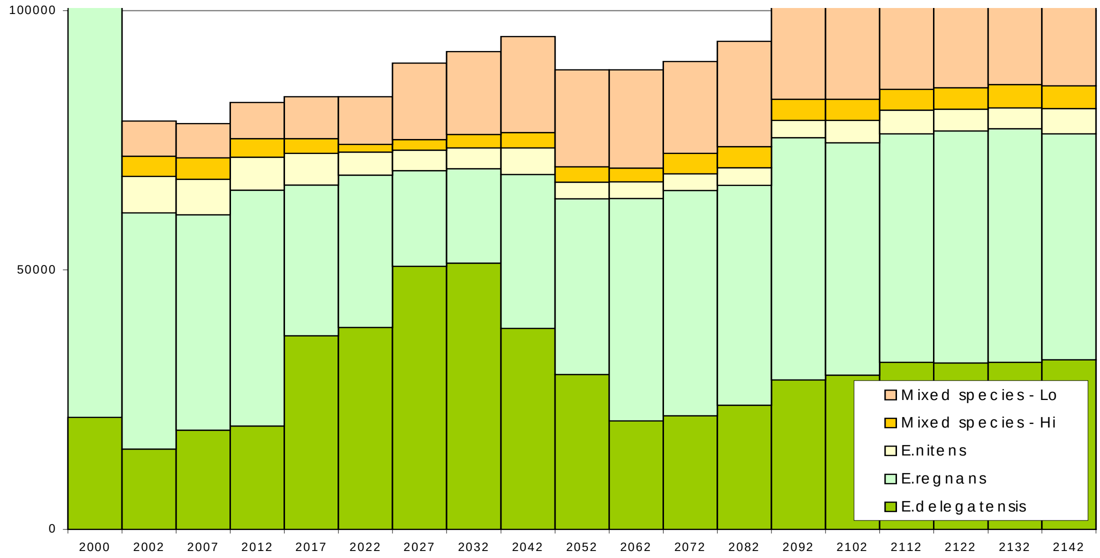

Figure A.3. Yields simulated with SYSS for Central Gippsland. Years refer to the start of a simulation period, which may span two, five or ten years. The first period (2000-1) reflects the current harvest.

Because the remaining ash is regrowth of 1926 or 1939 origin, the short-term wood supply situation is inflexible and may involve logs that are smaller and of poorer quality than those previously encountered by industry. SYSS simulations schedule many stands before the optimal rotation age. For instance, in the Erica catchment, mountain ash is often scheduled to be harvested at 60 years (with MAI_{60} = 2.3 m^3/ha/yr), even though the yield table indicates the maximum MAI (3.2 m^3/ha/yr) is attained only when the stand reaches 115 years. Simulations illustrated in Figure A.3 do not deliver the 87% ash committed in current contracts.

In an attempt to accommodate operational constraints, the forest area was divided into nine timber catchments for SYSS studies. This was necessary to ensure that water production obligations were met, but may be unnecessary finesse, as spatially explicit predictions remain unattainable. SYSS is unable to consider spatial interactions, making it difficult examine the extent to which the simulations satisfy water production obligations in the Thomson (max 150 ha/yr) and Tarago (max 782 ha every ten years) catchments, and regional prescriptions stipulating that contiguous clearfall areas should not exceed 120 ha. IFPS is well suited for exploring such issues, and the sustainable yield analysis should be repeated with IFPS as new data become available.

Contingencies and scaling factors

Contingencies include 1.6% for wildfire, a general contingency of 5%, and 10-20% for uncertainties in volume estimates (10% in high volume classes; 20% in low volume classes). The SYSS simulations involve adjustments averaging 29% and ranging between 24% (in almost half of cases) to 49% (mixed species forests in Maffra catchment).

Implications for licence renewal

Because of the large volumes and potential controversy in short-term supply, it would seem prudent to re-analyse the Central Gippsland situation when SFRI data are completed, using the full capabilities of IFPS.

Dandenong FMA

This assessment is based on the ERS (V5, 23-10-01), THS (August, 10-9-01), and SYSS files (v6.1.46, 3-9-01).

Yield estimates for Dandenong FMA are based on SFRI and SYSS, and do *not* provide an adequate basis for making long-term licence commitments.

Area estimates

Area estimates are derived from SFRI-25FS benchmarked to 2000. Net area estimates are based on buffering of streams (20 m), and exclusion of steep slopes (>30º; >25º in some catchments). An additional 400 ha was provided as stream buffers in the northern part of the FMA where the representation of streams in the corporate GIS was shown to be inadequate. A comparison between predicted and worked-over areas revealed a discrepancy of 18% in ash and 19% in mixed species forests, and area estimates were adjusted accordingly. All of the Special Management Zone (3200 ha) is assumed to be available for timber production. It is assumed that fauna and flora are adequately protected by the RFA.

The resulting net harvestable area is 41% of the State Forest area, one of the highest proportions in Victoria, and appears to be rather optimistic.

Inventory data

No inventory data were used in estimating the sustainable yields. Estimates of standing volume suggest 0.9 million cubic metres of D+ sawlog.

Volume estimation

Volume estimates used to calibrate standing volume equations were derived from direct log measurement obtained during routine harvesting.

Yield tables and growth estimates

STANDSIM was used to develop a yield table for regrowth ash. Data from recent harvesting suggested that this table overestimated yields by 12.5%, so it was adjusted downwards accordingly. The statistical significance of this (and other adjustments) was not tested.

No growth data or growth models exist for mixed species forest in this region, so a generic yield curve was scaled to estimate an MAI of 1.5 m^3/ha/yr at 80 years in high quality mixed species (HQMS). The curve for low quality mixed species (LQMS) was scaled to 64% of the HQMS. Comparisons with actual harvesting data over the last 10 years suggested that these curves overestimated yields, so they were further reduced by 20% and 31% for HQ and LQMS respectively. The resulting curves suggest an MAI of 1.2 and 0.66 m^3/ha/yr at 80 years in HQ and LQMS respectively.

Soils in the northern part of the FMA are derived from mudstone rather than granite, and growth appears to be slower. Accordingly, yield tables for this area were arbitrarily reduced by 14%, 32% and 50% for ash, HQ and LQMS respectively.

Yields for mature HQ and LQMS were based on HARIS and 10-year old anecdotes.

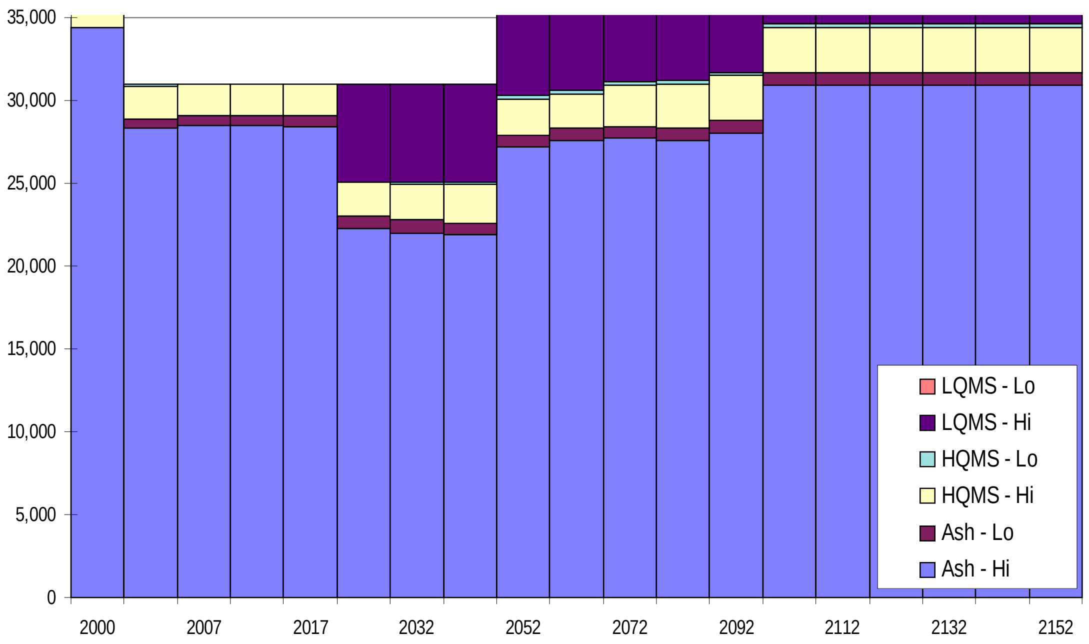

Figure A.4. Wood flows anticipated for the Dandenong FMA. Years refer to the start of a simulation period, which may represent two, five or ten years. Most of the sawlogs come from high quality ash forest.

Wood flows

Wood flows were simulated with SYSS, using four 5-year and fifteen 10-year periods to project yields for 170 years.

SYSS simulations project that most of the sawlog volume will be derived from high-quality ash forest, consistent with present trends. However, a substantial harvest from mixed forests is scheduled during 2022-51.

SYSS yield tables assume that single-tree selection or multi-stage harvesting systems that may be entertained for the low quality mixed species forest (LQMS), can be modelled as a 120-year rotation.

Contingencies and scaling factors

There is a 15% contingency allowance, plus a 0.5% adjustment for wildfire, an unsubstantiated guess. Scaling factors abound, and amount to 29% in ash, and to 82% in northern LQMS. These adjustments are not statistically substantiated.

Implications for licence renewal

The analysis does *not* provide an adequate basis for assessing the options surrounding long-term licences. Yield tables remain the weakest component in the analysis.

East Gippsland FMA

This assessment is based on the ERS (V2, 23-10-01), THS (Draft 2, 26-9-01), and SYSS files (v6.1.45, 25-9-01).

Yield estimates for East Gippsland FMA are based on SFRI and SYSS, and do *not* provide an adequate basis for making long-term licence commitments.

Area estimates

Area estimates are derived from SFRI-25FS benchmarked to June 2000. Net area estimates are based on buffering of streams (30 m), and exclusion of steep slopes (>25-30º). A small pilot study indicated that simple 30 m buffers provided approximately (within 5%) the same area reduction as the more computationally-intensive variable-width buffering employed in Benalla-Mansfield FMA. It is assumed that flora and fauna are adequately protected by the provisions of the RFA (i.e., SPZ and SMZ), and that there is no loss of area due to the Apiary Management Plan or the Draft Quoll Action Statement. It is also assumed that there will be no harvesting in Fire Management Zone 1, and that all of Zone 2 would be available for harvesting (with the caveat that no more than 5% of the zone area should be harvested in any 5-year period).

Inventory data

The SFRI programme in East Gippsland is not yet complete and data are not yet available, so equations for standing volumes in the adjacent Tambo FMA were calibrated to the East Gippsland FMA using data from 11,500 ha of operational harvesting. Before calibration, the Tambo equation predicted 53% of the volume out-turn; it was scaled using an equation with several variables to predict 90% of out-turns achieved during the last ten years (i.e., Tambo yields were scaled by factor ranging from 0.1 to 3.0).

Calibration did not scale yields to the observed volumes, because it seems likely that recent harvesting has targeted better-than-average stands. There is evidence to support the likelihood of coupe selection bias in East Gippsland. An analysis of yields (Y, m^3/ha) during the past 10 years indicates the relationship $Y=63+24/X$ (P=0.013), where X is years since 1990. This suggests that yields may tend to converge towards 63 (±3) m^3/ha, 10% less than the currently observed 10-year average, and supporting calibration to 90% of observed yields.

Estimates of standing volume suggest a standing volume of 7.3 million cubic metres of D+ sawlog, sufficient to sustain projected harvests for 55 years.

Volume estimation

Volumes used to recalibrate the Tambo equation were estimated from log measurements taken during operational harvesting.

Yield tables and growth estimates

Yield tables were adapted from those used in the Tambo FMA, and were calibrated to 90% of the yields observed in mature and 1939 regrowth stands, or to the MAIs reported in the TIS.

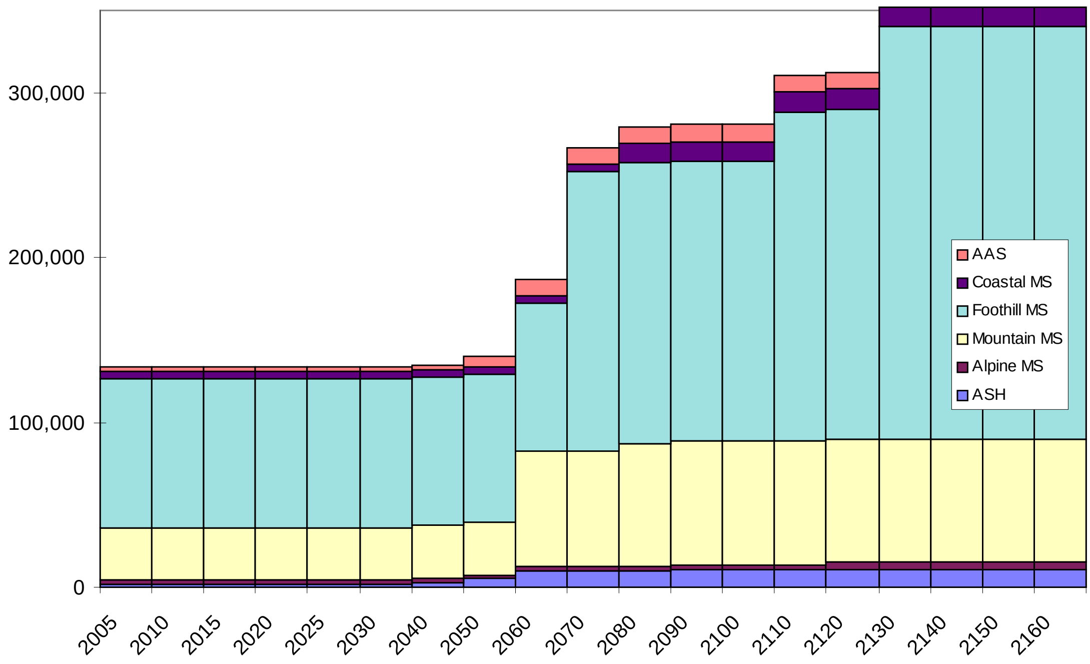

Figure A.5. Simulated non-declining yields for East Gippsland. Note that intervals may represent 5 or 10 years.

One of the scenarios examined includes thinning in more than 25% of stands in all forest types (mostly foothill mixed species). SYSS simulations assume that these thinnings will occur at about age 40, will allow a sawlog harvest at age 55, and will have a PAIs during this period 70% higher than those in comparable unthinned stands. There are no empirical data to support this expectation.

Wood flows

Wood flows were simulated with SYSS using six 5-year and fourteen 10-year periods to simulate yields for 140 years.

During the past decade, the volume of wood from foothill mixed species (FMS) stands has rarely exceeded 50%, but SYSS simulations anticipate that this forest type will contribute over 70% of the volume in the future. However, note that the definition of FMS used in SYSS differs from that used by local staff (and thus in logging records).

Contingencies and scaling factors

Contingency allowances include 1.3% for wildfire and a general contingency of 17%. There are also adjustments in the range 0.1 to 3.0 to scale the volume equation to East Gippsland. In addition, volumes north of Cann River have been reduced by 25%, and volumes in Alpine mixed species (AMS) stands have been reduced by 50 m^3/ha. These adjustments are not substantiated statistically.

Implications for licence renewal

The analysis does *not* provide an adequate basis for making long-term commitments regarding sawlog availability. Yield tables remain the weakest component in the analysis, especially in scenarios where thinning is examined.

Horsham FMA

This assessment is based on the ERS (V2, 19-10-01), THS (June, 26-9-01), and TRA (9-2-00).

Yield estimates for Horsham FMA are not based on the conventional SFRI-SYSS approach, but rely on measurements of diameter increment and estimates of volume growth per hectare, based on CFI plots. These data do *not* provide an adequate basis for offering long-term commitments. Large contingencies and unsubstantiated scaling factors detract from the rigour of the estimate. However, proposed harvest rates appear reasonable and standing volumes provide adequate reserves for the short term.

Area estimates

Area estimates are derived from spatial data collated for the RFA (field surveys by regional staff). Code of Forest Practice provisions were accommodated as a non-spatial 10% allowance rather than via explicit stream buffers. The only provision for fauna is the retention of all trees >80 cm dbh. While area estimates appear reasonable, it is likely that future SFRI estimates may differ.

Inventory data

Some 140 inventory plots established in Horsham FMA in 1998 contribute towards yield estimates. Plots were randomly-located, variable-radius, 15-tree plots. Diameters (dbh) were measured, and log lengths and defects were estimated for all trees on each plot.

Volume estimation

A linear regression was fitted to local individual tree data. The equation, V=0.0418dbh–1.58 (r^2=.58, n≈60) appears to offer reliable predictions for diameters in the range 40-80 cm dbh. The trees used to develop this equation were obtained through destructive sampling in conjunction with harvesting by a licensee under the supervision of a forest officer. Calibration revealed a 25% discrepancy between subjective estimates of defect and measured data from felled trees; due allowance was made volume calculations.

Yield tables and growth estimates

Two alternative approaches were examined. The first was more optimistic, assuming the mean diameter increment of 0.38 cm/yr observed in thinned CFI plots (the unthinned plot attained 0.22 cm/yr), and suggested a yield of 1200 m^3/yr. The second envisaged converting even-aged stands into an uneven-aged forest, and calculated the standing volume plus half the anticipated growth, divided by the conversion period, to estimate 660 m^3/yr over the 1932 ha of even-aged forest. The 2500 ha of uneven-aged forest were assumed to grow at 0.22 cm/yr, leading to an estimated yield of 350 m^3/yr, or 1010 m^3/yr over both strata.

Wood flows

No attempt has been made to simulate wood flows. However, standing volumes amount to over 100,000 m^3, sufficient to satisfy the envisaged annual harvest rate for over 100 years.

Contingencies and scaling factors

An adjustment of 10% is made to compensate for lack of stream buffers. A further 5% adjustment is made because CFI data from Woohlpooer (900 ha) were extrapolated across the whole resource (3800 ha). Together with the volume calibration (25%) these total 36%.

Implications for licence renewal

Although yield estimates are somewhat subjective and simplistic, the suggested annual harvest rates appear reasonable, and standing volumes have sufficient reserves for harvesting in the short-term.

Midlands FMA

This assessment is based on the ERS (V4, 19-10-01), THS (Draft 2, 26-9-01), and SYSS files (v6.1.47, 10-10-01).

Yield estimates for Midlands FMA are based on SFRI and SYSS, and provide a *weak* basis for renewing licence commitments.

Area estimates

Area estimates are derived from SFRI-25FS benchmarked to June 2000. Net area estimates are based on buffering of streams (20 m) and roads (3 m either side, since many roads are 6 m wide), and exclusion of steep slopes (>25-30º). Forest stands considered to be currently unproductive were excluded from the harvestable area. It is assumed that any new discoveries of historic sites or rare species will be accommodated by land-swaps. A 2% allowance is made for disease (*Armillaria*) at Mt Cole.

State Forests in the Midlands have a long perimeter, much of which adjoins private property or public roads. This creates special issues. Some owners have requested buffers along their boundary, and some advocate visual buffers along roads. Adoption of 20 m buffers along all private property boundaries and public roads would result in a further loss of 10% of the net area (6% and 4% respectively). Present calculations make a 3% allowance for landscape buffers, assuming that half the boundary with private land may have a 20 m buffer.

A study of recent harvesting suggested a 15% allowance to account for operational constraints relating to slopes, rocky areas and unharvested areas along roads and adjoining stream buffers. This is presumably the basis for the 5% adjustment for "temporal and spatial constraints". The THS suggested that 0.75% of the net area might be implicated in habitat retention prescriptions[2], but no explicit allowance has been made in the ERS.

Inventory data

Some 273 inventory plots were measured as part of the SFRI project. A subset of validation felling plots was used to determine the graded volume, and contributed to the 20% calibration factor used in developing the equation for standing volume estimates.

Volume estimation

Volumes were estimated using the TREEMAP-VOLCALC approach. The calibrated SFRI volumes were compared with operational yields from 38 clearfall coupes, and on average predicted 6% more than the harvested volumes. No adjustment has been applied to account for trees with single short logs, as it was assumed that these would be harvested due to the capacity to sell this material in conjunction with residual log sales.

[2] Operational Guidelines for the Implementation of Prescriptions for Habitat Retention in the Wombat State Forest (draft)

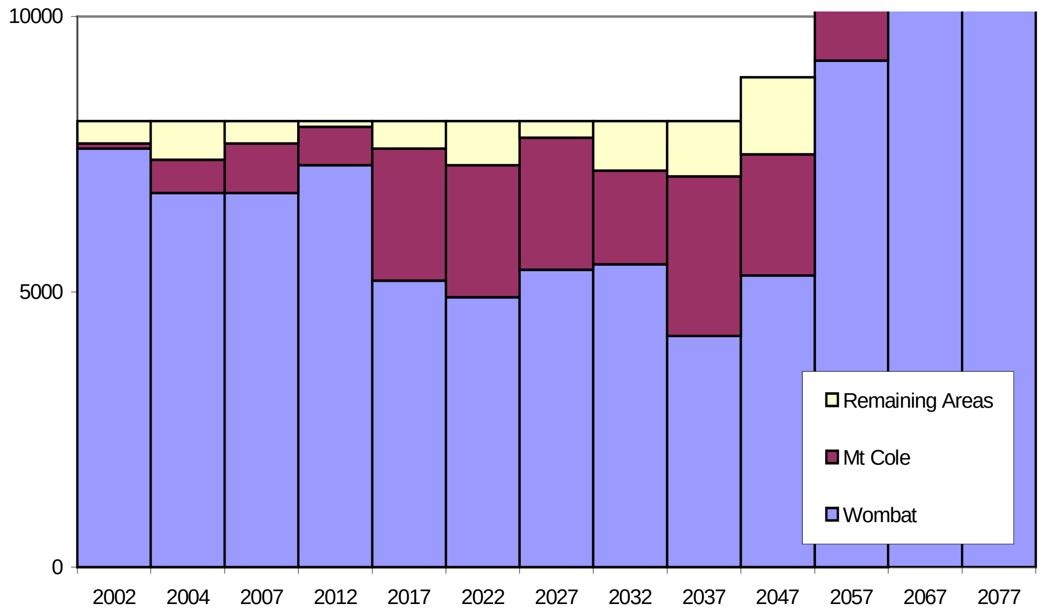

Figure A.6. Projected wood flows for Midlands FMA. Intervals may represent 2, 5 or 10 years.

Yield tables and growth estimates

Yield curves are based on work previously published as Technical Report 95-5. They have been adjusted downwards by 2-6 m^3/ha to reflect volumes forgone in seed trees.

Wood flows

Wood flows were predicted with SYSS using seven 5-year and ten 10-year periods to simulate yields for 135 years. This is a relapse, as IFPS was used in the previous review of sustainable sawlog yield (Holmes *et al*. 1995). The short- to medium-term outlook is tight, but current standing volumes are sufficient to sustain projected harvests for 55 years. An analysis of projected wood flows from the Wombat forest (Figure 14, Page 51) suggests that there is scope to improve scheduling in the medium term.

Contingencies and scaling factors

Contingency allowances include 0.2% for wildfire, plus 10% (12% at Mount Cole) for unquantifiable factors such as uncertainty associated with forest management zone boundaries, volume and growth estimates, limitations of the modelling and *Armillaria* infestation. Further allowances of 3% were made for landscape buffers, and 5% for logging waste.

Implications for licence renewal

The analysis provides a weak basis for assessing the options surrounding licence renewal. In view of the tight short-term supply situation, it would be prudent to repeat the analysis using IFPS.

Mid-Murray FMA

This assessment is based on the ERS (V6, 19-10-01), THS (Draft, 10-9-01), and spreadsheet files (H2, 25-8-01).

Yield estimates for Mid-Murray FMA are not based on the conventional SFRI-SYSS approach, but rely on cutting cycle analysis. These data do *not* provide an adequate basis for offering long-term commitments.

Area estimates

Area estimates are based on GIS analysis of 1987-1989 data adjusted for the proposed Forest Management Plan. In addition to the standard Code of Forest Practice exclusions, a 60 m buffer is maintained along the Murray River. No specific adjustment is made for unloggable areas unable to be mapped. In addition to the protection of flora and fauna through the land use zoning in the proposed Forest Management Plan, all trees exceeding 150 cm dbh are retained.

The net harvestable area represents 75% of the gross area of State Forest, which appears too optimistic, despite the easy terrain.

Inventory data

A generic stand table for use in yield calculations was compiled from some 789 temporary inventory plots were established in the late 1980s, including 472 plots at Barmah (measured in 1987) and 317 at Gunbower (in 1989).

Volume estimation

Volume estimates rely on a linear regression ($V = 0.0418 \times d - 1.5812$) fitted to local tree volume data obtained during recent harvesting operations. This is a non-conventional volume equation, and should not be extrapolated.

Yield tables and growth estimates

Diameter increments observed on 80 CFI plots in the Barmah forest provided the basis for growth estimates. However, lower estimates have been used in yield calculations:

Forest	CFI - dbh increment (cm/yr)	Productivity Class 1 (m^3/ha/yr)	Productivity Class 2 (m^3/ha/yr)
Barmah	0.35	0.28	0.03
Goulburn	–	0.19	0.03
Gunbower	0.26	0.15	0.02

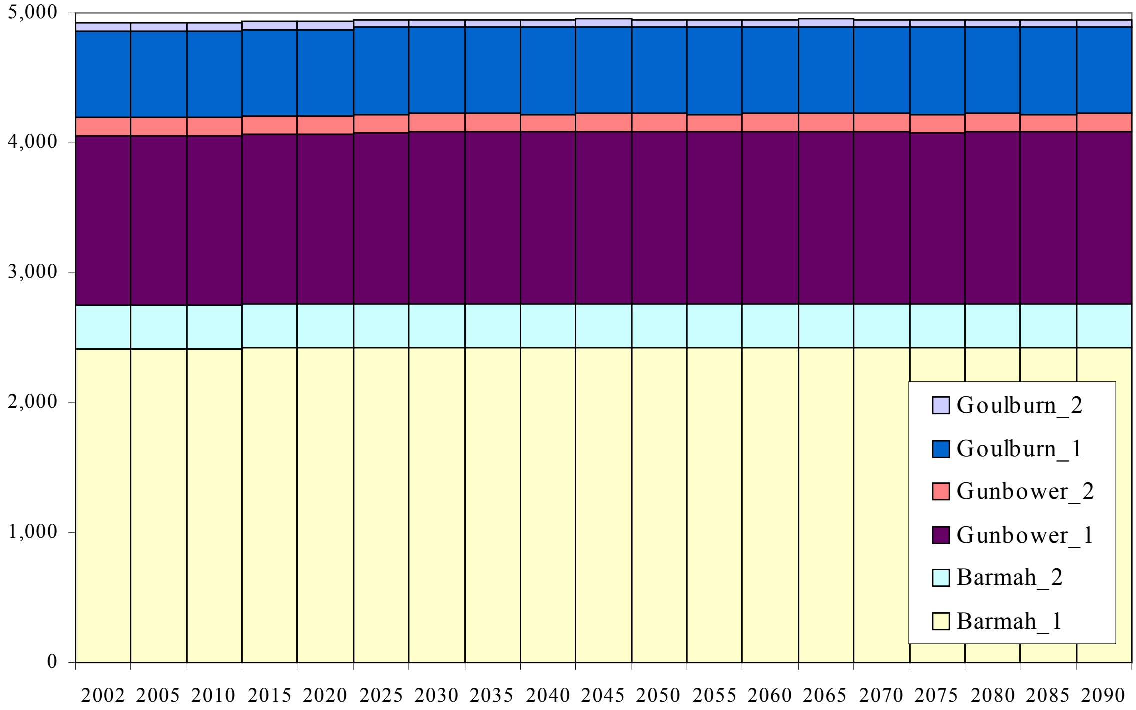

Figure A.7. Yields predicted for Mid-Murray FMA. Half of the sawlogs come from productivity class 1 stands in Barmah Forest.

Wood flows

A variant of cutting cycle analysis was used to determine wood flows over three cycles. Non-declining yields are not possible with current habitat prescriptions, and can only be attained (Figure A.7) under an alternative prescription (State Forest Flora and Fauna Habitat Management Working Group, Recommendations for the Retention of Wildlife Habitat within the General Management Zone of Victoria's State Forests, 2001) which involves setting aside 3% of the net harvestable area.

Contingencies and scaling factors

No explicit allowance has been made for contingencies in the current estimates.

Implications for licence renewal

These estimates do not provide an adequate basis for making long-term commitments, because of subjectivity in the data and simplistic assumptions inherent in the method.

Mildura FMA

This assessment is based on the ERS (V5, 19-10-01), THS (26-9-01), and spreadsheet files (9-10-01).

Yield estimates for Mildura FMA are not based on the conventional SFRI-SYSS approach, but rely on cutting cycle analysis. These calculations have not been available for scrutiny, and this assessment is based on the THS. These data do *not* provide an adequate basis for offering long-term timber harvesting commitments.

Area estimates

Area estimates are based on GIS analysis of 1987-1989 data, adjusted for the proposed Forest Management Plan zoning. Flora and fauna protection is accommodated through the land use zoning in the proposed plan. Standard Code of Forest Practice exclusions apply. A 50 m buffer is maintained around cultural sites. No specific adjustment is made for unloggable areas unable to be mapped.

The net harvestable area is only 1% of the gross area of State Forest, an unusually low proportion (cf. the adjacent Mid-Murray FMA with 75%).

Inventory data

Standing volumes indicate that the projected harvest can be sustained for over 200 years, suggesting that the projected harvests are conservative.

Volume estimation

Log measurements during harvesting operations provided the basis for yield estimates.

Yield tables and growth estimates

Growth estimates (0.20 and 0.03 m^3/ha/yr for SQ 1 and 2 respectively) are subjective, but play no part in the variation of cutting cycle analysis use to derive present estimates.

Yield estimates are prepared from the assumption that Productivity Class 1 stands will yield 8 m^3/ha when harvested, and that Productivity Class 2 stands will yield 0.8 m^3/ha from the first harvest, and 3 m^3/ha from subsequent harvests.

Wood flows

A variant of cutting cycle analysis was used to simulate wood flows on a 40-year cycle. The estimated sustainable yield represents 0.07 m^3/ha/yr, and 0.2% of the standing volume, both of which are conservative values.

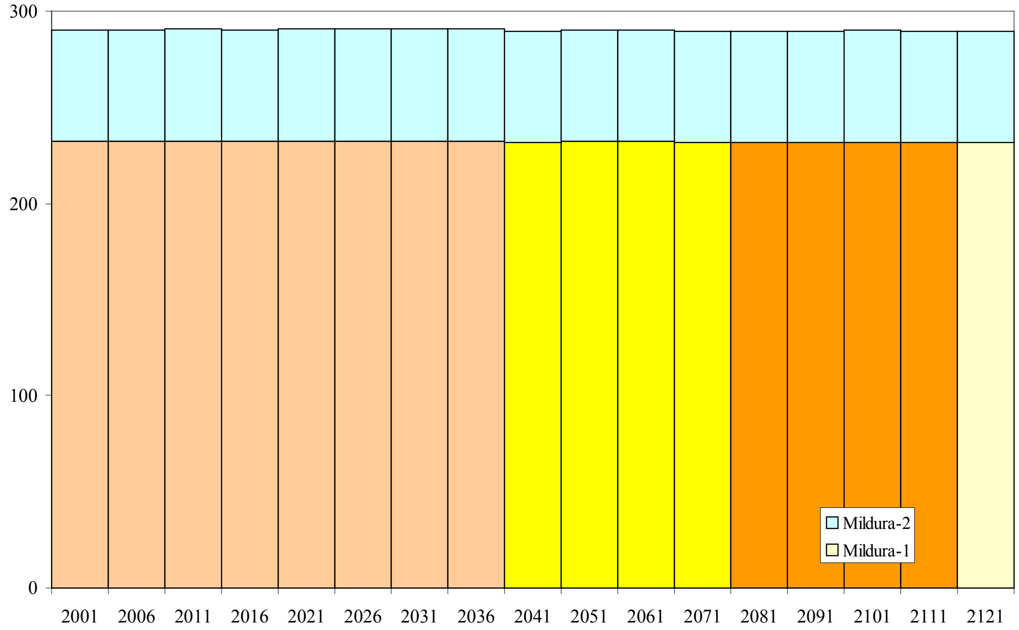

Figure A.8. Simulated wood flows from Mildura FMA (from THS). Note that intervals are represent 5 years during first cutting cycle, and 10 years during the second and third cycles.

Contingencies and scaling factors

No explicit allowance is made for contingencies.

Implications for licence renewal

The present data do *not* provide an adequate basis for making long-term commitments.

North-East FMA

This assessment is based on the ERS (V6, 24-10-01), THS (September, 17-9-01), and SYSS files (v6.1.47, 6-9-01).

Yield estimates for the North-East (Wangaratta and Wodonga excluding the eleven blocks known as North-east Gippsland) FMA are based on SFRI and SYSS, and provide a *reasonable* basis for renewing licence commitments. Large contingencies and unsubstantiated scaling factors detract from the rigour of the estimate.

Area estimates

Area estimates are derived from SFRI-25FS benchmarked to June 2000. Net area estimates are based on variable width buffering of streams (25-30 m), and exclusion of steep slopes (>25-30º) and small "islands" (<5 ha for ash and <10 ha for mixed species forests, nominally representing 800 m^3). Forest stands of species considered to be currently unmerchantable by local staff and industry were excluded from the harvestable area. No additional adjustment is made for unloggable areas unable to be mapped, but a case study with Landsat TM data suggest that 4% of the net harvestable area has no chlorophyll and may not carry merchantable timber. It is assumed that flora and fauna are adequately protected by the zoning provisions of the North East RFA and the North East Forest Management Plan.

Inventory data

Some 271 inventory plots (81 in ash, 190 in mixed forest) were established as part of the North East SFRI project in the Benalla-Mansfield, Wangaratta and Wodonga FMAs. These were supplemented with an additional 37 plots, and the pooled data (308 plots) were used to develop an equation to predict standing volumes. The new equation predicts volumes 34% lower than those predicted by the previous (Benalla-Mansfield) equation, but calibration data (from Tambo and Central Gippsland FMAs; no data available in North-East) suggest that the new equation still overestimates by 24%, and predicted volumes have been reduced accordingly.

Volume estimation

Volumes were estimated using the TREEMAP-VOLCALC approach, and may thus represent optimal rather than operational out-turn. Although volume estimation procedures are rigorous, a formal comparison of predicted versus operational out-turn would improve user confidence in the reliability of estimates.

Yield tables and growth estimates

Ash yield tables were based on STANDSIM, scaled to match the yields of 1939 regrowth. Separate yield tables were compiled for mature and regrowth stands, and were adjusted according to age, height and stand type. Yield tables for mixed species forests (both mature and regrowth) were based on a generalized yield curve scaled to match predictions from the standing volume equation.

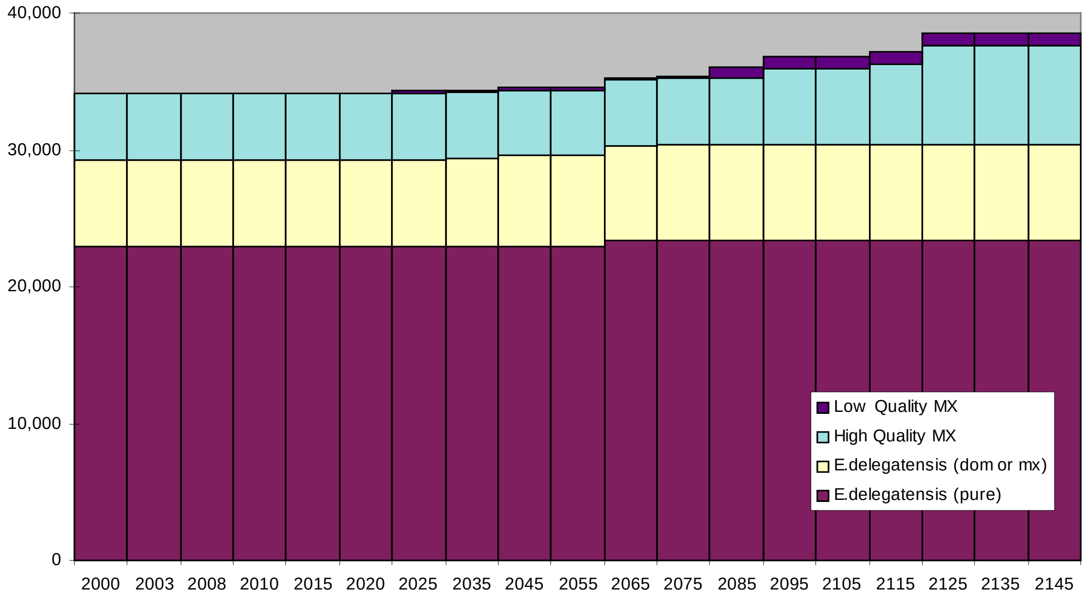

Figure A.9. Simulated wood flows in the North East FMA. Intervals may represent 2, 3, 5 or 10 years.

Wood flows

Wood flows were simulated with SYSS using four 5-year and fourteen 10-year periods to simulate yields for 160 years.

Note that yields simulated during 2000-2 correspond to the non-declining flow, not the actual harvest in 2000-1; this may affect yields during 2003-25.

Contingencies and scaling factors

Contingency allowances include 1.3% for wildfire, 5% for logging waste, and 7% for uncertainty associated with the data and with modelling. Scaling factors include 20% for single short logs, and a 24% adjustment to the standing volume equation. Many other adjustments were made in SYSS (e.g., cutover ash 0.42; under-stocked ash 0.01, low-quality late mature 1.18), but these are likely to have a relatively small effect on the overall yield.

Implications for licence renewal

The analysis provides a reasonable basis for assessing the options surrounding licence renewal. The lack of data concerning log grades and sizes has implications for licence commitments.

Otway FMA

This assessment is based on the ERS (V2, 23-10-01), THS (Draft 3, 6-8-01), and IFPS files (Run 49, 16-3-00).

Yield estimates for the Otway FMA are based on interim SFRI (incomplete benchmark) and IFPS. They do *not* provide an adequate basis for long-term licence commitments. Large contingencies and unsubstantiated scaling factors detract from the rigour of the estimate. SFRI should be completed in 2004 and the yield calculations should be revisited at that time.

Area estimates

Area estimates are derived from interim SFRI data compiled for the RFA process, with an incomplete benchmark to June 1998. Net area estimates are based on buffering of streams and rainforest (20 m and 40 m respectively), and exclusion of steep slopes (>15, 25 or 30º slopes excluded, depending on water supply catchment). Small "islands" (5 ha in ash and 8-15 ha in mixed species forest) were also excluded. It is assumed that flora and fauna are protected adequately by the SPZ and SMZ provided in the West RFA. No explicit adjustment was made for unloggable areas unable to be mapped, but an adjustment of 21-24% (mixed species and ash respectively) was made to account for the discrepancy between predictions and areas actually worked over (based on an analysis of areas recently logged). Despite this reduction, the final net area still represents 47% of the gross area of State Forest.

Inventory data

Estimates of standing volumes were derived from HARIS and local harvesting data. Some 442 inventory plots (ash only) exist in the Otway, but were not used in the present calculations.

Volume estimation

Ash volumes are presumably based on STANDSIM volume equations developed for the Central Highlands, while volumes of other species would have been based on the State-wide eucalypt volume table EVTAB.

Yield tables and growth estimates

Yield tables were based on estimates used by ANU's Centre for Resource and Environmental Studies (CRES) in a FORPLAN model developed in 1988-1990. The source and reliability of these yield tables is not documented, but it appears that ash and messmate yields were based on STANDSIM projections and that other yields are based on assumed MAIs.

A comparison of actual and predicted volumes in 30 coupes indicated that the current yield tables over-estimate the volume of Mountain Mixed Species by about 40%, but underestimate the volume of Mountain Ash and Foothill Mixed Species by 24% and 62% respectively. Corresponding adjustments to the predicted yields may be excessive, given the small size of the sample, the variability within the data, and the magnitude of the adjustments involved.

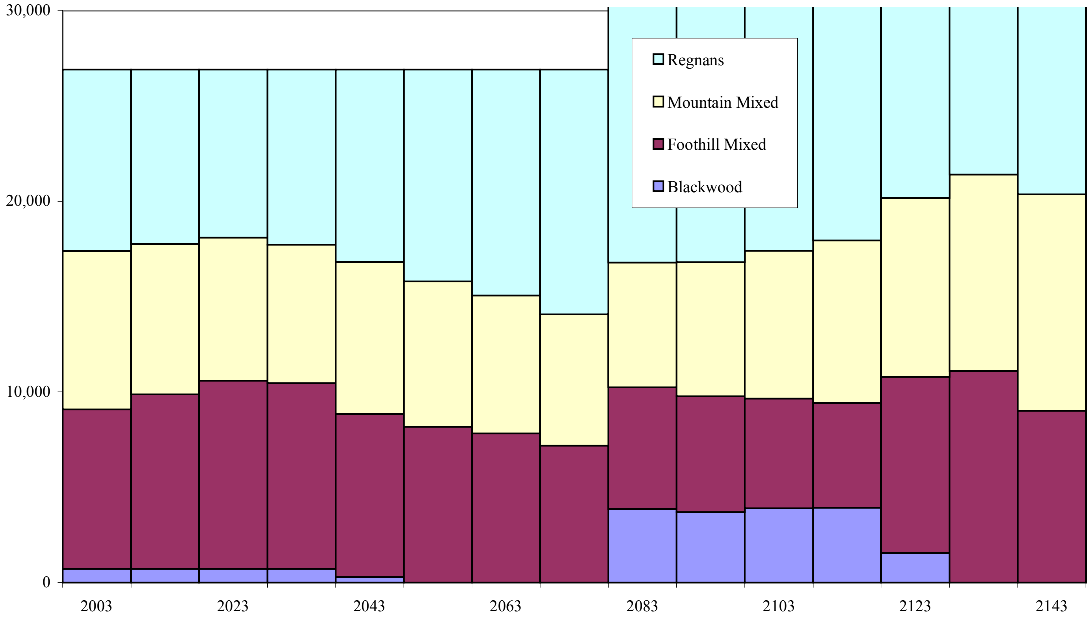

Figure A.10: Wood flows in Otway FMA, based on an area of 45606 ha (not the area currently assumed harvestable) and a 10% contingency allowance.

Wood flows

Wood flows were simulated with IFPS (Figure A.10), seeking to maximize the present net value of the wood flow (discount rate not stated). Note that prognoses include a fluctuating volume of blackwood, which is subject to different licensing arrangements.

Contingencies and scaling factors

Contingency allowances include 1.6% for wildfire, and 10% for other uncertainties. Scaling factors include an area adjustment (21& 24% for mixed species and ash respectively) and a volume adjustment (71,132 & 263% for MMS, MA and FMS respectively). The resulting estimate is 89% of the primary estimate for ash, and 50-184% for MMS and FMS respectively. The 10% contingency is not supported with empirical data, and the scaling factors are not statistically significant.

Implications for licence renewal

The data at hand do not provide an adequate basis for making long-term commitments. The area estimates appear to be the weakest component in the analysis. Benchmarking of SFRI for the Otway will be completed soon, and estimates should be revised when final SFRI data are available. The yield table also warrants further attention.

Portland FMA

This assessment is based on the ERS (V4, 19-10-01), THS (Draft 2, 29-6-01), and spreadsheet files (option 3 proposed 2307, 10-10-01).

Yield estimates for Portland FMA are based on SFRI and cutting cycle analysis. These estimates must be viewed as approximate and subject to revision, because of assumptions made in initializing the analysis, subjective growth estimates, and because there has been no documented attempt to check the reliability of predictions. Large contingencies and unsubstantiated scaling factors detract from the rigour of the estimate. The present data do *not* provide an adequate basis for offering long-term commitments.

Area estimates

Area estimates are derived from interim SFRI data (with an incomplete benchmark of June 1998), compiled for the RFA process. The net area excludes 20 m buffers along permanent streams and swamps, and 10 m buffers along minor streams in erosion prone areas. There are no slopes over 30^{o}. Some small "islands" (totalling 8 ha) of productive resource were excluded. It is assumed that flora and fauna are adequately protected by SPZ and SMZ created by the West RFA, and that half the SMZ will be available for timber harvesting. No specific adjustment was made for unloggable areas unable to be mapped.

Inventory data

SFRI inventory data are not yet available, so the Portland SFRI reports only species-height and growth stage, without volume assessments. Some 342 inventory plots were established within the FMA prior to 1986, but these have not been used in preparing the present yield estimate. In the present situation where the short-term supply may be problematic, estimates of the present standing volume are critical, as they determine harvesting options in the short-term.

Volume estimation

Yield tables are apparently based on log measurements during operational harvesting

Yield tables and growth estimates

Cutting cycle analyses rely on eight forest types defined by stand height (18-22, 22-28, 28-33 m) and proportion of messmate (25-50, 50-75, >75%). Each of these types may be allocated different yield (corresponding to PAIs 0.1-1.5 m^3/ha/yr) from and rotation or cutting cycle length (for even- and uneven-aged stands respectively). These PAIs are at odds with those stated elsewhere (THS, Table 12, 0.3-0.7 m^3/ha/yr).

Stands with no documented harvesting history are assumed to be of low productivity, and predicted yields are multiplied by the scaling factor 0.2. Conversely, it is assumed that following a regeneration cut, subsequent yields will be higher, and these are scaled by 2.5, based on field estimates.

These estimates are subjective, based on assumptions made in previous calculations and on the observation that 1 m3/ha/yr had been recorded on good sites with even-aged stands that

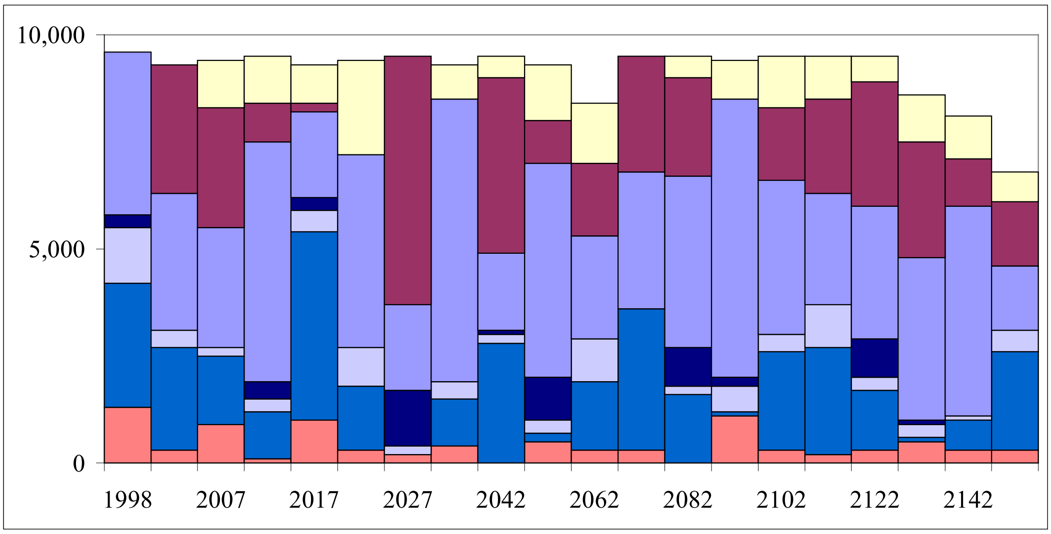

Figure A.11. One of several scenarios showing anticipated wood flows for Portland FMA. Note that the time intervals are not equal, and may represent 4, 5 or 10 years.

had been silviculturally treated. While the order of magnitude of these assumptions seems reasonable, they do not provide a basis for firm long-term commitments.

Wood flows

Cutting cycle analysis has been used to predict wood flows. It appears that substantial multipliers have been applied in the cutting cycle analyses (e.g., 0.2), but full details have not been made available. No-attempt has been made to simulate even wood flows (see Figure A.11).

Contingencies and scaling factors

A 10% contingency has been applied to sawlog yields, to allow for the limited data set, and structural differences within the forest due to previous harvesting, which are difficult to account for in a simple analysis. The Timber Harvesting Strategy also advocated a further 5% contingency for potential wildfire losses.

Yields predicted from some stands may have been scaled by 0.2 or 2.5.

Implications for licence renewal

As the yield calculation includes several subjective elements, it seems likely that any subsequent revision may lead to different estimates. There is no objective basis to assess the whether current commitments can be sustained for another similar period, or whether yield estimates may change substantially in the future.

Tambo FMA

This assessment is based on the ERS (V6, 24-10-01), THS (August, 4-9-01), and SYSS files (v6.1.46, 20-9-01).

Yield estimates for Tambo FMA include the eleven blocks from Wodonga known as North-east Gippsland. The estimates are based on SFRI and SYSS, but because of the subjective nature of growth estimates, offer a *weak* basis for long-term timber harvesting commitments.

Area estimates

Area estimates are derived from SFRI-25FS benchmarked to June 2000. Net area estimates are based on 30 m buffering of streams, and the exclusion of steep slopes (>25-30º) and small "islands" (< 7ha). Stands of species considered to be currently unmerchantable by local staff were excluded from the harvestable area. It is assumed that the SPZ and SMZ created by the Gippsland RFA make adequate provision for flora and fauna protection.

Inventory data

Some 224 inventory plots were measured in Tambo FMA as part of the SFRI project. These plots were pooled with plots in Central Gippsland FMA (823 plots in all) and used to develop an equation to predict standing volume by aggregate forest types.

Estimates of standing volume indicate a standing volume of 1.9 million cubic metres of D+ sawlog.

Volume estimation

Volumes were estimated using the TREEMAP-VOLCALC approach, and may thus represent optimal rather than operational out-turn. No adjustment was applied to account for trees with single short logs, as it was assumed that these would be harvested due to the capacity to sell residual logs from these trees.

Calibrated standing volume estimates were checked against operational yields from 125 coupes totalling 2300 ha and were found to predict 90% of the harvested volume. The 10% discrepancy is attributed in part to coupe selection bias, but no empirical evidence of coupe selection bias is presented.

Yield tables and growth estimates

Yield tables were based curves developed for the North-East FMA, adjusted to match the MAIs reported in the 1986 Timber Industry Strategy (which were apparently based on expert opinion). For ash, this means that the guide curve achieves a MAI of 2.0 at age 60. While this provides estimates consistent with previous work, it introduces a subjective element and detracts from the rigour of the analysis.

A number of additional adjustments were made for particular stands (e.g., stands harvested since 1985 but without regrowth have 1% of nominal volume; FMS stands regenerated prior to 1985 have 30% of nominal volume – due to selection logging).

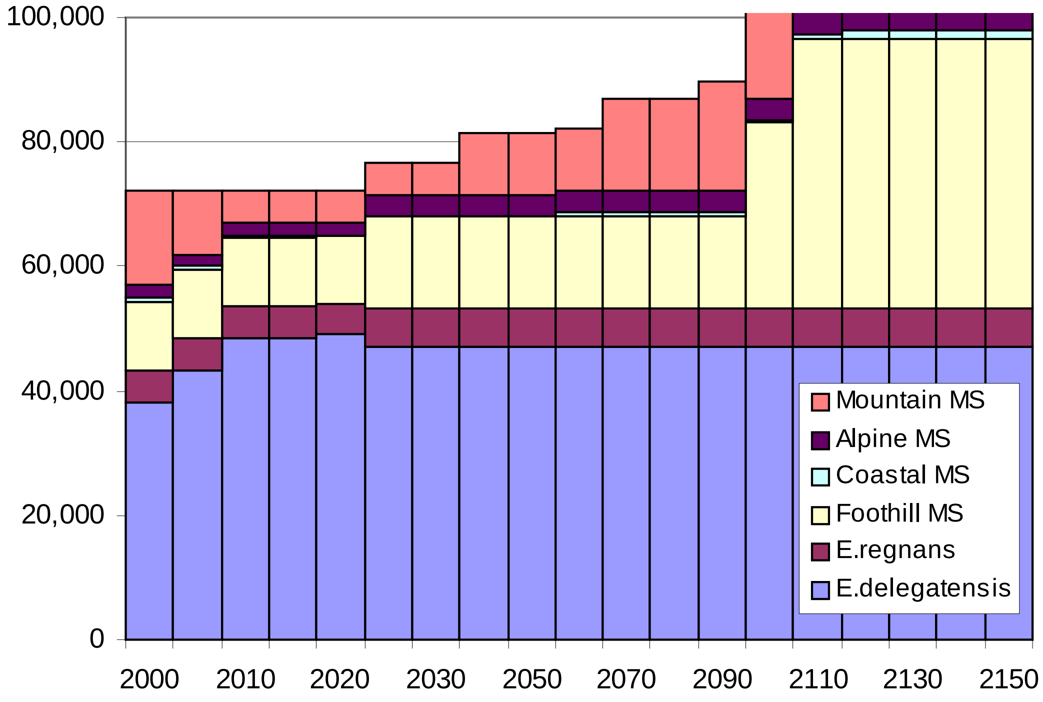

Figure A.12. Predicted wood flows for Tambo FMA. Intervals may represent 5 or 10 years.

Wood flows

Several scenarios were explored with SYSS using six 5-year and fourteen 10-year periods to simulate yields for 170 years. Figure A.12 illustrates a scenario that assumes only partial RL availability and satisfies current commitments in the short-term.

Contingencies and scaling factors

An allowance of 0.9% was made for wildfire in ash and high elevation mixed species and 2.7% for coastal and foothill mixed species. In addition a 15% contingency allowance was applied for uncertainties in estimating operable areas.

Implications for licence renewal

The analyses offer a weak basis for making long-term commitments. The weakest component of the analyses is the yield tables, which rely on several subjective inputs.

Annex 3 – Summary of key data by FMA

This annex summarizes the status of each FMA with regard to the following issues:

1 Overall and methodology issues
1.0 Nature of estimate (e.g., IFPS & SYSS)
1.1 Has an error audit been completed?
1.2 Changes in data and/or resource since previous estimate
1.3 Year of previous substantive assessment
1.4 Legislated Sustainable Yield (*Forests Act*)
1.5 Estimated Sustainable Yield (m^3/yr)
1.6 Change in sustainable yield estimate (%)
1.7 Licensed Volume (m^3/yr net)
1.8 Overcommitted volume (m^3/yr)
1.9 Overcommitted proportion (%)
1.a Sustainable yield per unit area (m^3/yr /ha)
1.b Sustainable Yield per unit growing stock (%)
1.c How long can the standing volume sustain the sustainable harvest (ignore growth; years)
1.d Overall assessment

2 Area estimates
2.0 Source of area data
2.1 Gross area of State Forest (ha)
2.2 Productive area after *Code of Forest Practices* & zone exclusions (ha)
2.3 Spatial adjustments: Stream buffers, slope exclusions & rainforest margins
2.4 Non-spatial adjustments: Adjustments for unmapped exclusions (e.g., rocky areas)
2.5 Any provision for flora & fauna additional to RFA/FMP zoning
2.6 Threshold for "islands" too small to work
2.7 Net harvestable area
2.8 Net harvestable area as % of gross area
2.9 Assessment of area estimation

3 Stand volume estimates
3.0 Standing volume (Million m^3)
3.1 Approach used to estimate
3.2 Local inventory plots used
3.3 Error % for estimated standing volume
3.4 Bias in stand volume estimates
3.5 All forest types equally well represented?

4 Tree volume estimates
4.0 Estimation of tree volumes: via volume equations or simulated merchandising?
4.1 Source of the volume data and general applicability
4.2 Compare prediction against out-turn
4.3 Allowance for defective stems, sections, and inclusions?

5 Yield Table
5.1 Yield table or growth model used to forecast timber yields
5.2 Number of yield tables used
5.3 Source of yield table
5.4 Plots used in compiling yield table or model
5.5 Do plots reflect current management regimes and practices?
5.6 Compare prevailing stand conditions with data used to develop model
5.7 Result of testing yield table or growth model in this region
5.8 How is site quality accommodated?
5.9 Assessment of volume estimation

6 Harvest Scheduling
6.0 How are yields scheduled?
6.1 Planning horizon (years)
6.2 Number of analysis units
6.3 Minimum rotation or cutting cycle (years)
6.4 Simulation approach: operational, prescriptions, or optimal?
6.5 Basis for girth limits, marginal yields/ha, species mix, and any other limits applied?
6.6 Compare predictions against out-turn from recent operations
6.7 Assessment of scheduling methodology

7 Practicalities
7.0 Are entitlements run-of-the-bush, or prescribed by species and/or grade?
7.1 Are defect allowances and minimum log sizes in simulations realistic and practical?
7.2 Do operations follow predicted schedules?
7.3 Document contingencies & other allowances
7.4 Total of contingencies and scaling factors
7.5 Contribution of contingencies not fully substantiated (e.g., statistically significant)

8 If entitlements specify grades…
8.1 How are log grades estimated?
8.2 Assumed proportion D grade (as % of D+)
8.3 C+ in current out-turn (%)
8.4 C+ grade annexures as % of licensed sawlog volume
8.5 Ash annexures as % of licensed sawlog volume

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