STRATEGIC PLANNING MODELS

How much wood have we got, when should we cut it, and what will it give us?

Dr Bruce Manley
NZ Forest Research Institute

ABSTRACT

Forest estate modelling systems have been widely used throughout New Zealand for long-term yield regulation, including the development of harvest strategies. They are linked with, and get input data from, stand record systems, stand prediction models, and inventory systems. Increasingly they are also being used for short-term harvest planning including stand harvest scheduling and log allocation.

INTRODUCTION

The question of wood availability is fundamental to harvest planning. Operational harvest planning requires, as input, information on the current and future level of harvest. This information comes from strategic and management (tactical) planning which is long-term in nature.

This paper describes the use of forest estate modelling systems for harvest planning. Forest estate models used in New Zealand are reviewed together with linkages to other planning systems. The use of the IFS and FOLPI forest estate modelling systems for long-term yield regulation is outlined. The evolution and application of these systems to short-term planning and the incorporation of log allocation to processing plants is then described.

FOREST ESTATE MODELS

"Forest estate model" is the term used in New Zealand to describe models for planning the management of aggregates of forest stands, i.e. forest estates. The forest estate might consist of an individual forest, or groups of forests at either a district, regional, or national/corporate level. In fact, the definition of a forest estate is open-ended — for planning purposes it is the set of stands[1] that are relevant to the particular planning exercise.

A number of forest estate modelling systems have been developed in New Zealand. They are frameworks within which specific forest estate models are built. This paper focuses on the IFS/ FOLPI forest estate modelling system developed at the NZ FRI. Other systems used in New Zealand are the RMS series of simulators developed by NZ Forest Products Ltd (and now Carter Holt Harvey Forests Ltd) (Allison, 1980), the RegRAM system developed by Tasman Forestry Ltd (McGuigan, 1995) and the Agroforestry Estate Model (AEM, Knowles 1994), a specialist spreadsheet-based modelling system developed at the NZ FRI for evaluating forestry on farms.

Forest Estate modelling systems allow managers to explore a wide range of management strategies (e.g. planting, silvicultural, harvesting and replanting strategies). They help identify the tradeoffs between alternative strategies in terms of such criteria as wood flow, cash flow, and

---

[1] The term stand as used in this paper refers to a management unit appropriate for the particular exercise. For example, in the case of harvest scheduling the term refers to logging units.

examine the sensitivity of each alternative to changes in key assumptions about the future. Typically a period of 2-3 rotations is modelled to ensure that the consequences of each management strategy are fully considered.

The Interactive Forest Simulator (IFS, Garcia 1981) was developed by NZ FRI to enable forest managers to model the consequences of different management decisions. It simulates the effects of implementing a specified management strategy on a forest estate and summarises the resulting flow of resources, such as log volumes or cash.

The complementary FOLPI optimiser (Garcia 1984) was subsequently developed to remove some of the trial and error associated with generating management strategies. FOLPI selects the best strategy to meet the objectives of management, subject to given constraints such as limits on cash flow or wood flow. The essential difference between IFS and FOLPI is that whereas the management strategy is an input to IFS, it is an output from FOLPI.

DATA SOURCES AND LINKAGES TO OTHER SYSTEMS

The forest estate modelling systems integrate the available resource database into a coherent framework within which estate models can be built. They require as input:

- stand area information (e.g. from a stand record system);
- yield tables for both clearfelling and production thinning (e.g. from a stand prediction model or inventory);
- costs, revenues and other resources associated with management and harvesting.

This input data is typically provided from other sources. The NZ FRI Integrated Modelling System illustrated in Fig. 1 gives an example of the linkages and data flows between other systems and the forest estate modelling systems. Components of the system are:

Management Inventory Package - STANDIN

STANDIN (Gordon 1992) is a general-purpose stand inventory package which stores, manages and processes data drawn from different types of inventory. It is intended for use in general management inventory such as assessment of silvicultural work content and quality control, measuring growth and evaluating stand health. Data can be transferred automatically to The Forest Master stand record system.

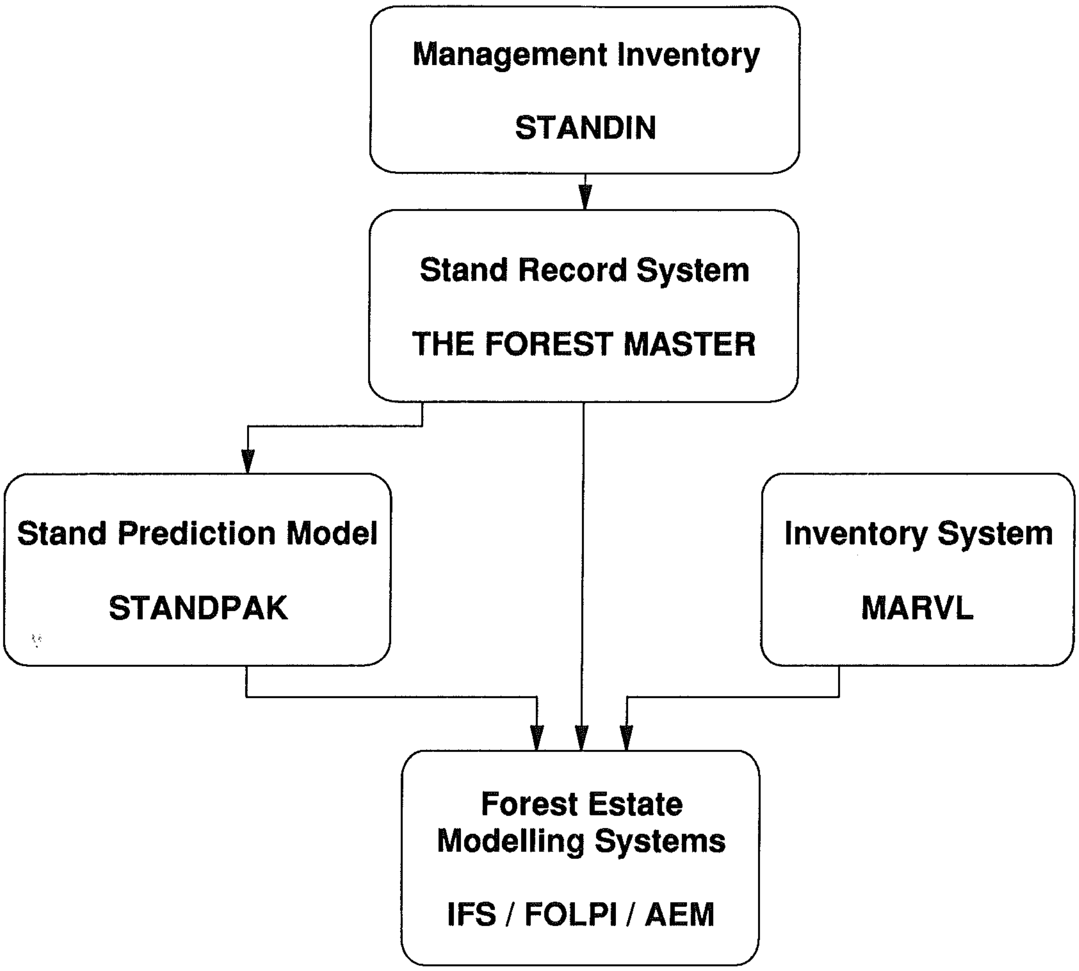
Stand Record System — The Forest Master

The Forest Master (Tennent 1992) is a database containing information about the land occupied by each stand and about the tree crop or crops on that land. It incorporates treatment histories and measurement details for each crop. It has reporting features to allow the selection of stands based on current or past forest information.

Stand Prediction Model — STANDPAK

The STANDPAK stand modelling system (Whiteside 1990) predicts the growth of stands allowing for the effects of site, silviculture and genetic improvement. STANDPAK incorporates stand growth models for young stands (Early, West *et al* 1982) and later growth (Garcia 1988; Goulding 1994). It provides estimates of total volume and volume by log grade at any stand age. It has an agroforestry module which models the effect of planting

FIG. 1 — NZ FRI Integrated Modelling System



trees on established pasture through the shading effect of the tree canopy and the effect of pruning and thinning debris on understorey pasture growth.

Major uses of STANDPAK are (West 1994):

- to provide yield tables as input to the forest estate modelling system;
- silvicultural regime evaluation at the stand-level;
- scheduling silvicultural operations such as pruning and thinning;
- the evaluation of land-use options involving forestry, pastoral farming or combinations of the two.

Inventory system — MARVL

The MARVL inventory system (Deadman and Goulding 1979, Goulding *et al.* 1993) allows for the assessment of the recoverable volume by log grade in a stand. It is a two-stage process consisting of a field cruise followed by a computer analysis. The field cruise involves the assessment of the size and quality of trees in a sample. During the computer analysis the cross-cutting or bucking of cruised trees into logs is simulated under different cross-cutting strategies.

The MARVL system has recently been upgraded (Gordon *et al* 1995) including the ability to generate yield tables for a range of cross-cutting strategies for each stand or cutting unit as input to the forest estate modelling system. Whereas the actual MARVL inventory provides a snapshot of current wood availability in a stand, the integration of growth models within the MARVL system allows for the estimation of future stand volume necessary for estate modelling.

LONG-TERM PLANNING

The focus of early application of the IFS/FOLPI system has been on long-term strategic and tactical planning over a time horizon of 60 to 90 years. The main purposes have been:

1. Yield regulation;
2. Management strategy and investment evaluation (see Manley *et al* 1991);
3. Forest valuation (see Manley and Threadgill 1991).

Yield regulation deals with determining the long-term allowable cut and evaluating alternative wood supply scenarios. It provides answers to the questions in the title of this paper:

— how much wood have we got?

— when should we cut it?

— what will it give us?

For long-term planning applications a forest estate has generally been aggregated into 20-60 different croptypes on the basis of species, silvicultural treatment, site productivity and terrain.

The croptype is an underlying concept of New Zealand forest planning which was adopted to link stands and forests. A croptype is an aggregation of forest stands which may differ in age and time of harvest, but are regarded as uniform with respect to future silviculture, yield production, and the associated streams of inputs and outputs. For forest planning purposes, stands are aggregated into croptypes with each croptype consisting of a table of areas by age-class for stands with a common yield table. The concept has facilitated forest planning in New Zealand and is flexible enough to accommodate a range of situations. For example, at one extreme each stand might be in a unique croptype whereas at the other extreme all stands in a forest might be assigned to the same croptype. Table 1 gives an example listing of the stands which are aggregated into a particular croptype.

Aggregation of stands into croptypes causes loss of detail. Rather than being able to model management activity by individual stand, the management unit becomes the age-class of a croptype. The assumption that all stands in a croptype have a common yield table causes additional loss of detail. On the other hand, use of croptypes reduces the planning problem to a tractable size and enhances comprehension of both the problem and the results.

The estate model constructed within IFS or FOLPI will generally contain:

1. Data files for each croptype giving:
- Area by age-class;
- Clearfell volume by log grade for potential rotation ages;
- Production thinning volumes by log grade;
- Clearfell and thinning revenues;
- Logging, loading, temporary roading and logging administration costs for potential rotation ages;
- Silvicultural costs (e.g. costs for replanting preparation, planting, pruning, thinning, Dothistroma spraying, fertilising);
- Annual maintenance and protection costs.

TABLE 1 — Listing of stands within an example croptype

CROPTYPE RAD HAULER			
Age	Stand	Stand Area	Aggregated Croptype Area
25	39 44 49	22.5 15.6 7.2	45.3
26	14	8.9	8.9
27	8 11 15 22 25	31.3 14.6 28.2 41.1 3.9	119.1
28	7 42	8.0 19.3	27.3

2. *Model scope:*
   - New land planting options;
   - Replanting options;
   - Silvicultural options;
   - Minimum and maximum clearfelling age.

3. *Management constraints:*
   - Minimum or maximum harvest levels;
   - Harvest smoothing or non-declining yield (NDY) requirements for total volume and different log grades;
   - Cash-flow or budgetary restrictions.

4. *Management objective:*
   In the case of FOLPI the objective will generally be to maximise the net present value (NPV) of future cashflows. (However there is flexibility for the user to specify their own objective or multiple-objectives as in the case of goal programming). For the IFS simulator, the criteria for determining the sequence of harvest will generally be set so that stands are harvested in order of declining age.

Outputs for the model will include:

— the annual harvest from clearfelling and production thinning by log grade;

— the area to be harvested each year by croptype and age-class;

— annual revenues and costs;

— the NPV.

Figure 2 provides a graphical example of some of the output for a model.

STAND HARVEST SCHEDULING

Recent (and on-going) hardware and software developments have had a major impact on the types and complexity of estate model that it is viable to build. The increase in computer power and development of database languages have allowed a greater level of detail to be modelled. For example, in the 1960s the Kinleith estate of NZFP was aggregated into two croptypes; by 1970 there were six croptypes; and by 1980 there were 12. During the late 1980s, 30 to 40 croptypes were used. Currently about 2000 croptypes are used (B. Rawley, pers.comm).

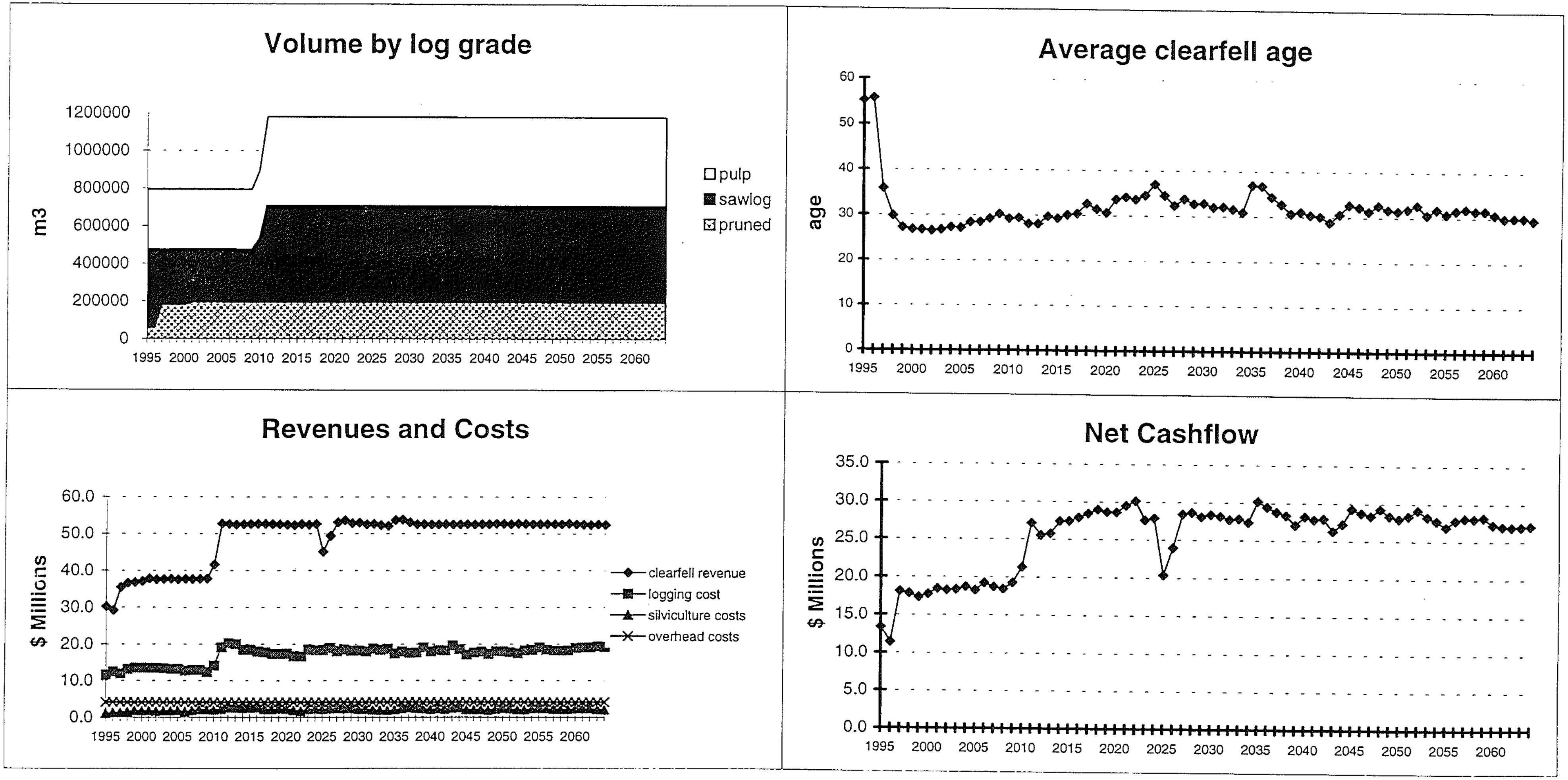


FIG 2 — Example of the output from the FOLPI system for one estate model run.

The computing advances allowed the development in 1991 of a short-term version of FOLPI capable of scheduling the harvest of 2000 stands over five periods. This version has been used for harvest scheduling (Gleason and Bailey, 1992).

A feature of this version of FOLPI was that it allowed estate models to be built which retained the identity of each stand.

These models selected the stands to be harvested in each year to maximise NPV while meeting such constraints as:

— the prescribed level of harvest by log grade;

— hauler gang capacity;

— restrictions on the area of each catchment cut during each year or over a rolling period.

VARIABLE RESOLUTION MODELLING

The long-term and short-term versions of FOLPI were developed in a planning environment where decision makers are faced with two conditional problems (among others);

— What is the best long-term management strategy for the company subject to meeting short-term operational constraints?

— What is the best short-term operational plan subject to the company's long-term management strategy?

The classical hierarchical approach is to solve each of these problems separately with models of different resolution linked by decomposition or heuristic techniques (e.g. Nelson *et al.* 1991).

However, there are advantages in solving the two problems simultaneously within a single model. This has become possible with the increases in computer power together with the current dynamically-sizing version of FOLPI and a variable resolution approach.

Under a variable resolution approach, both problems are incorporated within a single model with the selective aggregation of stands into croptypes depending on stand age. This involves retaining older stands as unique croptypes with the aggregation of younger stands into successively more aggregate croptypes. Manley (1994) provides an example of the application of a variable resolution approach to a 100,000 ha estate containing 9000 stands. The croptyping strategy summarised in Table 2 was used.

The motivation for the approach comes from work by Te Morenga *et al.* (in prep.) which indicates that variable resolution models provide accurate detail in the short-term while also incorporating long-term consequences.

TABLE 2 — Number of croptypes produced by a variable resolution croptype strategy for example of 100,000 ha estate

Stand age relative to minimum clearfell age	No. of Stands	No. of Croptypes
Within 5 years	1529	1529
5-15 years	» 2500	105
Over 15 years	» 5000	1
		1635

PROCESSING PLANT DEMAND AND LOG ALLOCATION

A trend in estate modelling has been towards greater consideration of the current and future demand of log products by the wood-using industry. Whereas the IFS simulator essentially stops at the forest gate, the FOLPI system allows the explicit modelling of the allocation of logs from forests to markets.

Additional inputs to forest estate models which incorporate log allocation include the specification of:

— demand by log grade or aggregations of log grade for individual markets (i.e. processing plants, export ports);

— required proportions of different log grades;

— the on-truck price (at-mill price less transport cost) for logs of each grade from a particular forest which are allocated to each market.

Output from these models include:

— the annual harvest by log grade;

— the area in each stand or croptype age-class which is harvested each year;

— the volume of each log grade which is allocated in each period from each forest to each market.

The trend towards incorporating greater processing plant detail into estate models is continuing. For example, a recent development in FOLPI has been to allow the flow of residues (e.g. chips) from solidwood plants to residue-using plants to be explicitly modelled. This means that the demand from residue-using plants can be met either by supplying logs or residues.

SHORT-TERM HARVEST PLANNING

The trend to using estate models for planning shorter and shorter time horizons has reached the stage where there is interest in modelling weekly log production and allocation. Here the issue is:

Given the volume available in stands and dumps, the logging capacity, the location of current logging and the next period's market demand for individual log products at each destination:

- which stands should be harvested?
- which cutting strategy should be assigned to each stand?
- what volumes of each log product type should be transported from each stand and dump to satisfy market requirements?

Currently, companies use manual methods and spreadsheets to match crew production and stocks with demand schedules. Clearly there is an opportunity to use analytical information tools in this area. A prototype model developed at FRI indicated the potential for such tools. Research is underway to develop an integrated harvesting management system (Cossens and Murphy 1995).

SPATIAL DETAIL

There has been very little spatial detail incorporated within estate models. Certainly with highly-aggregated croptypes there has been limited ability to do so. As stand-level detail is increasingly maintained in estate models, there is a need to be able to identify and model the interaction between stands, e.g. stands which it makes sense economically or environmentally to harvest simultaneously or to harvest in different periods. The restrictions placed in parts of the Pacific Northwest of North America on harvesting adjacent stands until 'green-up' has occurred is an example of this.

The incorporation of adjacency-type constraints into estate models imposes solution difficulties by changing relatively easy to solve linear programming (LP) formulations into mixed-integer LP formulations with exponentially increasing solution time. Research is currently being carried out to develop efficient solution strategies for solving FOLPI models incorporating adjacency constraints.

Another area being explored is the linkage between estate models and Geographic Information Systems (GIS). Integration of GIS within an estate modelling system provides opportunities for enhanced model formulation and reporting for problems where the spatial dimension is important.

CONCLUDING REMARKS

Forest estate modelling systems have traditionally been used for long-term yield regulation. However, computer hardware and software developments have expanded their domain of applications both in terms of the time horizon and the level of detail modelled.

The IFS and FOLPI estate modelling systems represent flexible frameworks within which a wide range of forest estate models have been built. Applications have varied in terms of:

- the user (private company, State-owned enterprise, consultant, teacher, researcher);
- the purpose;
- the time horizon modelled (1 week to 100 years);
- the estate size (50 ha to 1.4 million ha);
- the level of aggregation of the estate;
- the level of processing plant detail incorporated.

The natural progression of these tools means that not only can they help answer the questions:

- how much wood have we got?
- when should we cut it?
- what will it give us?

but also such issues as:

- what stands should be cut?
- what cutting strategy should be used?
- which processing plant should logs be sent to?

REFERENCES

Allison, B.J. 1980. RMS80 — Resource Maturity and General Management Simulator. NZ Forest Products Ltd.

Cossens, G.P. and G.E. Murphy 1995. New tools and techniques for managing value from plantation forests. In Moore J. and S.D. Carson (Comp.). Proceedings of the New Zealand Institute of Forestry Conference 1995 "Practical Applications for New Technologies": 125-141.

Deadman, M.W. and C.J. Goulding. 1979. A method for the assessment of recoverable volume by log types. New Zealand Journal of Forestry Science 9(2): 225-239.

Garcia, O. 1981. IFS, an interactive forest simulator for long range planning. New Zealand Journal of Forestry Science 11: 8-22.

Garcia, O. 1984. FOLPI, a forestry-oriented linear programming interpreter. In Nagumo, H. *et al.* (Ed.) Proceedings IUFRO Symposium on Forest Management Planning and Managerial

Economics. University of Tokyo: 293-305.

Garcia, O. 1988. Experience with an advanced growth modelling methodology. In: A.R. Ek, S.R. Shifley and T.E. Burke (Editors), Forest Growth Modelling and Prediction. US Dep. Agric. For. Serv., Gen. Tech. Rep. NC-120: 668-675.

Gleason, A. and C. Bailey. 1992. The market and harvest planning of the Kinleith Forest. In Whyte, A.G.D. (Ed.). Proceedings of IUFRO S3.03.01 Conference "Integrated Decision-making in planning and control of forest operations". University of Canterbury: 69-75.

Gordon, A. 1992. STANDIN - flexible forest management inventory. FRI. What's New in Forest Research No. 219.

Gordon, A.D., M.E. Lawrence and D. Pont 1995. Assessing The Potential Log-Yield of Stands Prior to Harvesting. In Proceedings 1995 Institute of Foresters of Australia Conference "Applications of New Technologies in Forestry", Ballarat, Victoria: 193-200.

Goulding, C.J., M.W. Deadman and M.E. Lawrence 1993. Assessing stem qualities and using dynamic programming to predict log-product volumes in inventory. In Nyyssonen, A., Poso S. and Rautala J., (eds), Proceedings of Ilvessalo symposium on National Forest Inventories, August 1992, Helsinki. Finnish Forest Research Institute Research Paper 444: 171-178.

Goulding, C.J., 1994. Development of growth models for *Pinus radiata* in New Zealand — experience with management and process models. Forest Ecology and Management 69: 331-343.

Knowles, L. 1994. New Zealand Experience with Silvopastoral Models at the Stand and Estate Levels. Proceedings Third North American Agroforestry Conference, Ames, Iowa, 16-18 August 1993.

Manley, B.R. and J.A. Threadgill. 1991. LP used for valuation and planning of New Zealand forests. *Interfaces 21*: 66-79.

Manley, B.R., S. Papps, J. Threadgill and S. Wakelin. 1991. Application of FOLPI: A Linear Programming Estate Modelling System for Forest Management. Ministry of Forestry, FRI Bulletin No. 164.

Manley, B. 1994. New Zealand experience in linking short-term and long-term forest planning. In Paredes, G.L. (Ed.). Proceedings of the International Symposium on Systems Analysis and Management Decisions in Forestry, Valdivia, Chile: 315-335.

McGuigan, B. and J. Scott. 1995. RegRAM-I — A flexible, forest harvest scheduling and industrial processing, global optimisation model. New Zealand Forestry 40(2): 17-20.

Nelson, J.; J.D. Brodie and J. Sessions. 1991. Integrating short-term, area-based logging plans with long-term harvest schedules. Forest Science 38(1): 101-122.

Te Morenga, L.; B. Manley and S.J. Wakelin in prep. Evaluation of alternative methods of croptyping in forest estate modelling. Paper submitted for refereeing for NZ Journal of Forestry Science.

Tennent, R.B. 1992. "The Forest Master, a Forest Management System". FRI Software Series No. 11.

West, G.G., R.L. Knowles and A.R. Koehler. 1982. Model to predict the effects of pruning and early thinning on the growth of radiata pine. New Zealand Forest Service, FRI Bulletin No. 5.

West, G.G. 1994. A review of the development and use of the New Zealand stand modelling system: STANDPAK. *In* Paredes, G.L. (Ed.). Proceedings of the International Symposium on Systems Analysis and Management Decisions in Forestry, Valdivia, Chile: 181-189.

Whiteside, I.D. 1990. STANDPAK modelling system for radiata pine. Pp. 106-111 *In*: James, R.N.; Tarlton, G.L. (Ed.). "New Approaches to Spacing and Thinning in Plantation Forestry". Proceedings of IUFRO Symposium. Ministry of Forestry, FRI Bulletin No. 151.