AN APPRAISAL OF METHODS AND DATA USED BY QDPI FORESTRY TO ESTIMATE WOOD RESOURCE YIELDS AS A PART OF THE RESOURCE ASSESSMENT FOR SOUTH-EAST QUEENSLAND

QUEENSLAND CRA/RFA STEERING COMMITTEE

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BUREAU OF RESOURCE SCIENCES

DEPARTMENT OF NATURAL RESOURCES

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FOREWORD

This is the report for the project 'Appraisal of methods and data used to estimate wood resource yields' prepared by Dr Brian Turner of the Australian National University. It is the product of a consultancy undertaken for the Bureau of Resource Sciences, Department of Primary Industries and Energy, based on the terms of reference that are included at the end of this report. The terms of reference were agreed to by project officers of both the Commonwealth Department of Primary Industries and Energy and Queensland Departments of Natural Resources and Primary Industries-Forestry. Dr Brian Turner is an independent expert consultant who was selected through a competitive selection process.

The project officers were:

- Mr Malcolm Taylor, Department of Primary Industries–Forestry, who provided presentations and written information, arranged access to other DPI-F staff and to forest resource systems, and provided comment on the draft report.

- Mr Jim Burgess, Department of Natural Resources, who assisted with the development of the terms of reference for this consultancy and provided comment on the draft report.

- Dr Dan Sun, Bureau of Resource Sciences, who managed the consultancy, provided advice on the Commonwealth's requirements on the project, and commented on the draft report.

The report has highlighted both the strength and limitations of the wood yield calculation methods used by DPI-F, and identified future research and development priorities.

This report forms the basis for the Commonwealth's accreditation of sustainable yield forecasting and data for the Regional Forest Agreement in south east Queensland.

The Commonwealth and Queensland governments wish to acknowledge Dr Turner's effort and diligence in preparing this report.

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The following have contributed information and ideas for this report and that assistance is gratefully acknowledged:

In QDPI(F):
Chris Bragg
Jane Siebuhr
David Mannes
Brian McCormack (for Figure 1)

In QDNR:
Jim Burgess

In BRS:
Dan Sun

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EXECUTIVE SUMMARY

This report is an appraisal of the methods and data used by Queensland Dept of Primary Industry Forestry (QDPI(F)) to estimate wood yields from native forests in south-east Queensland (SEQ). The appraisal represents part of the resource assessment of this region in accordance with the need for a Comprehensive Regional Assessment prior to a Regional Forest Agreement.

The system devised by QDPI(F) comprises three databases: the Area Information System, the Native Forest Inventory and the Native Forests Permanent Plot System, and various derived models. The simulation model (**sked**) incorporating these and related predictive functions provides a means of simulating future growth and removals under various levels of harvest to see whether they are sustainable.

Area information is handled through the Area Information System (AIS). State forests within an allocation zone are subdivided for management purposes into Management Units (MUs) and these into Sub Units (SUs). MUs are logical sale units; SUs represent homogeneous areas within a MU. Previous reviews in 1992 and 1996 expressed concern about the relatively poor accuracy of Sub Unit area estimates. Despite some improvement, there are still serious problems in estimating net harvestable areas. The difficulties in the estimation of net areas are in part a result of the selection management systems used, which mean that harvest unit boundaries are diffuse in space and time. In addition, it is conceivable that the reductions in harvestable area over time are real, reflecting increasing attention being paid to environmental and ecological protection. Of concern is that there continues to be no direct link between this database and a GIS to provide a check on area estimates.

The current status of the forest (Native Forest Inventory) is determined by sampling the forest within Sub Units. The aim is to have at least two plots located within each Sub Unit; where this is not possible, plots are 'shared' from similar nearby Sub Units, a practice considered an interim measure. Despite the improvement from 76% of shared plots in 1992 to 56% in 1997, still more than half the Sub Units are represented in the database by plots, which are only subjectively attributed to them. An active inventory program allows old plots to be retired as new ones are measured and the current database consists mostly of plots measured in the last few years. Eighty percent of the current database of about 8300 plots are less than ten years old.

Previous reviews have found that realised volumes from logging sales have been less than assessed volumes from plot measurements. To compare actual harvested volumes with estimates from inventory measurements, the outcomes of 58 Management Units logged over 1992-97 were reviewed. On average, using the most recently determined net areas, pre-logging inventory

estimates and new volume models, the estimates were greater than the actual volumes by about 14%.

A new database of about 5000 trees has now been accumulated for checking models used for estimating volumes of standing trees through a 10% sample of trees marked for removal. Until all these data are analysed in depth it can only be hypothesised that most of the differences between realised and predicted volumes are due to a combination of factors, including estimating the merchantability of the standing trees and the increasing tendency to retain trees for various purposes.

Past growth is estimated by remeasurement of permanent plots. There has been a progressive rationalisation of plots to remove redundant plots and add new ones in a more representative sample of the forest sites. There are now about 410 permanent plots in the database as opposed to 290 in 1992, but the consequence of this rationalisation is that many of them have only the initial measurement. Most permanent plots are remeasured every five to six years. It represents a unique set of data in its representativeness.

The basic premise of growth, mortality and recruitment prediction is that cohorts of trees can be characterised by logistic models to predict the proportion of trees changing diameter classes or merchantability classes, from living to dead, etc., and the probability of recruitment occurring. There has been some validation of these models in recent years but not in a systematic manner.

The **sked** prediction system grows the forest annually and imposes a harvest when defined criteria (such as minimum operable area and log size) are met. MUs may either be cut on a regular time cycle (the cutting cycle) or when required to meet an imposed annual harvest. It is assumed that if a number of key indicators examined have reached a steady state within a hundred years or so, the input constant allowable cut is sustainable.

Sensitivity analysis can be used to test the responsiveness of the models to changes in minimum log size, minimum loggable areas, etc. Simulations conducted previously suggest that the harvest levels at which steady state conditions are reached are not very sensitive to minor variations in mortality and recruitment despite some concerns about these functions.

Yields of products other than sawlogs such as poles and pulpwood will be able to be simulated using methodologies under development. Models for total wood fibre potential are to be developed under a RFA project.

The simulator **sked** can be run in stochastic mode meaning that the growth, survival, recruitment and merchantability-change models are subjected to chance perturbations. From a large number of iterations, the likely distribution of the final outcomes can be assessed. Stochastic simulation using Central Qld data showed a dispersion in allowable cut of a few percent in the near future increasing to a range of about 30% at 100 years.

The likely impact of Ecologically Sustainable Forest Management (ESFM) considerations on the yield prediction system has been addressed in terms of stream buffers, wildlife corridors and other informal reserves, steepness, rock outcrops, etc., and silvicultural regime modifications.

Several items have been identified where further analysis or investigation would be expected to lead to improved accuracy and value of sustainable yield estimation. These are: alternative methods for estimating net areas, alternative methods for estimating merchantable volumes, modifications to the yield simulator, modifications to the allocation zone basis of yield estimation and addressing ESFM concerns.

There are many assumptions built into this kind of a yield projection system. The most significant is probably that the future can be adequately modelled by the past. While the form of the models developed for SEQ are such that minor extrapolation is probably safe, the growth models may not be able to accurately simulate major alterations to the past harvesting patterns.

The system developed over many years to estimate sustainable yields in SEQ by QDPI(F) is unique, well conceptualised, and includes models, which are of world class and are based on a very large database for a natural forest. The simulator is quite flexible and is able to reflect better than most the many constraints operating in the real world. Residual problems with data quality, which are being addressed, should not be allowed to overshadow the overall high utility of the yield prediction system for strategic planning.

An Appraisal of Methods and Data used by QDPI Forestry to Estimate Wood Resource Yields as a Part of the Resource Assessment for South-East Queensland

by

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1. Introduction

This report is an appraisal of the methods and data used by Queensland Dept of Primary Industry Forestry (QDPI(F)) to estimate wood yields from native forests in south-east Queensland (SEQ). The appraisal represents part of the resource assessment of this region in accordance with the need for a Comprehensive Regional Assessment prior to a Regional Forest Agreement. It should be noted that the region for CRA/RFA purposes is not coincident with the QDPI(F) Region in that the former includes some coastal parts of the Central Region of the QDPI(F).

2. Conduct of this Consultancy

In accordance with the Terms of Reference for this consultancy I have worked with the Bureau of Resource Sciences (BRS), QDPI(F) and Queensland Dept of Natural Resources (QDNR) to develop a works program for an appraisal of wood yield methods, data and ecological sustainable forest management (ESFM) considerations. This review supplements and updates previous reviews including some in which I have been involved, in particular Turner and Ferguson (1992) and Turner (1996).

In this report I comment on the following:

- the basis of QDPI(F)'s calculation of native forest wood yields
- methods and data used, including capacity to accommodate various management systems
- accuracy of predictions, and strengths and weaknesses of methods and systems
- appropriateness of datasets and systems as compared with other Australian approaches
- expected reliability of yield forecasts from the system as a whole.

I have also identified priorities for future R&D to improve yield calculation methods, including ESFM considerations. It was intended that I seek input from members of the ESFM Expert Panel for SEQ and comment on the capacity of the systems to meet their concerns, but this group has not yet been formed. However comments on an early draft of this report have been received from two parties with ESFM concerns and responses to their concerns have been included in this version .

3. Broad Methodology of the Review

In the course of this consultancy I have conducted an evaluative review of the appropriateness of the datasets, models, systems and methodology used in the calculations of the sustainable yield of wood products from public native forests in south-east Queensland, including the capacity of models to accommodate different management systems. This has been done primarily through review of documents and interviews with those responsible for making the yield calculations in QDPI(F).

The four components of the yield estimation system are:

3.1 Datasets:

Among the datasets which have been evaluated are the following:

- Forest area estimation and means of stratification, including API procedures for the native forests
- Current growing stock statistics - as derived from forest inventories or other means
- Estimates of past growth of forests as derived from permanent plot measurements and perhaps other methods
- Measurements of actual removals from forests and comparisons with standing volume estimation

3.2 Models:

Mathematical models evaluated for their applicability and accuracy include:

- Models for estimating volumes of standing trees
- Models for predicting growth and mortality of forests under various conditions
- Models for estimating product outturn from predicted gross volumes

3.3 Systems:

Computer and other systems critically reviewed include:

- Computer systems used to project forest statistics into the future and to take into account constraints on the predictions
- Systems set up to verify and validate predictions from growth models
- Systems used to keep area and growing stock statistics current

3.4 Methodology:

The methodology used in various parts of the sustainable or continuing yield calculation process has been evaluated. This includes:

- Sampling methods used to gather data for input to the systems, including growing stock information, growth information and removals information
- Actual methods used to calculate sustainable yields including an evaluation of the underlying assumptions
- Methods used to estimate the reliability of the predictions

My approach has been to review all relevant documentation, to request verbal explanations where information is found to be missing or obscure and then to evaluate each component against my knowledge of current best national and international practices. Strengths and weaknesses of the various components are indicated in the report and the expected reliability of the estimates are commented upon.

4. Basis of QDPI(F)'s calculation of native forest wood yields

The major purpose of the calculation of native forest wood yields by QDPI(F) is to help set every five years the annual allocations of sawlogs to Crown sawmills within timber Allocation Zones of which there are 13 in the SEQ Region. The method by which this is done is to project wood production on the forests in each allocation zone, with reductions for harvesting, about 100 years into the future and examine the trends in a number of indicators as to their sustainability. Sustainability of such indicators as total standing volume, size of removed sawlogs, etc., is indicated by the attainment of a steady state condition. This then is the definition of sustainable yield used by QDPI(F).

It is not the role of this consultancy to criticise this definition nor its implementation. However it has been indicated elsewhere (e.g., by Turner and Ferguson, 1992) that this is an acceptable approach to what is quite a difficult problem, i.e., the definition of sustainable yield for forests managed under uneven-aged selection-type regimes as are used in most of the managed native forests of SEQ. For forests managed under even-aged systems the maximum long-term sustainable yield can be estimated by assuming a balanced series of age-classes and full stocking of stands within them. This is not possible where ages are not easily defined because of the nature of the harvesting system, viz., one where stands are not clearfelled but are revisited several times (according to “cutting cycles”) in the lifetime of an individual tree.

The usual approach is to try to define some desirable structure (e.g., a negative exponential distribution of trees over diameter size classes) of such forests and then design harvesting rules so that this structure is approached over time. In Queensland these harvesting rules have been modelled and used in the simulator, which then applies them to the growing forest estate. If the structure is not being approached it will show up in the simulations as a deviation from a steady state condition of selected indicators. The maximum sustainable yield will be the highest constant yield that can be applied without a deviation from steady state conditions.

The system devised by QDPI(F) comprises three databases and various derived models, all of which come together in a simulator. The three database systems are:

1. the Area Information System, a module for storing and retrieving area estimates,

2. the Native Forest Inventory, a module for storing and retrieving data on standing timber, and

3. the Native Forests Permanent Plot System [1], a module for storing and retrieving growth and related data.

The latter (together with silvicultural research plots) provides the basis for a series of predictive functions that can be used to simulate removals, growth, mortality and ingrowth and so bring Native Forest Inventory plots up-to-date or to predict future behaviour. The simulation model (**sked**) incorporating these and related predictive functions thus provides a means of simulating future growth and removals under various levels of harvest to see whether they are sustainable. The relationships among these are shown in Figure 1.

5. Datasets

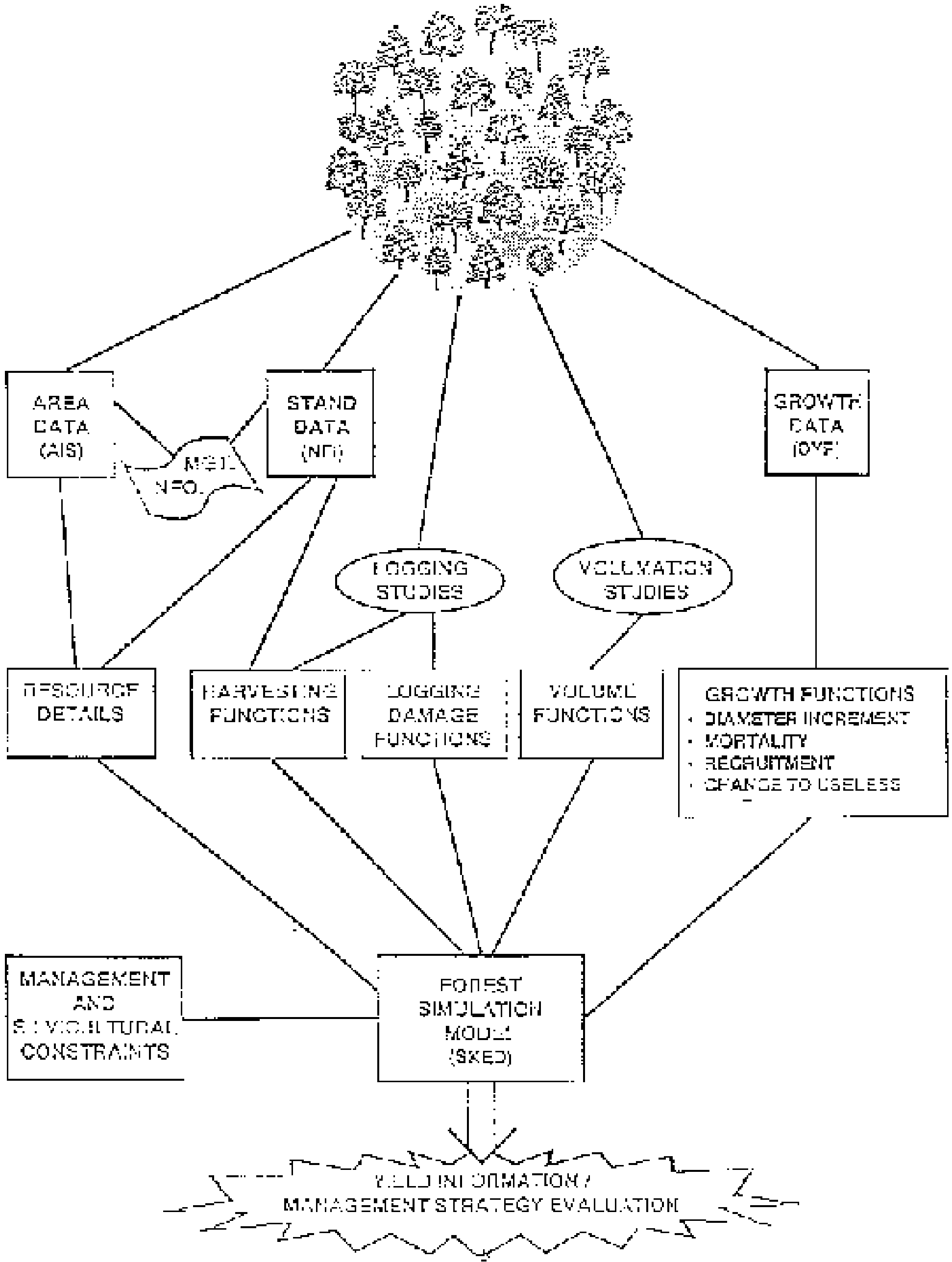
As indicated above there are three basic datasets which provide input to the yield prediction system. In addition there are some derived and ancillary datasets. These are now described in more detail.

5.1. Forest area estimation

Area information is handled through the Area Information System (AIS). State forests within an allocation zone are subdivided for management purposes into Management Units (MUs) and these into Sub Units (SUs). MUs are logical sale units, the boundaries of which are geographically fixed by roads or topographic features. SUs are typically of a single forest type and represent homogeneous areas within a MU. Their boundaries may change over time, following harvesting or other major changes. In SEQ, typical sizes of MUs and SUs are respectively of the order of 300 and 50 ha although the range of SU sizes is from a few hectares to over 250 ha. Most of the SUs on which timber production occurs are at the upper end of this range.

[1] Formerly called Detailed Yield Plots

Fig. _ DECISION SUPPORT SYSTEM
FOR
NATIVE FOREST RESOURCE MANAGEMENT



Area data are stored on a HO mainframe computer (database is written in Progress 4GL), to which all districts have on-line access. The basic unit of data capture is the Sub Unit. For each Sub Unit, the following data are stored:

- gross area
- accuracy statement for area rated on a scale from 1 to 5
- percentage reduction factor to estimate net area, to account for non-productive land or forest which is non-harvestable
- productivity, access and management intent classifications
- type of logging likely next harvest
- forest type (floristic/structural)
- historical data
- standing and loggable volumes per hectare and accuracy estimate rating for these (on 1-5 scale)
- identification numbers of Native Forest Inventory plots either in the Sub Unit or 'shared' from nearby Sub Units of the same forest type and structure (McCormack, 1988)

The review of 1992 expressed concern about the relatively poor accuracy of Sub Unit area estimates (Turner and Ferguson, 1992, p.13). Turner (1996) indicates that the poor estimation of the net area of Sub Units was identified as a major reason for the need to reduce quotas in the Central Qld region. For example in two allocation zones the net area estimates dropped 20-25% between 1991 and 1996. It was noted in summary that "the accuracy of the estimates of net areas of productive forest is improving but is still of concern". (Turner, 1996, p. ii) That report recommended a campaign to upgrade the accuracy of area estimates in the SEQ Region and that apparently has happened. Table 1 shows the current status of gross area estimates in the SEQ Region as compared to earlier estimates for the whole of Queensland. It shows that the current situation for SEQ is better than the state average in 1996, which was appreciably better than the situation in 1992.

My understanding is that the improvement of accuracy of area estimates has become a high priority of districts. Progress has been accelerated by the use of GPS, and it is proposed to gather data in the future using differential GPS (higher accuracy) wherever possible. Despite this there are still serious problems in estimating net harvestable areas. Preparation of the new estimates of quotas for the SEQ Region has shown that reductions in net areas (up to 30% in some allocation zones, due to changes in operability, species acceptance, etc.) have been a major reason for reductions in recommended quotas. This is further reviewed later.

A cause for concern is that there continues to be no direct link between this database and a GIS. While this in itself would not necessarily lead to improved area accuracy, the consistency in record-keeping of the GIS has been found by other forestry organisations to be an effective discipline. Even though most districts have digitised their Management Unit boundaries, not many of the Sub Units have been digitised. There still seems to be some corporate reluctance to fully embrace the GIS technology, which is surprising given the effectiveness of its use in project-level analyses such as the Wet Tropics, Fraser Island and the Conondales.

TABLE 1. Distribution of Areas of Sub Units for State Forests (percentage of total), Available for Logging, by Accuracy Classes

Accuracy Class	**State Forests 1992 (from Turner & Ferguson, 1992, Table 1)**	**State Forests excl. Nth Qld 1996 (from Turner, 1996, Table 1)**	**SEQ Region 1997**
1-Surveyed boundaries	4	4	4
2-Low intensity assessment	33	31	44
3-Thorough field inspection	26	40	37
4-General field inspection	15	15	9
5-Rough estimate	23	10	6

5.2 Current growing stock statistics

"The current status of the forest (Native Forest Inventory) is determined by sampling the forest within Sub Units. The most common method is to use a random cluster of temporary variable radius (prism) plots within Sub Units. The aim is to have at least two plots located within each Sub Unit; where this is not possible, plots are 'shared' from similar nearby Sub Units." (Turner and Ferguson, 1992, p. i)

On the plots are measured the species, diameter at breast height over bark (dbhob), product/quality code and merchantable log length of all live trees above 10 cm dbh which are within the 'plot' (McCormack, 1989). Stems which are likely to be removed in the next harvest cut are so noted ("visual thinning"). No non-timber attributes are recorded. A basal area factor of 2 to

5 is usually used, the aim being to sample a minimum of 30-35 trees in 6-10 sub-plots. The starting point of plots are now marked in the field so that a random sample of them can be check measured. Since this procedure was adopted the accuracy of plot measurement has been found to be high. This is in contrast to plots which were installed several years ago and were able to be relocated and checked.

The practice of using 'shared' plots for Sub Units lacking actual plot data has been considered an interim measure and high priority is being given to replacing them with measured plots. All areas of the SEQ forest except very low productivity classes are now covered by measured or shared plots. This represents a considerable improvement over the last few years. Despite the improvement from 76% of shared plots in 1992 to 56% in 1997, these figures indicate that more than half the Sub Units are represented in the database by plots which are not actually on those areas but which have been subjectively determined to represent them. This is commented on further later.

In 1992 Turner and Ferguson (1992) noted that much of the database consisted of plots measured many years before, even 20 or more years ago. As new plots have been measured these old ones have been retired and the current database consists mostly of plots measured in the last few years (see Table 2). Since these will reflect current merchantability standards, they will provide much more accurate predictions. By way of comparison, in 1992 there were about 3900 plots (28% of the total number of plots) in the SEQ database less than ten years old whereas today there are about 7500 plots (90%) less than ten years old.

TABLE 2. Age Distribution of Native Forest Inventory Plots for SEQ Currently Held in Database

Year of measurement	No. of plots	Percentage of plots
Pre 1980	245	3
1980-89	535	6
1990-95	5434	66
1996-97	2064	25
TOTAL	8278	100

5.3 Estimates of past growth of forests

Past growth is estimated by remeasurement of permanent plots (the Permanent Plot System). Since the report of Beetson and Nestor (1992) there has been a progressive rationalisation of plots to remove redundant plots and add new ones in a more representative sample of the forest sites. This was initially based on topoclimatic zonation, but following the recommendations of Turner and Ferguson (1992), geologic parent material is now included in the stratification. There are now about 410 permanent plots in the database as opposed to 290 in 1992, but the consequence of this rationalisation is that many of them have only the initial measurement.

Most permanent plots are remeasured every five to six years. "In hardwood forests, Detailed Yield Plots are 0.5 ha in size.... Attributes measured have been described in detail in Beetson and Nestor (1992). They include diameter at breast height over bark, total height, species, stem class, merchantable height and crown class.... A subsample of small trees were measured on sub-plots. Plot characteristics are also recorded in detail. Most of the Detailed Yield Plots received the same cultural treatments (including logging) as applied to the surrounding forest and records were kept of those treatments. Tree locations were mapped in about 60 plots." (Turner and Ferguson, 1992, p.23) Procedures for location and measurement of permanent plots have been documented (QDPI Forest Service, 1994; QDPI Forest Service, 1995; Cant, 1997).

The effort put into the design and measurement of this set of growth plots is commendable and it represents a unique set of data in its representativeness. Some of the plots abandoned in the rationalisation process are being maintained by QDNR for monitoring purposes.

5.4 Comparison of standing estimates of volume with actual removals

Turner (1996) found that the loggable volume per hectare was significantly less in some Central Qld allocation zones in 1996 as compared to 1991 (by 48% in one case) and recommended that following harvest, removed volumes should routinely be compared with assessed standing volumes from inventory plots on the Unit. This is now being done.

For this consultancy, QDPI(F) analysts reviewed the outcomes of 58 Management Units which had been cut over since 1992. This represents most of the MUs fully cut over in that period. Results are displayed in Appendix A. A summary follows:

Total area from the current database	21 038 ha
Total area according to the 1992 database	25 146 ha
Reduction in harvestable area 1992-97	16%
Total actual volume removed in harvesting	134 724 m^3
Total estimated volume available using 1992 data	212 810 m^3
Total estimated volume available using old inventory data with new volume models and updated net areas	152 986 m^3
Overestimation using new models and areas	14%
Ratio of actual volume to that predicted by best data (average)	88%
Range of actual volumes to best predictions by individual MUs	9% to 289%

If the total area of productive forest in SEQ is taken as 694 000 ha [2], then the density of actual inventory plots is about 1 per 84 ha. The area included in the 1992-97 sample of MUs should therefore be represented by about 250 plots which should be enough to get estimates of volume with a standard error of around 5% (assuming a coefficient of variation of 50-100%). This suggests that an average bias of 14% in estimation of total volume removed warrants further investigation, as does the large range in volumes for individual MUs. It is too much to expect however of a strategic level inventory that volume estimates for individual MUs will be accurate since they will be represented by only four plots on the average.

The overall reduction in net area and the overall result that actual realised volumes are less than assessed volumes have been attributed by some QDPI(F) staff to the increasing concern of field staff to implement Code of Practice procedures even prior to them becoming mandatory. This is at least plausible.

6. Models

6.1 Models for estimating volumes of standing trees

Both one-way (dbhob predicts volume) and two-way (dbhob and merchantable height predict volume) models are used in the yield prediction system to predict standing volumes for individual species. Two-way models are used to set initial conditions for prediction but one-way models are used in **sked**. For some time there have been some concerns about the relationship between these two. Turner and Ferguson (1992, p.4) also expressed concerns about the lack of models for the less common species and recent analysis by staff has suggested that there may be some bias in some models at the low and high ends of the site quality spectrum. New data for checking on these possibilities are now being collected. On one day in ten of tree-marking, markers measure dbhob and merchantable height of all trees marked and subsequently relate these to measured volume of the logs. A new database of about 5000 trees has now been accumulated, mostly of course in the most commonly harvested species. Analysts in DPI(F) are however unsure exactly how these new data should be used, e.g., whether they should be used purely for error analysis, for calibrating the old models or for developing new models and whether old measurements should be added to the new set or scrapped. There is still difficulty in getting enough data to model uncommon species, even though tree-markers are instructed to collect data on these species when opportunity exists. A side-benefit to this data collection system is that since the tree-markers are also frequently the inventory-plot measurers, they are able to use this program for self-training in estimation of products.

2 A. Keto, pers comm.

No progress has been made in developing taper models which might be useful in determining volumes of trees which might be utilisable for non-sawlog purposes. This has not had a high priority in the Department.

6.2 Models for predicting growth and mortality of forests under various conditions

"Growth prediction is carried out through a series of models which express the expected proportion of stems changing from one state to another. The methodology ... for hardwoods is as yet unpublished but is similar to that used for the Queensland rainforests as described by Vanclay (1989)" and Vanclay and Preston (1989).

"The models are distance independent, dynamic and deterministic and based on diameter distributions (Vanclay et al, 1987). The basic premise of growth, mortality and recruitment [prediction] is that cohorts of trees can be characterised by logistic models to predict the proportion of trees changing diameter classes or merchantability classes, from living to dead, etc., and the probability of recruitment occurring." (Turner and Ferguson, 1992, p.28) More specifically, there are models for diameter increment, deterioration in merchantability, probabilities of survival, harvesting and recruitment, and amount of recruitment for seven different regions, one of which is the SEQ Region.

The models were developed using remeasurement data from the Native Forest Permanent Plot System plus some data from silvicultural research plots. Other than the harvesting models which have been recently updated using post 1991 data, the models reflect the management situation prior to the mid-Ì80s. Nevertheless because the logistic models for growth take into account that growth is reduced proportionately to the stand density of trees larger than the predicted cohort, they can be expected to be able to model growth and mortality reasonably well over a range of regimes provided these do not differ appreciably from regimes of the 1980s. The range of basal areas of the plots can be examined to determine their applicability for modified regimes.

There has been some validation of these models in recent years but not in a systematic manner. Simulations conducted for and reported by Turner (1996) suggest that the harvest levels at which steady state conditions are reached are not very sensitive to minor variations in mortality and recruitment despite some concerns which had been expressed within QDPI(F) about these functions. "The probability of recruitment was varied by plus and minus 99% separately and the probability of mortality was set to 0%. The results indicate that ... the [simulation] model is not highly sensitive to these parameters." (Turner, 1996, p. 10). Presumably this is because reductions in future yields due to high mortality or low recruitment can be compensated by moving other MUs up in the harvesting order, i.e., by slightly shortening the cutting cycle. However it is still conceded by analysts that the models for recruitment are unstable because of the small sample size of data used for their construction.

There has been some discussion within DPI(F) about how to estimate change in total fibre volume over time. The approach that seems to be favoured is to produce this as a multiple of sawlog volume although there is little data available for this at present.

6.3 Models for estimating product outturn from predicted gross volumes

QDPI(F) has concern principally for the estimation of sawlog volumes since sawlogs (defined as meeting historically accepted utilisation standards) are the only products subject to quota control. Volumes of other products such as poles, small and poor quality logs and pulpwood will be able to be estimated from the yield projection system when procedures have been completed. A contract is current for the development of a set of models to estimate total wood fibre. There is anecdotal suggestion that excessive cutting of pole-size material in the last decade will have deleterious effects on future sawlog volumes, but the current **sked** considers poles and sawlogs (current and potential) as separate populations so is unable to show this effect.

7. Systems

7.1 Computer systems used to project forest statistics into the future and to take into account constraints on the predictions

The computer programs called **sked** used for yield projection have been indirectly described in various papers but its details are not available in published form. In its favour is the fact that it has existed in essentially its current form for more than a decade and has been in frequent use over that time for yield scheduling. Its use has until recently been restricted to a few analysts in HO; however in recent years attention has been paid to making it more user-friendly so that it might be used more widely. A Users Manual is now available and it can be hoped that this is followed by publication of the algorithms which it uses.

Input to the simulation model consists of a list of MUs together with the Native Forest Inventory (NFI) plots which represent the included SUs. Various constraints, e.g., minimum average sawlog volume, minimum harvestable yields, minimum species mix and wet weather logging areas, can be specified for a simulation run. Then a constant annual yield is specified and the time period over which the simulation is to run.

The first phase in the simulation is to "grow" the NFI plots to a common starting point in time (usually the current year). This is necessary because of the varying ages of plot data.

In the second phase there is a choice to run a “cutting cycle analysis” or a “yield scheduling”. Under the former a cutting cycle period is nominated and all MUs are harvested (assuming they meet other constraints) according to this fixed return cycle. Under the more commonly used yield scheduling, the method consists of an annual cycle of aggregating plots for each SU to determine its suitability for logging, aggregating these into MUs and further checking for suitability and ranking them either according to an imposed list or some other criterion, applying the predicted harvesting rule to the M Us in order until the annual harvest is satisfied, and then "growing" each plot according to the models of growth, mortality, recruitment, tree-marking and merchantability. The time of return to a MU under yield scheduling is variable depending on its growth rate and meeting operational constraints. Similarly the age at which a tree is harvested is highly variable and the concept of “rotation” has no relevance.

Output from the simulation model indicates the order of logging of MUs and gives detailed descriptions of expected harvested materials and the condition of the forest during and at the end of the projection.

7.2 Systems set up to verify and validate predictions from growth models

Two specific systems set up recently to monitor predictions of volumes have already been mentioned. These are the 10% sample of trees marked for removal in logging operations, and the procedure for checking volumes taken from a Management Unit following logging against the estimated available volume from inventory plots on the area. There are no specific systems in place to check on the accuracy of growth predictions.

7.3 Systems used to keep area and growing stock statistics current

As indicated above, there has been a concerted effort over the last few years to update area and growing stock statistics consistent with maintaining a large and representative sample. This process seems to be well managed and it can be anticipated that this will settle down into a systematic procedure of replacing old data with equivalent new data.

8. Methodology

8.1 Sampling methods used to gather data for input to the systems, including growing stock information, growth information and removals information

The native forest inventory system in Qld is almost unique in Australia in its attempt to sample all Sub Units to an acceptable level of precision (approximately defined only as a minimum of two plots per Sub Unit). This should ensure that the forest is well sampled over its full range, to a level not attained in most other States. However in reality the database is still a long way from meeting this goal, hence the common use of shared plots in unsampled Management Units. The rigorous review of the sample of permanent plots begun as a result of the report by Beetson and Nestor (1992) is commendable and provides the basis for a set of data for growth estimation which ranks high in the country for representativeness and comprehensiveness.

8.2 Actual methods used to calculate sustainable yields including an evaluation of the underlying assumptions

The **sked** prediction system grows the forest annually and imposes a harvest when defined criteria (such as minimum operable area and log size) are met. MUs may either be cut on a regular time cycle (the cutting cycle) or when required to meet an imposed annual harvest, in which case the MUs with the largest unit volumes are scheduled first. Minimum conditions of operable volume, average log size, average dbh of harvested trees, etc., can be set. Sustainable yields are estimated from examining the output resulting from simulations using **sked** over a century or more. Common practice in the US and elsewhere is to run simulations for about a rotation and a half, and a hundred years is of this order. It is assumed that if a number of key indicators[3] examined have reached a steady state by then, the input allowable cut is sustainable. The input harvest level can then be raised until a point is reached where one or more indicators show undesirable trends. This would indicate that the maximum sustainable yield has been exceeded. The sustainable yield volume is also dependent on the imposed constraint levels. See Appendix B for example output.

The way in which these indicators is used is not explicit and it is desirable for transparency to have clearly-defined decision rules on how the data should be interpreted. For example it isnÌt clear how much departure from the steady state is acceptable and for how long a steady state condition is required to consider that a sustainable yield has been attained.

The growth and harvesting models within **sked** are based on statistical analysis of permanent plot data. The basic assumption therefore is that future conditions will be within the range of the collected data. Most plots are subjected to the same kinds of treatment as the surrounding forest so will be representative of the range of stand conditions resulting from harvesting and growth patterns of the (recent) past. Other assumptions such as operational constraints can be varied to determine their importance (i.e., sensitivity analysis can be used to test the responsiveness of the models to changes in minimum log size, minimum loggable areas, etc).

8.3 Methods used to estimate the reliability of the predictions

The simulator **sked** can be run in stochastic mode as an alternative to deterministic. Stochastic mode means that the growth, survival, recruitment and merchantability-change models are subjected to chance perturbations to determine the effect of error on the final outcome. From a large number of iterations, each one representing a chance perturbation from mean values, the

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[3] The following indicators are currently plotted against time: standing merchantable volume, net available area, harvested and standing volume in m^3/ha, standing basal area, average volume per sawlog and mean stand dbh.

likely distribution of the final outcomes can be assessed. This represents only the error associated with the growth models, and not other major sources of variation such as sampling and measurement errors.

9. Evaluation

9.1 The basis of QDPI(F)'s calculation of yield

The assumptions behind the method used to estimate sustainable yield, with some evaluative comments, are as follows:

- *Assumption:* The appropriate unit for the estimation of sustainable yield is the Allocation Zone, of which there are 13 in the SEQ Region. Turner and Ferguson (1992) recommended that these be reviewed to ascertain whether aggregating units would give a higher joint sustainable yield, a possibility if the timing of past harvesting has differed appreciably in the different allocation zones. This suggestion was considered and not implemented. It can reasonably be expected that market zones which existed in the past may now be larger as mills aggregate and transportation networks improve. This would provide a rationale for making allocation zones larger.
- *Assumption:* The current statistics on growing stock are best obtained by sampling each SU to an acceptable degree of precision or where this is not possible, by ascribing the characteristics of similar nearby areas to that SU. The latter is unfortunately not yet past history. It is suggested that alternatives to this, such as using GIS data or API-determined structural types as strata, should be trialed if an opportunity arises.
- *Assumption:* The future growth of stands can be modelled by using data from measurement of past growth and assuming cohorts of similar trees will grow in a similar manner in the future. There is little option to this except to ensure that models are so structured that changes can be accommodated. As far as it has been possible with available data, the models used in SE Qld meet this condition.
- *Assumption:* Harvesting patterns of the future can be best modelled by considering how trees have been marked for harvest in the past, modified by imposed operational constraints. While harvesting patterns remain relatively constant, this seems a rational approach. Alternative patterns could be relatively easily accommodated if they can be related to the same kinds of predictive variables as in the current models to predict probability of harvest, viz., dbh of tree, time since previous logging and various stand parameters such as basal area and site quality or site form.
- *Assumption:* Sustainable yield can be best estimated by simulation of growth and harvest over a long period of time, typically 100 years, assuming the largest-volume MUs are cut first, and monitoring a number of indicators for departures from acceptable ranges or trends towards unsustainability. The period of simulation could be as long as desired but the assumptions become increasingly tenuous with time. The range of indicators used provide variable viewpoints on sustainability and

additional ones could be viewed if supported by the data and models in the simulator.

9.2 Methods and data used

The methods and data have been described. A deficiency in the system results from the concept that permanent plots are accorded the same treatment as the surrounding forest, i.e., they are considered as a Continuous Forest Inventory system. This means that these plots only reflect that range of conditions. Turner and Ferguson (1992) pointed out that this is neither essential nor entirely desirable and that at least some data should be collected for conditions of radical departure from the norm, such as the retention of more large trees (for wildlife habitat) at harvesting. However it must be said that the form of the models (including as they do, terms for reduction of growth and recruitment according to amount of overstorey) are such that even such radical departures are probably reasonably well modelled, and the volume of data supporting the models is impressive by most standards.

9.3 Accuracy of predictions and strengths and weaknesses of models

It is virtually impossible to analytically determine the accuracy of predictions in a complex system which consists of datasets some of which can have associated sampling errors and some not, and a large number of models which individually may have estimation errors but which interact in complex ways. The use and limitations of the stochastic form of the simulator and of sensitivity analysis as ways of gaining some idea of the total systems errors have been described. Major sources of error still exist in estimating net harvestable areas and current (harvestable) volumes, and research is urgently needed to better determine why these errors have occurred in the past, and to prevent their future occurrence. It appears that these errors are of much higher magnitude than errors in the growth models.

The strengths of the yield projection system are its high degree of site specificity and the fact that all data used is based on past measurements and not on theoretical expectations. The latter is also its weakness, as it may not be able to accurately reflect radically different circumstances of the future. The site specificity doesnÌt mean that it is possible to estimate accurately the future yield of single MUs (a strategic-level system is not designed to do this) but that if some MUs are removed from the system, future yields can be re-estimated with little loss of accuracy.

9.4 Appropriateness of datasets and systems compared to other States

Despite their deficiencies, identified above and by Turner and Ferguson (1992) and Turner (1996), it has to be recognised that the datasets used for determining growing stock levels and for growth modelling and harvest modelling in SEQ are among the best in Australia in terms of size (number of plots, number of models) and representativeness (coverage) for the area of forest. The matter of data quality is being rectified in a systematic way.

The errors in the estimation of net areas are in part a result of the silvicultural systems used. The selection management systems used mean that harvest unit boundaries are much more diffuse in space and time than those resulting from even-aged methods, making area determination more difficult. Perhaps partly for this reason, GIS seems to be less involved in harvest planning than in some other States, and the discipline of area determination which it enforces is less apparent in SEQ.

The yield prediction system used in Qld is unique in Australia but has evolved from a consideration of how selectively managed stands change over time. Historically its roots are in the cutting cycle analysis method also used in northern NSW, but it has been able to develop well beyond this due to the strength of its database. To my knowledge it is the only system in Australia to allow for stochastic simulation of the growth of native forests. However some States have extended their yield projection simulators to take into account financial costs and returns, in some cases then allowing for the optimisation of physical or financial criteria. These systems, generally using linear programming, allow for incorporation of models of other outputs such as water production and of alternative silvicultural regimes. These are not possible with the current **sked** model.

10. Expected reliability of yield forecasts from the system

It has not been possible to do a rigorous error analysis of the SEQ yield projection system in the time of this consultancy, and for reasons stated above it is probable that it could not be done anyway. However various parts of the system have been audited for reliability.

10.1 Area statistics

85% of the Sub Unit areas in SEQ are considered to have an accuracy of 3 (resulting from thorough field inspection) or better. This appears to be an improvement on the situation of 1992. However the net area of Sub Units harvested since 1992 was on average 16% less than that estimated. Since there is an organised program for continuing upgrading of accuracy, this major source of past error can probably be considered as under control.

10.2 Current growing stock

91% of the temporary inventory plots used to establish existing growing stock statistics are less than eight years old and only 3% are older than 20 years. Again this is an improving situation and must be considered as acceptable, given that an inventory cycle of ten years is internationally considered as good.

Data supplied by QDPI(F) analysts showed that the average volume per hectare harvested from Sub Units since 1992 was 29% less (5.9 vs 8.0 m^3) than that estimated by inventories prior to 1992. Subsequent analysis using updated net areas and improved volume models has reduced this to about half (see Section 5.4). Part of the difference might be explained by recent analysis of estimated and actual trees which showed that about 7% of trees estimated as sawlogs were actually 'duds' (this was up to 16% for spotted gum in some allocation zones). On the other hand the actual log lengths of trees were consistently *underestimated* by measurers by *on average* up to 25%. This seems excessive. The problem is more likely to be in judging the point at which logs will be cut (perhaps a confusion between bole height and log length) than in estimating the height to that point, but analysis of the causes would seem to require urgent attention.

Although the yield projection system is based on site-specific information, the number of plots representing an individual MU is very small and inadequate to give an accurate estimate. The use of the simulator to give a schedule of operations on MUs is not recommended except at an indicative level. Again this indicates that the system is designed only for strategic-level decisions.

10.3 Models

Stochastic simulation using Central Qld data showed a dispersion in allowable cut of a few percent in the near future increasing to a range of about 30% at 100 years (Turner, 1996). Similar results could be assumed for SEQ. Given the uncertainties of the future, these results for the growth models would seem acceptable.

11. Ecologically Sustainable Forest Management Considerations

An urgent need is to ensure that the systems and in particular the simulator are able to provide for whatever ESFM requirements come out of the RFA process. A search of databases may be desirable to identify data relevant to ESFM considerations when these become apparent.

Despite the absence as yet of an ESFM Expert Panel to provide guidance it is perhaps possible to anticipate what the main issues are likely to be and then address whether the current yield modelling and prediction system will be able to accommodate those considerations. Remarks have already been made about some of these issues.

11.1 Stream Buffers, Wildlife Corridors and Other Informal Reserves

In the mapping of Management Units, stream buffers have in the past been defined as separate (non-harvested) Sub Units. Any modification of the size of these buffers then will require new mapping which, given the current state of area determination, could not be handled quickly and easily. Plots located in operational Sub Units might fall into buffer Sub Units requiring revision of the AIS records and the **sked** database. Other reserves for wildlife, aesthetic purposes, etc, would require similar alterations to AIS and inventory database records. This would be more easily accommodated if an operational GIS was fully implemented, particularly if it were felt necessary to consider various options on these and their impacts.

11.2 Steepness, Rock Outcrops, etc.

ESFM considerations may require that more latitude be given to operational impediments such as steepness and rockiness within operational Sub Units. Currently these are generally handled through the Sub Unit's discount factor. Alteration of this would be a simple matter but determining the correct value would require costly intensive field assessment. Since these areas are generally too small for definition as (part of) a different Sub Unit, it is doubtful that conventional GIS scales would assist very much, although high resolution remotely sensed data might be useful.

11.3 Silvicultural Regime Modifications

Modifications to the standard silvicultural regimes may be considered desirable from ESFM perspectives. Most likely these would be manifested as requirements for more or different retained stems for habitat purposes, or in different spatial patterns. These will have different impacts: scattered retained trees will impact success of regeneration and growth of smaller trees and therefore perhaps require modification of these models (although they do have terms in the models to compensate for overstorey). Retained clumps of trees may best be handled as reductions in net area of harvestable land. Allowing some trees to live longer before harvesting may require some changes to the harvesting functions.

11.4 Likely Impact of ESFM Considerations on the Yield Prediction System

It is probable that the effects of ESFM modifications to current management could be modelled in an approximate way without a great deal of modification to current models. Database research and some analysis of a few months duration should show whether the changes were within the limits of existing models. If changes to the net areas of SUs are needed, several months to years are indicated. Likewise changes to the harvesting and growth functions will not be measurable for several years.

12. Research and Development Priorities

In the course of this evaluation several items have been identified where further analysis or investigation would be expected to lead to improved accuracy and value of sustainable yield estimation. It is not necessary that QDPI(F) carry out all these R&D activities. Some could be contracted out in particular as post-graduate or honours research projects at appropriate universities. Given the acute shortage of staff for these activities in the Department, these possibilities should be pursued.

12.1 Alternative methods for estimating net areas

There are a number of alternatives to the methods used by QDPI(F) for estimating the net area of logging areas (Sub Units). Other States (e.g., Tasmania) rely much more on API and GIS for this purpose. The process of improving these data is well in hand but further investigation of alternative approaches might be worthwhile.

12.2 Alternative methods for estimating merchantable volumes

QDPI(F) relies heavily on measurement of temporary plots for growing stock information. This provides good spatial information (except where no plots have been measured) but data measurement errors, especially biases can cause havoc with accuracy. An alternative (as used in Tasmania) is to use API to stratify the forest into structural classes, then use a stratified sample of plots to estimate statistics. This would normally mean that a fewer number of plots may be necessary, so it may be efficient to spend more time collecting more detailed (and perhaps more accurate) information on each plot. For example it may be cost-effective to measure log lengths more accurately and to estimate volumes of multiple products in a stem through dendrometry on a smaller number of trees (plots) than currently sampled. The disbenefit of this method is that it is likely that many Sub Units will have no plots within them but have growing stock statistics ascribed to them by virtue of their membership of API classes. A cost-benefit analysis of these methods (and perhaps variants) might be useful to gauge their relative advantages. (Since Sub Units contain only a single forest type, this would not seem a difficult exercise.)

A sub-project of the above is to determine the cause of errors in the estimation of the merchantability of stems (overestimated) and the estimation of log lengths (underestimated). It is perhaps fortunate that these errors are compensating, but their magnitude and consistent bias over estimators and forest types suggest that estimates would be improved through further analysis and subsequent training of measurers. However it is recognised that these are the most difficult items of all to estimate and require considerable experience for high accuracy.

Another sub-project worthy of further investigation is how to best use the new information being collected on the comparison of estimated and measured merchantability characteristics, i.e., whether it should be used to modify existing volume tables, create new ones or be used as calibration factors.

12.3 Modifications to yield simulator

Further work is needed to determine whether there would be advantages in adding financial measures into **sked** and being able to optimise on volume or value, rather than simulate scenarios. Such additions would seem consistent with the increased commercialisation of QDPI(F). Additional indicators (e.g., species composition changes over time) may be easily incorporated to address ESFM issues.

At some future date it may become desirable to consider whether and how non-sawlog values might be incorporated into **sked** or its successor. These might include smallwood, water or wildlife habitat. Some other States (Victoria and NSW) are addressing some of these.

12.4 Modifications to Allocation Zone basis of yield estimation

Some analysis should be done to determine whether there are advantages to aggregating Allocation Zones for sustainable yield calculation purposes. Thirteen sustainable yields for SEQ seems excessive when compared with the single yield for all the public native forests of Tasmania.

12.5 Addressing ESFM concerns

When ESFM concerns become apparent, it will be necessary to determine how the data collection and yield calculation methods will respond. It could be assumed that ESFM considerations might suggest modification of silvicultural practices to retain a higher proportion of growing stock in harvesting operations than currently practiced, so a search might be initiated to determine whether such data are already represented in the permanent plot database. If this is not so, plans should be initiated to install an experiment to collect such longterm data. However it seems premature to make such plans until the full extent of ESFM needs is clarified.

13. Conclusions

The method used by any forestry organisation to calculate sustainable yield tends to be strongly influenced by its past history of data collection and model building. QDPI(F) has had a strong tradition of extensive field data collection and empirical modelling from these data, but not of API nor GIS, and this is reflected in their current systems. In the current system, areas within state forests are defined as Management Units and within these are relatively homogeneous Sub Units. From measurements of the trees on each plot and the area of the Sub Unit, the sawlog volume and other statistics for the Sub Unit can be estimated and aggregated up to a volume for the Management Unit. Statistics for all Management Units in an Allocation Zone are collected up, "grown" to a common point in time and then projected forward in time under the direction of empirical growth models derived from the measurement of permanent plots. Empirical harvesting models impose reductions in growing stock emulating past practices either on a regular cutting cycle or in response to a need to meet an imposed level of cut. By varying this level, within constraints, the maximum sustainable yield can be found.

Previous reviews have found that the models are well constructed, based on ample data and appear to reasonably reflect those data. In response to these reviews the data on current growing stock have been updated, the accuracy of area statistics has improved and the distribution of permanent plots has been rationalised to better reflect the range. Nevertheless information collected in recent monitoring activities and provided by QDPI(F) analysts suggests that there could still be some serious problems in accurately estimating the merchantability of trees. Comparison of actually harvested volumes with predictions also suggests that there are still data quality problems although procedures are in place to detect and remedy these deficiencies. A measure of caution is suggested in interpreting outcomes from the system until these deficiencies are rectified.

There are many assumptions built into this kind of a yield projection system. The most significant is probably that the future can be adequately modelled by the past. While the form of the models developed for SEQ are such that minor extrapolation is probably safe, the growth models may not be able to accurately simulate major alterations to the past harvesting patterns. If ESFM considerations require changes to harvesting methods such that the new stand patterns are not adequately represented in the data used to construct the models, the current simulator may be inadequate. Similarly massive changes due to fires or cyclones, or gradual changes due to climate modification will only be reflected if the trends do not differ from the past.

A number of R&D studies have been identified, mostly requiring more detailed analysis of existing data. These are: alternative methods for estimating net areas, alternative methods for estimating merchantable volumes, modifications to the yield simulator, modifications to the allocation zone basis of yield estimation and addressing ESFM concerns. Existing staff in the Department are hard-pressed just to maintain the complex system and provide routine information to managers, and it is suggested that some of these studies could be outsourced.

The system developed over many years to estimate sustainable yields in SEQ by QDPI(F) is unique, well conceptualised, and includes models which are of world class and are based on a very large database for a natural forest. The simulator is quite flexible and is able to reflect better than most the many constraints operating in the real world. Residual problems with data quality which are being addressed by the Departmental analysts and field crews should not be allowed to overshadow the overall high utility of the yield prediction system for strategic planning.

14. References

Beetson, T. and M. Nestor. 1992. Enhancing the native forest detailed yield plot system. Queensland Forest Service Internal. Rep.

Cant, M. 1997. Native Forest Permanent Plot Remeasure Cycle Analysis. Internal Report.

McCormack, B. 1988. Area Information System Field Procedures Manual. Dept of Forestry, Qld. Internal Report.

McCormack, B. 1989. Timber Inventory Manual for the Native Forests of Qld. Dept of Forestry, Qld. Internal Report.

QDPI Forest Service. 1994. Native Forest Permanent Plot System Field Manual - Plot Remeasure after Disturbance. Ed. 1. Internal Report.

QDPI Forest Service. 1995. Native Forest Permanent Plot System Field Manual - Establishment and Initial Measure. Ed. 2. Internal Report.

Turner, B. J. 1996. Review of Native Forestry Sawlog Allocation Methodologies. Internal Report for Qld DPI Forestry.

Turner, B. J. and I. S. Ferguson. 1992. Review of Sustained Yield Management Data for Native Forests Managed by the Queensland Forest Service. Internal Report for Qld For. Serv.

Vanclay, J. K., et al. 1987. Report of the Native Forest Resources Task Force. Dept of Forestry, Qld Internal Report.

Vanclay, J. K. 1989. A growth model for north Queensland rainforests. Forest Ecology and Management 27:245-271.

Vanclay, J. K. and R. A. Preston. 1989. Sustainable timber harvesting in the rainforests of northern Queensland. In: Forest Planning for People. Proc., 13th Bienn. Conf. of IFA: 181-191.

Appendix A.

Comparison of Areas (1992 and recent) and Harvested Volumes (estimated and actual) for Management Units Harvested between 1992 and 1997

MU; ZONE	SKED 92 AREA (ha)	NEW AREA (ha)	%AREA CHANGE (NEW-SKED 92)	REALISED (SALE) VOLUME (m^3)	SKED 92: EST VOLUME: OLD MODELS	ESTIMATED VOLUME USING NEW MODELS, AREAS (m^3)	% VOLUME DIFFERENCE (NEW-REALISED)	REALISED VOLUME AS % OF NEW EST VOLUME
MU1	344	344	0.0%	4506	5965	5251	16.3%	86%
MU2	148	139	-6.1%	2223	1420	1273	-42.5%	174%
MU3	168	189	12.5%	656	1276	1379	110.2%	48%
BGGB Total	1160	1172	1.0%	7390	8661	7913	7.1%	93%
MU4	1301	1270	-2.4%	1646	6240	4441	169.8%	37%
MU5	137	137	0.0%	93	694	657	589.0%	13%
MU6	1206	490	-59.4%	3524	12560	4459	26.5%	79%
MU7	44	44	0.0%	188	1909	322	71.2%	58%
MU8	636	549	-13.7%	7251	11935	7248	0.0%	100%
B-G Total	3374	2540	-24.7%	12792	33463	17223	34.7%	74%
MU9	403	273	-32.2%	1243	1271	710	-42.9%	175%
MU10	104	104	0.0%	1018	1258	1148	12.7%	89%
BNE Total	507	377	-25.6%	2261	2529	1858	-17.8%	122%
MU11	794	631	-20.5%	1827	4525	2965	62.3%	62%
MU12	300	326	8.7%	429	1379	1010	135.3%	42%
MU13	759	759	0.0%	4132	5913	4401	6.5%	94%
MU14	248	248	0.0%	1945	967	1240	-36.2%	157%
MU15	693	693	0.0%	3045	7268	5336	75.2%	57%
MU16	1100	1100	0.0%	7292	4840	3630	-50.2%	201%
MU17	930	930	0.0%	1755	4371	4371	149.1%	40%
MU18	1048	930	-11.3%	4611	9222	7998	73.4%	58%
E-M Total	5871	5617	-4.3%	25027	38291	30951	23.7%	81%
MU19	1003	994	-0.9%	1414	3907	4469	216.1%	32%
MU20	523	523	0.0%	1294	5543	5020	288.0%	26%
MU21	747	747	0.0%	2545	8291	6872	170.0%	37%
G-M Total	2272	2263	-0.4%	5253	17741	16361	211.5%	32%
MU22	55	55	0.0%	351	313	253	-27.8%	139%
MU23	498	265	-46.7%	135	883	355	163.1%	38%
G-T Total	553	320	-42.1%	486	1196	608	25.2%	80%
MU24	165	158	-4.7%	387	2220	2162	458.2%	18%
MU25	126	117	-7.2%	249	1498	1508	504.3%	17%
MU26	193	176	-8.8%	1091	4118	4768	337.1%	23%
MU27	225	194	-13.8%	170	2005	1996	1072.4%	9%
MU28	48	48	0.0%	229	456	483	110.4%	48%
GYMA Total	758	693	-8.5%	2127	10297	10915	413.2%	19%
MU29	413	168	-59.3%	5964	4252	2465	-58.7%	242%
GYMB Total	413	168	-59.3%	5964	4252	2465	-58.7%	242%
MU30	408	121	-70.3%	2482	2802	859	-65.4%	289%
GYME Total	408	121	-70.3%	2482	2802	859	-65.4%	289%
MU31	70	62	-10.7%	1779	1167	1212	-31.9%	147%
MU32	448	415	-7.4%	2356	2120	1696	-28.0%	139%
MU33	732	719	-1.7%	2805	2861	3521	25.5%	80%
MU34	200	199	-0.2%	1414	2270	3146	122.5%	45%
GYMG Total	1449	1395	-3.7%	8354	9418	9575	14.6%	87%
MU35	188	159	-15.7%	5692	3945	4348	-23.6%	131%
MU36	547	402	-26.5%	7542	4757	2454	-67.5%	307%
MU37	464	222	-52.3%	3518	6298	3135	-10.9%	112%
MU38	158	104	-34.3%	3252	5037	2735	-15.9%	119%
MU39	267	104	-61.0%	3557	3570	2186	-38.5%	163%
MU40	175	125	-28.4%	3557	4468	2939	-17.4%	121%
MU41	1834	1204	-34.4%	2676	10258	5293	97.8%	51%
K-WJ Total	3635	2320	-36.2%	29794	43343	23090	-22.5%	129%
MU42	258	210	-18.6%	1113	2268	1280	15.0%	87%
MU43	308	302	-1.9%	2233	2136	2023	-9.4%	110%
MU44	593	542	-8.6%	4743	2431	2060	-56.6%	230%
MU45	401	322	-19.3%	2491	2285	1575	-36.8%	158%
MU46	331	337	1.9%	511	2790	1754	243.4%	29%
MU47	297	177	-40.3%	604	1262	697	15.3%	87%
MBR Total	2173	1883	-13.5%	11695	13212	9339	-19.7%	125%
MU48	260	260	0.0%	341	1115	1115	227.2%	31%
M-W Total	260	260	0.0%	341	1115	1115	227.2%	31%
MU49	384	376	-2.1%	7685	9859	9687	26.1%	79%
MU50	93	85	-8.9%	485	899	873	79.3%	56%
NCZB Total	477	461	-3.4%	8170	10758	10560	29.3%	77%
MU51	129	46	-64.5%	221	908	268	21.3%	82%
MU52	115	46	-59.8%	230	608	198	-14.0%	116%
MU53	116	114	-1.2%	1306	1527	1448	-21.1%	127%
MU54	199	143	-28.0%	2505	3144	2093	-20.6%	129%
MU55	183	159	-13.5%	2570	2459	2110	-21.0%	127%
NCZJ Total	746	508	-32.0%	7592	3675	5117	-19.4%	124%
MU56	335	281	-16.2%	4309	4410	2703	-37.3%	159%
MU57	341	255	-25.3%	196	751	729	271.3%	27%
MU58	303	303	0.0%	432	379	345	10.3%	90%
Y-TB Total	379	309	-14.4%	4397	5041	3977	-20.4%	125%
Grand Total	25146	21023	-16.3%	134724	112810	152986	13.6%	88%

Appendix B.

Examples of graphical output from **sked**, showing projections over 100 years of 7 indicators:

1. total merchantable standing volume for allocation zone
2. total net area available for harvesting
3. average yield (volume harvested) per ha
4. average merchantable volume per ha
5. average standing basal area per ha
6. average volume per sawlog
7. mean dbh of standing trees

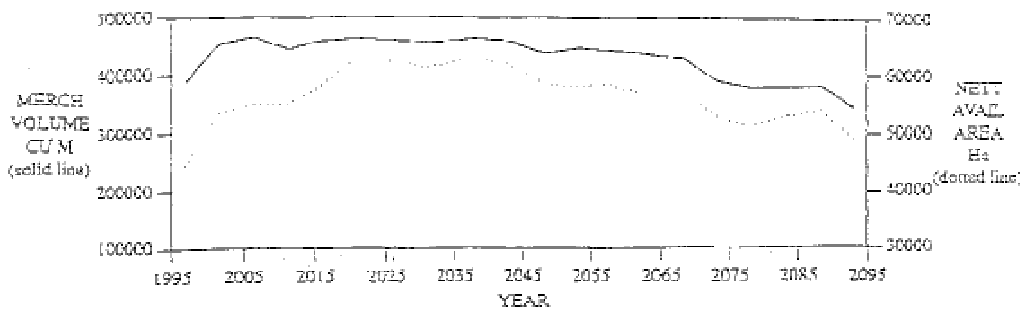
(a) illustrating a reasonably sustainable harvesting level

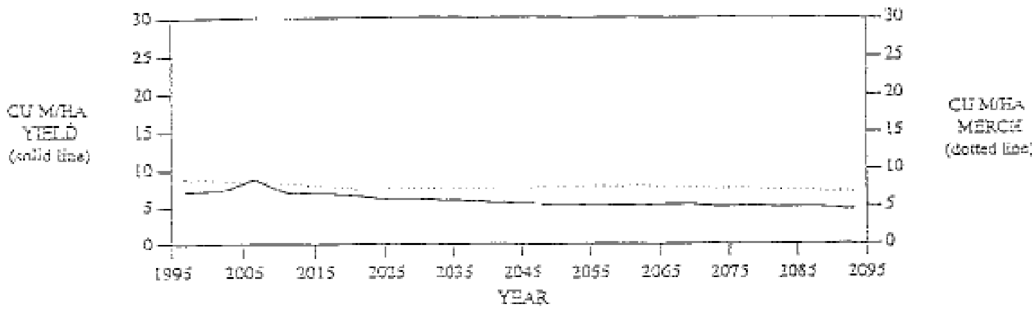
(b) illustrating an unsustainable (excessive) harvesting level

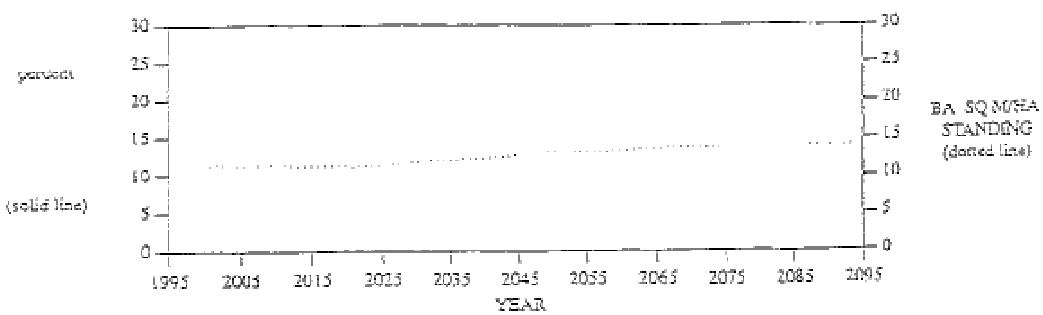
Appendix B (a)

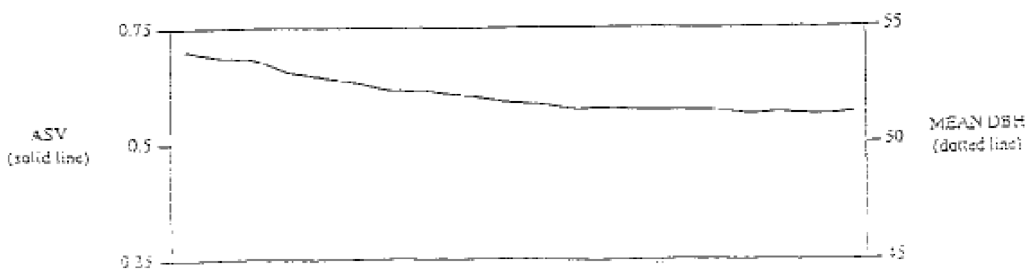
				SU	MU	AV	
Harvesting	1000+	cu m/ann					
Gross Productive Area	117352	ha	Minimum ASV	0.00	0.00	0.00	cu m
Minimum Return Period	25	years	Minimum Yield	2.00	2.00	3.00	cu m/ha
Minimum Sale Volume	500	cu m	Species of Log Volume	SPG 77 SGU 11 NRI 3 FRG			percent

Equation file: /u1/users/davew/zone/codes/cq96-hwdenle Model 05 Factor 1.000









Appendix B(b)

				SU	MU	AV	
Harvesting	[illegible]	cu m/ann					
Gross Productive Area	431250	ha	Minimum ASV	0.00	0.00	0.00	cu m
Minimum Return Period	25	years	Minimum Yield	2.00	2.00	3.00	cu m/ha
Minimum Sale Volume	500	cu m	Species of Log Volume	SPG 77	SGU 10 NRI	3 FRG	percent

harv 0 dinc 0 mort 0 eul 0 recp 0 reca 0
Equation file: /ul/users/davew/zone/codes/cc96-iwdcode Model 03 Factor 1.000