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EVALUATION OF THE ECONOMIC VALUES OF WOOD AND WATER FOR THE THOMSON CATCHMENT

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SUMMARY AND CONCLUSIONS

The Thomson Catchment is a large component of Melbourne Water's total system capacity. It is known that a reduction in timber harvesting in the catchment would result in greater streamflow yields and hence an increased water supply to Melbourne. An extensive research program into catchment hydrology, undertaken by Melbourne Water, has defined the relationship between streamflows and the age of forest stands.

The purpose of this study has been to assess the economic values of timber and water production from the Thomson catchment and to evaluate a range of options, involving different mixes of wood and water production, from a viewpoint of maximising the net economic value of catchment outputs.

The study has been funded jointly by Melbourne Water and the Department of Conservation and Environment. It was directed by a Steering Committee comprising representatives of Melbourne Water, Department of Conservation and Environment, Department of Water Resources, the timber industry and the conservation movement.

Scope of Analysis

The Thomson catchment forms part of DCE's Central Gippsland forest management area (FMA) and the present policy is to harvest the entire FMA on an 80 year rotation. Timber yields and volumes have been simulated for eight discrete silvicultural options which were specified by the Steering Committee for this consultancy:

- *Status quo (80 year)*
- *Cease logging now (NO LOG)*
- *Longer rotation (120 year)*
- *Very long rotation (200 year)*
- *Short rotation (40 year)*
- *80 year rotation in combination with thinning (80 thin)*
- *200 year rotation in combination with thinning (200 thin)*
- *Corridor thinning followed by long rotation (BIG STRIP)*

However, it is stressed that the "best" of those options does not necessarily represent an optimal mix of wood and water production. That is, there could be better options than the eight discrete options nominated for this study. The consultancy has considered a wider set of options in a conceptual framework and by using dynamic programming models but the major thrust, in terms of professional input, has been directed at an evaluation of the eight options which were nominated by the Steering Committee.

Simulation of Wood Yields

The gross volumes of wood produced under the eight discrete options were estimated by means of STANDSIM, a model for simulating the growth and yield of even-aged stands of several species of Eucalyptus. The validity of the model for the Ash-type stands of the Thomson catchment was tested in a number of ways. Simulation models of forest production were developed for each of the eight management options and these models took account of the different forest types according to species and a age.

Simulation of Water Yields

The streamflow observed at the Thomson Dam is not generated uniformly over the catchment area. Ash type forests are found on the more elevated parts of the catchment, where rainfall is higher, and contribute 60 per cent of the total water yield. Mixed species eucalypt forests occur in lower rainfall locations. There are small, but significant areas of non-eucalypt species. Water yield from the Thomson catchment is currently increasing, as the ash forest recovers from the 1939 bushfires.

Flow sequences were computed for each option by assuming water yields, based on research findings, for the main vegetation species of the catchment. The expected flow sequences for each scenario were used in conjunction with projected consumption levels to determine the timing of future augmentations to the Melbourne supply system.

Overall, the no logging option yields the most water. There are significant differences between options with respect to the (1) water yields from the Thomson catchment and (2) the likely timing of future augmentations to the capacity of Melbourne Water's urban system. The most significant effects on future augmentations occur well into the next century.

Timber and Water Prices

At the outset, it must be emphasised that values of timber and water are compared on a common basis. Water is valued in the streams of the catchment and timber is valued standing in the catchment prior to harvest.

The prices of both timber and water are set by Government rather than determined by competitive forces in a market. For an economic analysis, it is necessary to estimate such a market price. This cannot be done with great precision; therefore, a range of prices is considered for each commodity. In both cases, the true but unknown value is judged to lie within the relevant range.

Unfortunately the demand characteristics for Melbourne's urban water supplies are not clearly understood. However, there is considerable published information available which has been of use in forming judgements about the demand schedule for urban water. Harvested water is valued in the streams of the catchment in the year that it enters the reservoir. The consultants have assessed that, for the purposes of this study, values in the stream are likely to lie in the range $235 to $675 per ML or higher.

Harvested timber is valued in the year that it is cut. Royalties represent prices for standing timber in the catchment but are administered by Government rather than being determined competitively in a market. For the purposes of this economic study, a range of shadow prices for timber is tested:

"high" prices	*70 per cent above royalty*
"base" prices	*estimates which represent 33, 41 and 61 per cent above royalty for A and B, C and D class logs respectively.*
"low" prices	*royalty*

Results

The general approaches to the problem (analytical solution and dynamic programming) show that the starting position for the catchment affects considerably the optimal rotation. For the situation where the starting position is bare land, the optimal "rotation" would involve keeping the catchment as bare land; that is, to destroy forest regrowth as it occurs. However, when the initial situation is one of standing forest, then the optimal rotation depends on the age of forest in the initial situation.

For a standing forest, economic output would be increased the most by either ceasing logging or by increasing rotation length together with an increased use of thinning techniques. There is insufficient evidence from this study to determine categorically which of those changes would yield the greatest benefit.

The optimal solution for the Thomson Catchment is influenced considerably by the expected rate of increase in demand for water in Melbourne. Melbourne's actual demand growth is presently more than 2 per cent. At a rate of growth in consumption of about 1.5 per cent or higher, the optimal solution of the dynamic programming model involves no logging. At lower rates of growth in *consumption, the optimal solution involves the continuation of logging with longer rotations and/or increased use of thinning.*

Taking into account the uncertainties associated with the forestry, hydrologic and economic analyses, it is judged that the accuracy of this analysis has been suitable for an assessment of the relative merits of one option versus another, but not for the purposes of predicting absolute levels of additional value for catchment outputs.

The results are best summarised as indicating that a change in management of the forests in the Thomson Catchment would increase the economic value of catchment outputs. The important message is that the status quo does not maximise the total value of timber and water outputs from the catchment and that a range of changes to catchment management would result in significant gains.

While the consultants have specified a range for many prices, they have nominated their preferred estimates within those ranges as the "base case" for analysis. The prices used for that base case include the following:

Discount rate	*4 per cent*
Water value	*$530 per ML*
Sawlog value	*Royalty plus 33 to 61 per cent*

The present value of the net gain from changing to each of the options is presented in the graph on the next page. Only the relative change in NPV is presented since the approach adopted has involved "partial budgets". The partial budgets used do not provide meaningful estimates of the absolute size of economic values for catchment outputs.

Long rotations (with or without thinning) or the cessation of logging, each involves a NPV of catchment outputs which is about $100 M to $170 M greater than the status quo. It is concluded that an increase in rotation length or a cessation of logging would increase substantially the value of catchment outputs, but that a superior option may be to increase rotation length in conjunction with the introduction of corridor thinning.

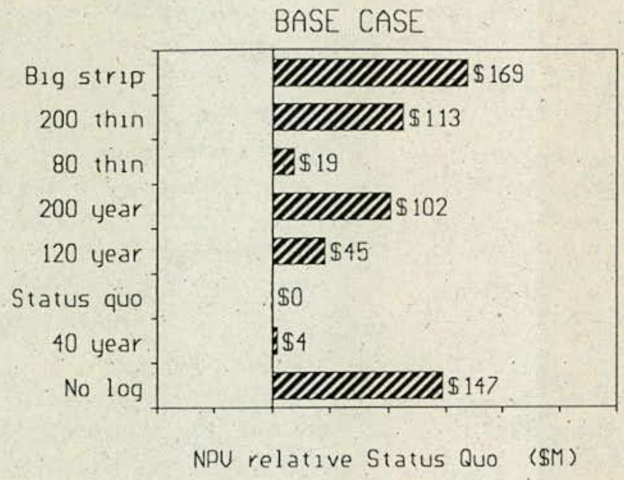
The ranking of the options is not very sensitive to changes in timber prices and water prices over the range tested. Water prices influence greatly the size of the gain to the economy from a reduction in timber harvesting for each option, but not the relative ranking between the options. The discount rate used in the analysis does not affect greatly the ranking of options except that the no logging option becomes superior to all other options the lower the discount rate.

Overall, the sensitivity analyses undertaken have led the consultants to the conclusion that the base case ranking of the options is robust over the range of prices and costs tested. A robust solution being one in which further detail would not change the decision as to which is the most efficient option from the set considered. Further detailed analysis beyond that point would improve only the estimate of the margin by which a particular option was the most efficient, but not the decision to which is the most efficient option. However, further consideration could be given to additional options.

The choice between ceasing to log and adopting long rotations is a very difficult one. They would each appear to lead to a similar Net Present Value (NPV) of catchment outputs and each have similar degrees of risk. Either avoids the risk of precluding other options in the future.

Another way of interpreting the results is to consider what can be gleaned from the results without estimating a water price. This can be ascertained by asking the question "How high does the value of water in the streams of the Thomson have to be in order to justify a reduction in timber harvesting?".

The results show that price to be about $150 to $200 per ML for the no logging and long



rotations (with and without thinning). That is, the value of additional water in the streams of the catchment would exceed the value of the timber foregone for any price of water in those streams of greater than $150 to $200 per ML, depending on the option. Therefore, it would be necessary for water at the tap to be worth at least that amount plus the costs of supplying the additional water from the streams to the taps in Melbourne.

Melbourne Water has indicated that the only costs involved in transforming the additional water in the stream, resulting from changed forest management, to water at the tap in Melbourne are the additional pumping and disinfection required and those costs amount to about $25 per ML. Only those costs are considered because the capital costs for the existing headworks and distribution infrastructure and the maintenance costs must be ignored as they have already been committed and would not vary because of additional water yield from the catchment.

Given our assessment that the economic value of water in the stream is likely to lie in the range $235 to $675 per ML or higher, it is concluded that the value of additional water in the streams of the catchment would exceed the value of the timber foregone for all options other than the status quo.

Further Study

It must be emphasised that this study has considered the mix of catchment outputs only from the viewpoint of economic outputs. Before a final decision can be made for the Thomson Catchment, it would be necessary to consider other viewpoints. For example, consideration needs to be given to:

- *implications of various management strategies for recreation values and conservation values of the catchment; for example, environmental values such as flora and fauna reserves, wildlife corridors, areas prone to landslip and erosion, areas of landscape significance, and sites of archaeological, cultural and historic interest;*
- *implications for employment levels and the regional economy;*
- *implications for non-consumptive uses of water from Thomson catchment; e.g.*

flushing of Gippsland Lakes.

- *implications for the administration of State Forests by the Department of Conservation and Environment.*

In hindsight it would have been useful to examine some additional options to the eight options nominated by the Steering Committee. In particular, consideration could be given to evaluating the following:

- *Specify the status quo as involving the harvest of 1/80th of the productive area in every year, thereby avoiding the confusion introduced by the fact that DCE intends varying the rate of harvest between decades.*

- *The "Big Strip" option gave the highest level of catchment outputs, but it is not clear whether this result would vary greatly for options involving corridor thinning in conjunction with shorter or longer rotations.*

- *In order to evaluate fully the effects of uniform thinning, it would be necessary to specify an option(s) involving uniform thinning alone, preferably for a range of rotation lengths.*

- *It has been clearly established for ash-type forests that water yields are lower early in the rotation, that is, when volume growth and sapwood cross-sectional area are at a maximum, usually from about ages 10 to 40 years. This suggests that a non-commercial thinning, say at age 10 years, may provide a considerable increase in water yield.*

Such non-commercial thinning options could be evaluated for a range of rotation lengths.

It must be remembered that technical aspects of corridor thinning have been predicted based solely on the results of research trials. Further study would be required into aspects such as the appropriate orientation of cleared strips, appropriate layout for roading, environmental impacts for flora and fauna, the extent of regrowth from the cleared strip in the longer term, and the longevity of water yield increases.

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1. INTRODUCTION

The purpose of this study has been to assess the economic values of timber and water production from the Thomson catchment and to evaluate a range of options, involving different mixes of wood and water production, from a viewpoint of economic efficiency. This involved simulating the quantities of wood and water to be produced under a range of catchment management options and identifying those options which produce the greatest net economic value of catchment outputs for the State. The terms of reference for this study are presented in Appendix A.

The study has been funded jointly by the Department of Conservation and Environment (DCE) and by Melbourne Water. It was directed by a Steering Committee comprising representatives of Melbourne Water, DCE, Department of Water Resources, the timber industry and conservation movement. Members of the Steering Committee are listed below:

Mr. P. O'Shaughnessy, Melbourne Water (Convenor)
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This report contains four main sections in which are considered the process of simulating timber yields (Section 2), simulation of water yields (Section 3), and the economic valuation of those yields and evaluation of a range of management options using several approaches to economic analysis (Section 4).

For ease of reading, the main report does not include full documentation of source material, but this is included in the detailed Appendices attached to the report.

2. SIMULATION OF STAND GROWTH AND TIMBER YIELDS

Timber growth and harvested yields have been simulated for the eight discrete silvicultural options which were specified by the Steering Committee for this consultancy. DCE provided considerable data for use in the simulation of stand growth and timber yields. Information about the timber resource in the Thomson Catchment which has been provided by DCE is presented in Appendix B.

2.1 SILVICULTURAL OPTIONS CONSIDERED

The Steering Committee acknowledged from the outset that a list of eight options was a major constraint on the study and urged the consultants to identify further promising options which might emerge during the course of the study. Accordingly a number of changes were made during this study, in consultation with the Steering Committee, to the definition of the eight options. Furthermore some suggestions for further study are presented in Section 4.6. The eight options modelled during this study are described below.

2.1.1 Status quo (STATUS QUO)

The present management of the Thomson catchment is in accord with DCE's published policy that minimum rotations should be 80 years for ash-type stands. If the Thomson Catchment was considered in isolation, one would expect an 80 year rotation to involve the harvesting of $1/80^{th}$ of the productive area in each year; that is, about 158 ha per year of ash-type forest. However, the Thomson Catchment is not managed in isolation, but as a part of the Central Gippsland Forest Management Area (FMA).

The Central Gippsland FMA is being managed on a sustainable yield basis to yield 183,000 cubic metres per year of all species. For a number of reasons, including the presence or otherwise of roads, different parts of the Central Gippsland FMA are harvested at different rates. So far, relatively little of the Thomson Catchment has been harvested.

The average area clear felled in the Thomson has been less than 40 ha per year over the past two decades which is much less than the 158 ha per year expected of an 80 year rotation. However, DCE's policy for the Thomson Catchment is to increase the rate of cutting for ash-type stands to range between 184 and 216 ha per year over the next four decades. This is to be followed by a rate of 124 per hectare per year for the following two decades, substantially less than $1/80^{th}$ of the total area. Thus harvesting in the Thomson, which is expected to take 85 years, will peak in the next 40 years and then decline.

To simulate the future outputs from the STATUS QUO, the consultants used these DCE estimates of the area of each forest type which it expects to be clear felled over the next 60 years, that is, up to the decade ended 2042. Thereafter it was assumed that $1/80^{th}$ of the productive stands would be cut each year. For particular age stands, where all forest is less than 80 years old, then no timber is cut again from those stands until the forest regrowth reaches an age of 80 years.

2.1.2 Cease logging now (NO LOG)

Cease logging immediately throughout the Thomson catchment.

2.1.3 Short rotation (40 year)

From 1992 onwards it was assumed that harvest schedules for ash-type stands would represent $1/40^{th}$ of the productive stands being clear felled each year for all areas available for wood production. It was not considered appropriate to harvest mixed species at 40 years owing to their slower growth rates. Instead the harvest schedules for mixed species would represent $1/80^{th}$ of the productive stands being clear felled each year.

2.1.4 Longer rotation (120 year)

A conventional 120 year rotation involving clear felling of equal areas of forest each year followed by regeneration from seed. It was assumed that harvest schedules henceforth from 1993 would represent $1/120^{th}$ of the productive stands being clear felled each year for all areas available for wood production.

2.1.5 Very long rotation (200 year)

A conventional 200 year rotation involving clear felling of equal areas of forest each year followed by regeneration from seed. It was assumed that harvest schedules henceforth from 1993 would represent $1/200^{th}$ of the productive stands being clear felled each year for all areas available for wood production.

2.1.6 80 year combination thinning rotation (80 THIN)

An 80 year rotation involving a uniform thinning, removing 40 per cent basal area, of ash stands at age 20 years to be followed by corridor thinning at age 50 years and clear felling at age 80 years prior to regeneration from seed.

Uniform thinning is unsafe on very steep slopes and DCE provided an estimate that the area of potentially thinnable areas of ash type forest (forest slopes $< 18^0$) was only 7140 ha. However, DCE also advised the Steering Committee that only 25 per cent, or 1785 ha, of that area would be suitable for thinning. Consequently only 1785 ha of 1939 ash regrowth forest is assumed to be suitable for uniform thinning. The remaining area of ash-type forest and mixed species is specified as being harvested according to the schedule assumed above for the "status quo" rotation; that is, not thinned.

2.1.7 200 year combination thinning rotation (200 THIN)

A 200 year rotation involving uniform thinning, removing 40 per cent basal area, of ash stands at age 20 years to be followed by corridor thinning at age 50 years and clear felling at age 200 years prior to regeneration from seed. Once again, only 1785 ha of 1939 ash regrowth forest is specified as suitable for thinning.

2.1.8 Corridor thinning with long rotation (BIG STRIP)

A hypothetical rotation involving the corridor thinning of 200 ha for each of the first 30 years 1993 to 2022, to be followed by clear felling of $1/200^{th}$ of the total productive area in the Thomson catchment each year. The corridor thinning of 6,000 ha would involve clearing alternate corridors of 35 metre width thereby leaving 3,000 ha as cleared strips with only understory cover and 3,000 ha as strips of forest. That is, about half of the productive area of 1939 ash-type regrowth would be transformed into alternate strips of forest and cleared land.

The strips of forest would be managed as part of the overall rotation whereby, once they reached a suitable age, the strips would be clear felled as part of the overall harvest program involving 1/200th of the total productive area in the Thomson catchment each year. The strips which were cleared earlier, and which would support mainly understory species would then be cleared also in order to promote regeneration for the subsequent rotation.

2.2 SIMULATION OF STAND GROWTH

The main wood-producing tree species of the Thomson catchment are the three ash-type species *Eucalyptus regnans, Eucalyptus delegatensis, and Eucalyptus nitens.*

The gross volume of wood yielded under each option was estimated by means of the simulation model, known as STANDSIM. STANDSIM is a Fortran-coded program which is used for simulating the growth and yield of even-aged forest stands under a range of thinning options. STANDSIM was specified initially for *E. regnans* (Opie 1972), but with the capability of adaptation for other species. The model was modified subsequently to improve its speed and accuracy, to accommodate various forms of strip thinning and other eucalypt species, to operate stochastically and to suit personal computers (Incoll 1974, Campbell 1974, Coleman 1990).

The growth information available for the study was of three kinds:

1. As embodied in the STANDSIM model, which provides growth and yield estimates for the ash species *E.regnans* and *E.delegatensis*, and a relatively fast growing representative of the "mixed species" group, *E.sieberi*. STANDSIM incorporates extensive growth information for these species taken from a large selection of spacing studies, thinning trials, yield plots, taper studies and individual tree data from throughout south eastern Australia.

2. Various published data on growth and yield for the Thomson catchment.

3. Further data on mean annual increment (MAI) of ash-type and mixed species stands of the Thomson catchment provided during the course of the study by DCE (see Appendix B).

The DCE data were necessarily restricted in their coverage, particularly in respect of stand age and response to thinning. Estimates of yield data were required for a wide range of stand ages (from ages 10 to 250) as well as for certain thinning treatments, a task which requires a variable density yield table or a comprehensive stand growth model such as STANDSIM. The question of applicability of the STANDSIM model for the particular case of the Thomson was accordingly addressed.

The data used in the development of STANDSIM for the ash-type species was drawn largely from the ash forests of the Central Highlands of Victoria, of which the Thomson catchment appears to be reasonably representative. Since its initial development STANDSIM has undergone a number of changes. Therefore, it was considered prudent to re-establish the validity of the model for the Thomson catchment.

The task of establishing whether the growth and yield estimates of STANDSIM were compatible with the two sets of estimates provided by DCE proceeded as follows:

> Compatibility for the ash species was tested initially by running simulations of stands to age 40 years and comparing the diameter distributions and other outputs so obtained with actual stands of that age, as recorded in the DCE documents. At a later stage testing was also done by comparing STANDSIM output for the ash-type species with MAI data provided by DCE.
>
> The mixed species simulation was tested by comparing STANDSIM output for *E.sieberi* of several site indexes with mean annual increment data provided by DCE. The mixed species of the Thomson contain little if any of the relatively fast-growing *E.sieberi.*

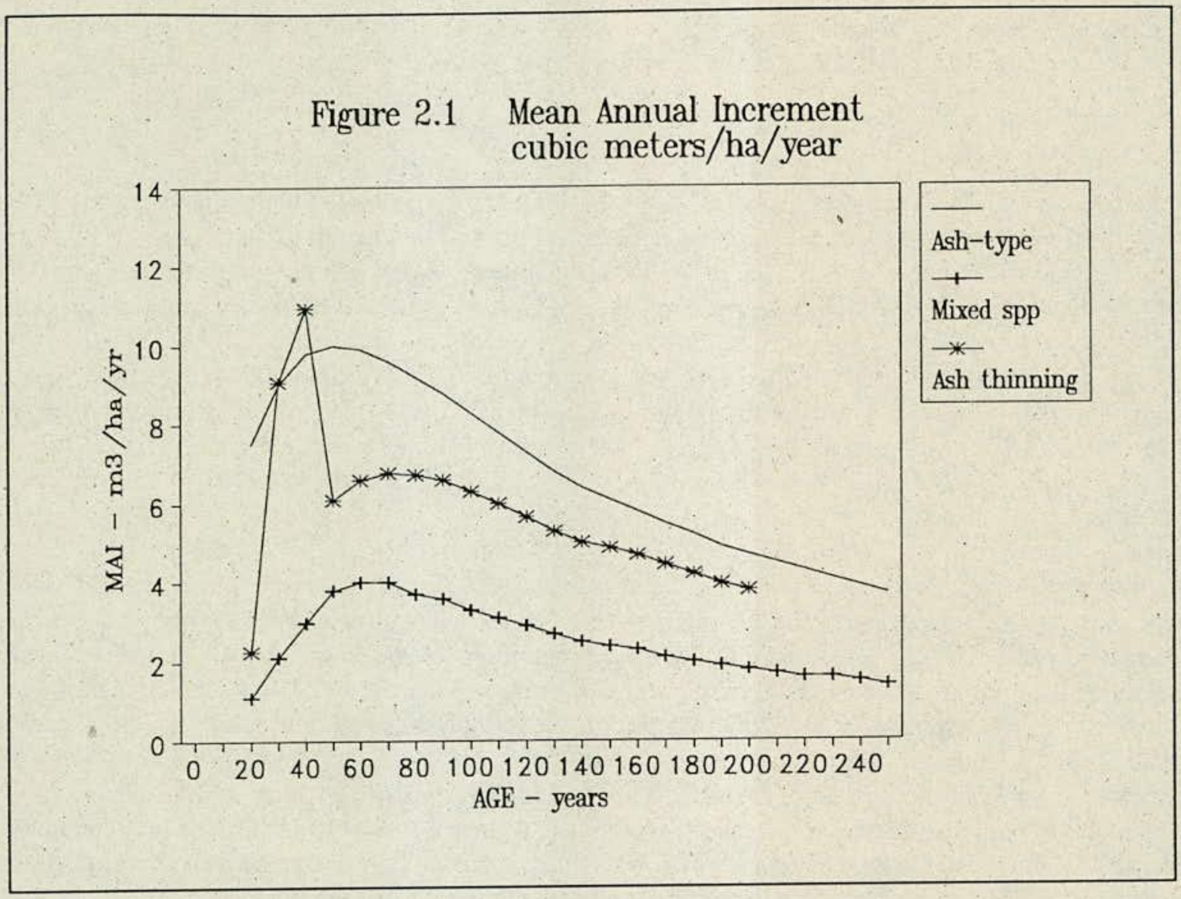
With respect to the MAIs, the figures provided by the DCE for the Thomson catchment data were, over most of the range, reasonably compatible with STANDSIM simulations of average site index. There was, however, an important discrepancy concerning the peak of the MAI curve. Certain theoretical and empirical considerations suggest that in this matter the DCE data may be understating the maxima, and displacing it too far to the right. Nevertheless, to be conservative, a compromise position was adopted. With respect to the mixed species, it was found that the DCE data for the Thomson catchment were in aggregate much lower than STANDSIM estimates for E.sieberi stands of medium to poor site index. In the case of the mixed species, STANDSIM was used only to indicate the general form of the yield curve, which was then scaled down. The estimated mean annual increments which have been adopted for this study are presented in Figure 2.1.

2.3 SIMULATION OF HARVESTED TIMBER VOLUMES

From the basic data of the forest resource base, provided by DCE (see Appendix B), a series of spreadsheet models of the forest resource was developed to provide data for the water yield simulation and economic studies. Simulation models of forest production were developed for each of the eight silvicultural management options outlined in Section 2.1. These models took account of the different forest types (ash type and mixed species) and a series of forest stand age classes in each forest type, and were applied for harvesting periods of ten years duration throughout the planning period nominated by the Steering Committee, namely 200 years from 1992 .

In the timber harvesting schedules applied to the ash-type stands, the oldest age classes were not necessarily harvested prior to starting on the younger stands. It was recognised that manipulation of woodflows may be achieved by a variety of harvesting schedules.

The spreadsheet models were based on growth and stand yield data simulated by the consultants using the STANDSIM model described in Section 2.2. These yield data were developed into a series of "Standard Yield Tables" which provided the basic information for the various computer models developed for the studies.



The standard yield tables are presented in Table 2.1 and detail:

- mean annual increment (MAI) m^3/ha/year;
- mean A class and B class[a] sawlog yields - m^3/ha;
- mean C class sawlog yields - m^3/ha;
- total mean sawlog yields - m^3/ha;
- mean pulpwood yields - m^3/ha.
- total mean merchantable timber yield - m^3/ha

To develop the spreadsheet models, the forest resource data provided by DCE and the standard yield tables were combined to provide the following for each 10 year period:

- areas of forest progressively harvested;
- timber yields to be obtained by sawlog classes and pulpwood;
- ages and areas of regrowth;
- the remaining areas not harvested during each 10 year period including areas excluded from harvesting.

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[a]*DCE mostly grades timber produced from native forests into four sawlog grades, A to D, and pulpwood. Sawlogs are graded either A, B, C or D on the basis of a variable relationship between log size and the number, size and severity of defects. For the purposes of timber yield calculation for this consultancy, Classes A and B have been combined owing to the very small proportion of Class A logs produced. Also Class D logs have been grouped with pulpwood owing to their generally poor quality.*

The ash resources were simulated at 10 year intervals for a period of 250 years from 1942 to 1992 and the mixed species at 10 year intervals for 350 years from 1852 to 2192. These differing time periods were used to take account of the areas available for harvesting of the various age classes of the forest types. For example, due to reservations and exclusions from harvesting for various environmental reasons, only ash type forests originating from the 1939 bushfires and later are available for harvesting, on the other hand for the mixed species forests, 4145 ha estimated to originate from wildfires in the 1850s are available for harvesting.

The spreadsheet models in essence provide the following information:

For the Dynamic Optimising Model

Two series of yield projections were prepared at 5 year intervals and 10 year intervals providing:

- mean annual growth increment (MAI) m^3/ha/year;
- total merchantable timber yields m^3/ha;
- class A and B sawlog yields m^3/ha
- class C sawlog yields m^3/ha
- pulpwood yields m^3/ha

For the Water Simulation Studies

Spreadsheet models were developed for the eight different silvicultural options, the ash type and mixed species forest types and each current forest age class, which provided:

- the area cut during each 10 year harvesting period;
- the uncut area remaining;
- the various ages of the regrowth present in each 10 year period;
- the area of each age class of regrowth existing for each 10 year period.

For the Economic Analyses

Spreadsheet models were developed of the eight different silvicultural options, which simulated wood supplies for the range of nominated harvesting schedules from both ash type forests and mixed species forests, and the various age classes present for each 10 year period. The information provided comprised, for each forest type and age class:

- the area harvested for each age class;
- area remaining for the age class;
- timber yields of A class and B class sawlogs - m^3;
- timber yields of C Class sawlogs - m^3;
- total sawlog yields - m^3;
- pulpwood yields - m^3;
- combined timber yields of sawlogs and pulpwood - m^3;
- total timber yields for the catchment for each sawlog class and for pulpwood - m^3.

The areas of forest harvested in each decade are presented in Appendix C. The combined timber yields of sawlogs and pulpwood which have been simulated for each option are presented in Figures 2.2a and 2.2b.

TABLE 2.1 - STANDARD YIELD TABLES

ASH-TYPE

Year	1942	1952	1962	1972	1982	1992	2002	2012	2022	2032	2042	2052	2062	2072	2082	2092	2102	2112	2122	2132	2142	2152	2162	2172	2182	2192
Age	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250
Periodic MAI m3/ha/yr			7.5	9.0	9.8	10.0	9.9	9.6	9.2	8.8	8.3	7.8	7.3	6.8	6.4	6.1	5.8	5.5	5.2	4.9	4.7	4.5	4.3	4.1	3.9	3.7
Tot. Merch. Yld m3/ha			120	216	314	400	475	538	589	634	664	686	701	707	717	732	742	748	749	745	752	756	757	754	749	740
S'log A&B Yld m3/ha			0	0	0	69	82	116	127	136	143	148	151	152	154	157	160	161	161	160	162	163	163	162	161	159
S'log C Yld m3/ha			0	0	125	91	108	153	168	181	189	196	200	202	204	209	212	213	213	212	214	215	216	215	213	211
Sawlog Yld m3/ha			0	0	125	160	190	269	294	317	332	343	350	354	358	366	371	374	374	372	376	378	378	377	374	370
Pulpwood Yld m3/ha			120	216	188	240	285	269	294	317	332	343	350	354	358	366	371	374	374	372	376	378	378	377	374	370
Total Merch. Yld			120	216	314	400	475	538	589	634	664	686	701	707	717	732	742	748	749	745	752	756	757	754	749	740

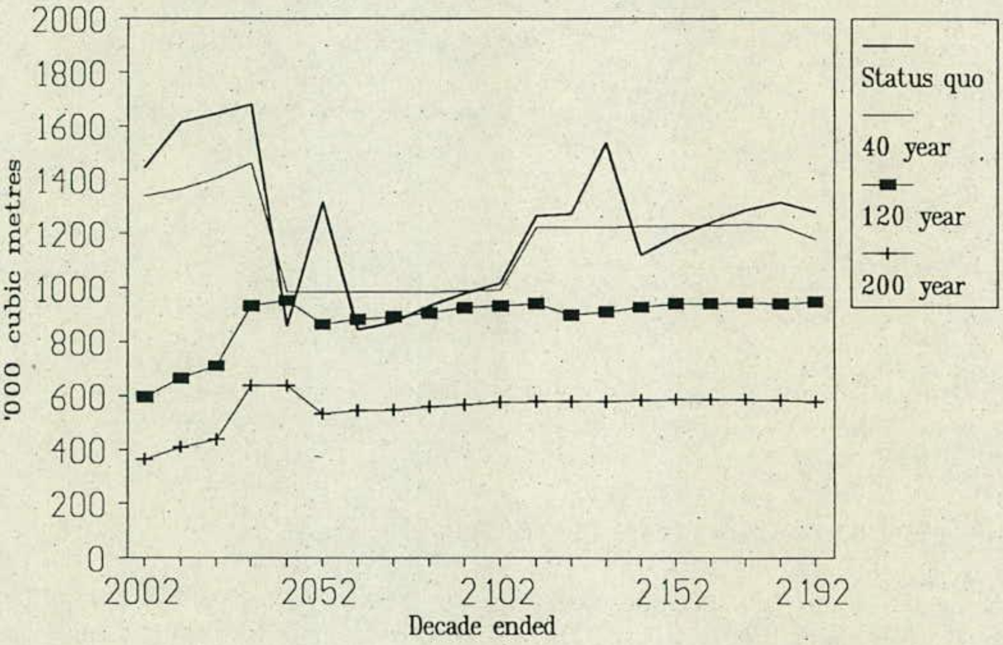
MIXED SPECIES TYPE

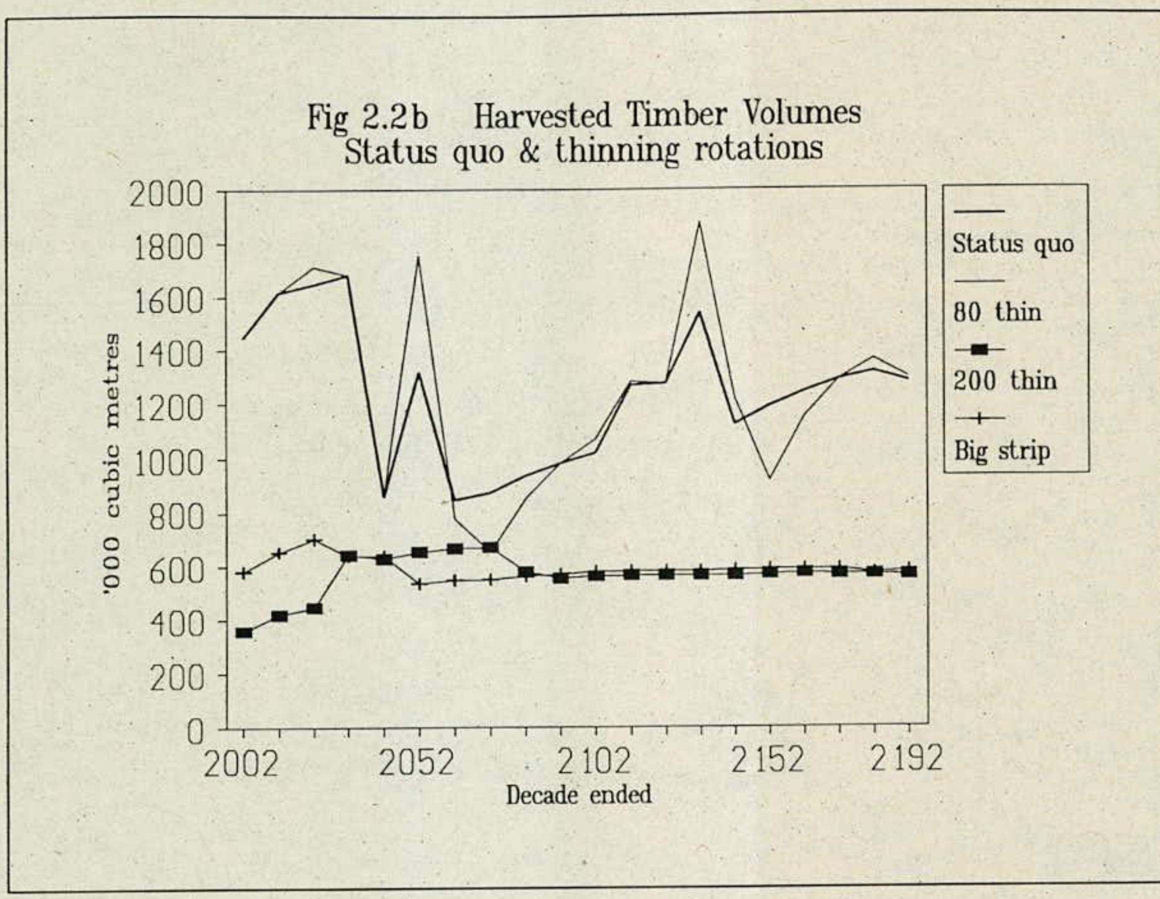
Year	1852	1862	1872	1882	1892	1902	1912	1922	1932	1942	1952	1962	1972	1982	1992	2002	2012	2022	2032	2042	2052	2062	2072	2082	2092	2102	2112	2122	2132	2142	2152
Age	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250	260	270	280	290	300
Periodic MAI m3/ha/yr			1.1	2.1	3.0	3.8	4.0	4.0	3.7	3.6	3.3	3.1	2.9	2.7	2.5	2.4	2.3	2.1	2.0	1.9	1.8	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.2
Tot. Merch. Yld m3/ha			18	50	96	152	192	224	237	259	264	273	278	281	280	288	294	286	288	289	288	286	282	294	288	280	291	281	291	278	288
S'log A&B Yld m3/ha			0	0	0	0	0	11	11	12	13	13	13	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
S'log C Yld m3/ha			0	0	0	51	64	79	83	91	93	96	98	41	41	42	43	42	42	42	42	42	41	43	42	41	43	41	43	41	42
Sawlog Yld m3/ha			0	0	0	51	64	90	95	104	106	109	111	47	47	48	49	48	48	48	48	48	47	49	48	47	49	47	49	46	48
Pulpwood Yld m3/ha			18	50	96	101	128	134	142	156	158	164	167	234	233	240	245	238	240	241	240	238	235	245	240	233	243	234	243	232	240
Total Merch. Yld			18	50	96	152	192	224	237	259	264	273	278	281	280	288	294	286	288	289	288	286	282	294	288	280	291	281	291	278	288

ASH TYPE THINNING MODEL

Year	1992	2002	2012	2022	2032	2042	2052	2062	2072	2082	2092	2102	2112	2122	2132	2142	2152	2162	2172	2182	2192
Age	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
Periodic MAI m3/ha/yr			2.3	9.1	10.9	6.1	6.6	6.8	6.7	6.6	6.3	6.0	5.7	5.3	5.0	4.9	4.7	4.5	4.2	4.0	3.8
Tot. Merch. Yld m3/ha	0	0	36	218	350	244	317	379	431	475	506	528	542	549	559	586	600	605	606	602	610
S'log A&B Yld m3/ha	0	0	0	0	0	52	68	82	93	102	109	114	117	118	120	126	129	130	130	129	131
S'log C Yld m3/ha	0	0	0	109	175	70	90	108	123	135	144	150	155	156	159	167	171	172	173	172	174
Sawlog Yld m3/ha	0	0	0	109	175	122	158	190	215	238	253	264	271	275	279	293	300	303	303	301	305
Pulpwood Yld m3/ha	0	0	36	109	175	122	158	190	215	238	253	264	271	275	279	293	300	303	303	301	305
Total Merch. Yld	0	0	36	218	350	244	317	379	431	475	506	528	542	549	559	586	600	605	606	602	610

Fig 2.2a   Harvested Timber Volumes
Status quo & non-thinning rotations





2.4 ASH TYPE THINNING YIELD PROJECTIONS

The basic model for thinning operations was the run of the bush yield model developed for ash-type forests by the consultants. That basic model was modified using the following assumptions:

For age 0 - 20 years

The basic model is unaltered.

At Age 20

Assumption No. 1

A uniform thinning removing 40% of stand basal area from below removes 30% of standing volume. Volume removed = 45m ^{3}/ha.

Age 21 - 50 years

Assumption No. 2

The retained stand (i.e. dominants and codominant class trees) grows with a volume increment equivalent to 500 m^3, over this 30 year period, i.e. gross increment with no mortality.

At Age 50 — **Assumption No. 3**

Strip thinning removes 50% of standing volume. Volume removed is 303 m^3/ha.

At Age 50 to End of Rotation — **Assumption No. 4**

The section of retained stand grows at the same rate as the ash-type model, i.e. there is loss due to mortality, and there is no significant response to the creation of strips.

2.5 RATIO OF SAWLOG TO PULPWOOD OUTPUT

The yield of merchantable volume for each type of forest, as provided by STANDSIM, is subdivided into sawlog and pulpwood after making due allowance for losses incurred through breakage during harvesting and internal defect attributed to fungal and insect attack.

2.5.1 Losses sustained during harvesting and from insect and fungal attack

2.5.1.1 Insect and fungal attack

Ash-type species are susceptible to fungal and termite attacks. Both types of attack occur in natural stands, and arise from damage sustained by trees under natural conditions providing points of entry, eg. from past ground fires, falling spars rubbing and/or rupturing the bark of standing trees, snow break and wind break. Other damage is sustained during construction of access - i.e. tracks and roads. Additional points of entry for fungi and termites are provided where branches are shed and trees may not completely occlude the break.

Surveys by Webb (1966) indicate some 28 per cent of all trees in the ash stands surveyed have suffered some damage which may be classed as natural. The actual merchantable volume lost to industrial use because of natural damage will vary throughout the catchment, and will depend also on the intensity of insect/fungal attack. A rule-of-thumb of 10 per cent reduction of merchantable volume to cover losses due to rot and insect attack, was applied to STANDSIM yield for ash-type species.

2.5.1.2 Breakage during harvesting

In the course of harvesting operations, breakage of trees occurs which results in some volume being unavailable for use. The amount lost in this way varies with the topography, incidence of ground debris (e.g. rocks, old stumps from previous operations), and skill of the harvesting operators. A general figure of 10 per cent loss has been applied. This is derived from studies (as cited in the appendices), experiences of harvesting reported for Tasmania, and general experience of the consultants.

2.5.1.3 Overall

A total yield reduction of 20 per cent was adopted based on the above.

2.5.2 Ash-type forests

The sawlog to residual roundwood ratios were derived by the consultants drawing on information obtained from the Department of Conservation and Environment, private growers, unpublished data obtained from Melbourne Water, and the experience of the consultants. It is emphasised that the ratios derived are theoretical. Actual operational ratios of saw to pulp logs would be influenced markedly by market demand, stocking in stands and the policy of forest contractors. The ratios derived are:

For Ash-Type Forests (Unthinned)

At Age	Sawlog	:	Pulpwood
20 years and under	0	:	1
21 years to 39 years	0	:	1
40 years to 60 years	1	:	1.5
70 years to 350 years	1	:	1

For Ash-Type Forests (Thinned)

20 years (uniform thinning)	0	:	1
50 years	1	:	1
80 years and 200 years	1	:	1

The data used in the derivation of these rations are presented in Appendix C.

2.5.3 Mixed species forests

The sawlog to pulpwood ratios for mixed species forests were derived by the consultants assuming, on the basis of their experience, the following:

For Mixed Species Forests

At Age	Sawlog	:	Pulpwood
0 - 40 years	0	:	1
50 - 60 years	1	:	2
70 - 120 years	1	:	1.5
130 plus	1	:	5

This schedule, unlike that provided by the Department of Conservation and Environment, provides for changes with increasing age. Certainly for the mature/over mature (130 plus years) section of the schedule, the ratio is strongly based on the Department's data plus the knowledge of the consultants that extensive areas of mixed species in the Thomson catchment contain low yielding peppermint, and cut-over messmate gum stands.

Further details of data used in simulating the ratio of sawlog to pulpwood ratios are presented in Appendix C.

3. SIMULATION OF WATER YIELDS

This Section describes how estimates of projected water yields were made for the catchment of the Thomson River at Thomson Dam. Forecasts of expected inflows were made for the eight different timber management scenarios which were described in Section 2.1. The projections were made at ten year intervals for the next 200 years, and used to estimate the timing of future augmentations to the Melbourne water supply system.

Section 3.1 gives land cover and climate details for the Thomson catchment. Selection of values of the water yield rates for each type of land cover is given in Section 3.2. In Section 3.3, these yields rates are applied to the respective areas of land cover appropriate for different timber harvesting options to give estimates of total projected water flows to the Thomson Dam. The latter are used, in conjunction with Melbourne Water's future demand curve, to determine the extent to which projected consumption can be met from the Thomson system (Section 3.4). A brief summary of the work and its main findings (Section 3.5) concludes Section 3.

3.1 THE STUDY AREA - THOMSON CATCHMENT

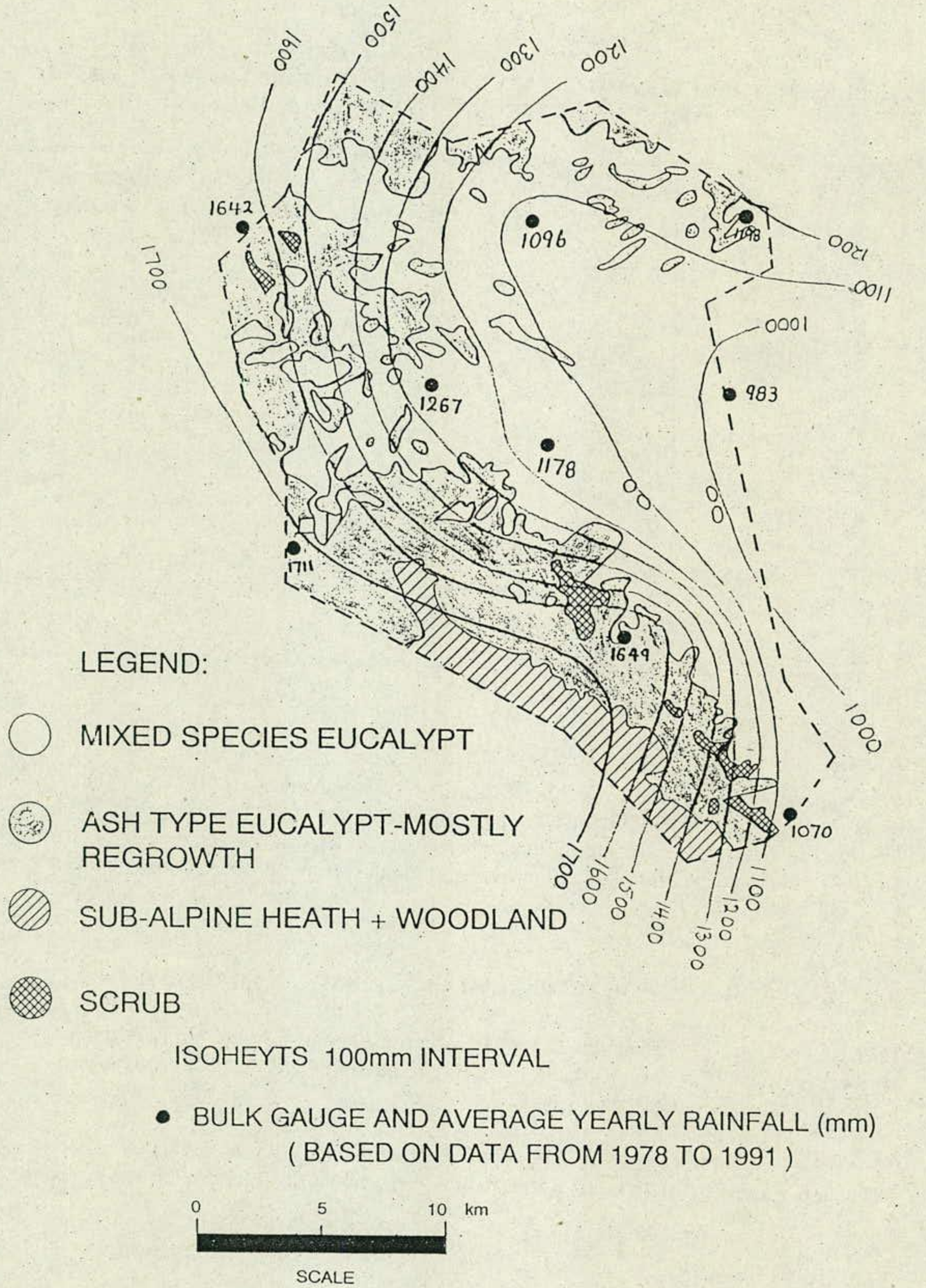
The amount of streamflow observed at the Thomson Dam is not generated uniformly over the catchment area (see Section 3.2). The depth of rainfall varies significantly; this in itself leads to different runoff rates. The main consumption of water, evaporation (which includes transpiration) from vegetation, is dependent on the type and age of the forest.

3.1.1 Land cover

Figure 3.1 shows the distribution of the main types of vegetation species in the Thomson Catchment. It is worth noting that ash forests are found on the more elevated parts of the catchment, where rainfall is higher. Mixed species eucalypts occur in lower rainfall locations. There are small, but significant areas of non-eucalypt species. Information provided by DCE (see Appendix B) shows the area currently occupied by the main vegetation classes. Since age is a factor in evapotranspiration from eucalypts (especially ash-types), the main age-classes are also listed. It can be seen that most of the ash area dates back to regrowth following the 1939 bushfires in the catchment.

3.1.2 Rainfall and evaporation

It should be noted that rainfall figures in Table 3.1 are *averaged* over the catchment; as shown in Figure 3.1 the observed rainfall depths range from 980 to 1710 mm depending on gauge location.



3.1: MAP OF THOMSON CATCHMENT SHOWING RAINFALL AND MAIN CLASSES OF VEGETATION (SUPPLIED BY MELBOURNE WATER, SLIGHTLY MODIFIED).

TABLE 3.1: RAINFALL AND EVAPORATION DATA FOR THOMSON CATCHMENT (DATA SUPPLIED BY MELBOURNE WATER)

Year	AVERAGE ANNUAL RAINFALL OVER (mm)	ANNUAL PAN EVAPORATION AT DAM (mm)
1980	1302	566
1981	1256	577
1982	907	605
1983	1316	559
1984	1338	530
1985	1452	562
1986	1562	458
1987	1365	515
1988	1391	623
1989	1415	516
1990	1532	557
Mean	1348	551
S.d.	174	46

The evaporation figures are for a U.S. Class A Pan positioned near the Thomson Dam. To estimate evaporation from the water body itself, a pan coefficient of about 0.8 would apply. This would make the average evaporation loss from the reservoir about 440 mm. There is only a small annual variability in the evaporation figures, so evaporation rates from the reservoir can be taken as constant.

3.2 WATER YIELDS FOR DIFFERENT CLASSES OF LAND COVER

Each of the main types of land cover for the Thomson catchment has different characteristics relating to generating runoff (water yield). In this Section, the unit water yields (in Mℓ/ha/year) adopted for different types of vegetation and land covers are discussed.

The unit yield figures adopted for this work are drawn mainly from the results of extensive catchment research programs by Melbourne Water and the Department of Conservation and Environment.

3.2.1 Ash-type species

The ash-type species (*Eucalyptus regnans, Eucalyptus delegatensis, and Eucalyptus nitens*) require deep soils and a high rainfall environment. They are susceptible to death in bushfires, but regenerate vigorously after such an event.

In terms of water use by trees, mature ash forests consume much less than the unit yield figures adopted for this work which are drawn mainly from the results for preliminary studies on the

Thomson. Kuczera (1985) proposed a relationship between water yield from ash and forest age as follows:

Equation 3.1:

$$Y = M - LK(t-2)e^{1-K(t-2)} \quad ; \quad \text{if } t \geq 2$$
$$= M \quad ; \quad \text{otherwise}$$

where Y = water yield (Mℓ/ha/year)

M = yield from mature forest

= 11.9 Mℓ/ha/year

L = maximum yield reduction below that for mature forest

= 6.1 Mℓ/ha/year

t = time in years since bushfire (= age of regrowth)

K = reciprocal of (time taken for maximum yield depression, less 2)

$$= \frac{1}{(27.5-2)}$$

$$= 0.039.$$

This relationship is plotted in Figure 3.2 and shows that bushfire destruction of ash forests has both a large and long-term effect on water yield.

It should be noted that Kuczera's model ignores observed increases in yield immediately following bushfires. This increase is of the order of 2-3 Mℓ/ha/year for five years; Eqn. 3.1 gives a reduced yield after only two years. It is not possible simply to change Kuczera's parameters to simulate better the early increases; the parameters L and K have been determined for the zero-increase, decline-after-two-years assumptions. However, it is legitimate to add yield independently of the model to simulate the observed yield in the early regrowth years.

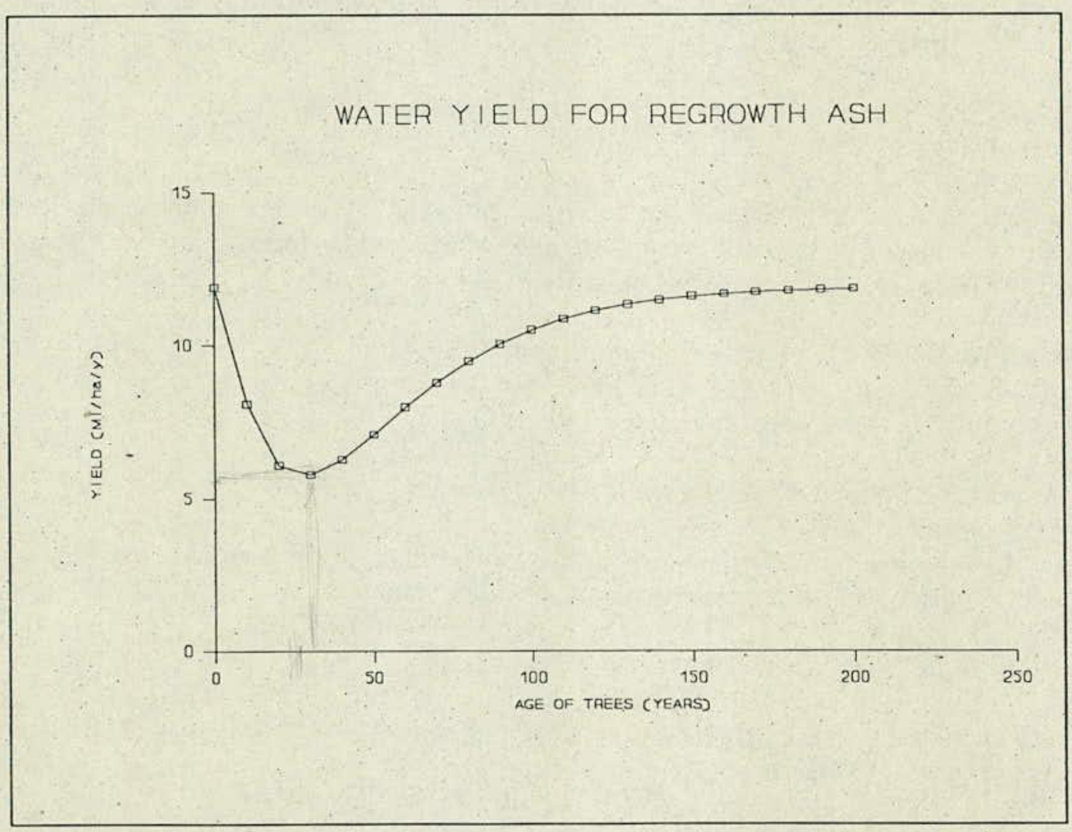


FIGURE 3.2: KUCZERA'S (1985) RELATION FOR REGROWTH OF ASH AFTER BUSHFIRES

3.2.1.1 Clear-felling of Ash

It is generally assumed (e.g. O'Shaughnessy and Jayasuriya, 1987, pp.437-463) that Eqn. 3.1 is also applicable for water yield of ash for regeneration after clear-felling. It then becomes possible to use the equation to examine the effect on water yield of management options involving the clearing and regeneration of forest areas.

For this study, Eqn. 3.1 has been adopted to simulate clearfelling for timber harvesting in ash. For the short rotations (~ 40 years) an extra 2 Mℓ/ha/year for the first five years after harvest has been added. This increase in yield was based on that reported by Duncan et al., 1980 (Table 8.3, p.152). Its effect on yield for rotations longer than 40 years was investigated and found to be negligible.

3.2.1.2 Uniform Thinning of Ash

Uniform thinning of ash is taken here to mean a 40 per cent reduction in basal timber area, carried out when the stand is 20 years old. For the treatment, Eqn. 3.1 is assumed to apply to the regrowth forest as a whole, but with an extra yield of 2 Mℓ/ha/year, declining uniformly to zero over 15 years, applied to the thinned area.

3.2.1.3 Strip Thinning of Ash

For this management practice, the forest is divided into long "strips", each about 35 m wide. Alternative strips are clear felled and not immediately regenerated; remaining strips are left to age for a normal harvest rotation. After harvesting, the whole area is regenerated.

For the cleared strip, the water yield has been assumed to be 13.9 Mℓ/ha/year for 5 years, and 11.9 Mℓ/ha/year thereafter until the whole area is regenerated.

3.2.2 Mixed species

Mixed species eucalypts are found in the lower rainfall areas (1000-1300 mm) on the Thomson catchment. In contrast to ash, they have thick bark which enables them to survive forest fires. Consequently, there is no observed reduction in yield after such events.

Yield from mixed species forests is far lower than ash because:

1. the rainfall is lower where they grow, and

2. evaporation (transpiration) rates are higher.

Reported values of yield are in the range 1-3 Mℓ/ha/year (i.e. much lower than ash). Wu et al., 1984, gave figures for catchments at Reefton (rainfall 1233-1308 mm) of 1.8 to 2.6 Mℓ/ha/year.

For this study, it has been assumed:

1. that unproductive areas (Appendix B) of mixed species yield 1.9 Mℓ/ha/year. These areas are generally at the lower end of the rainfall range.

2. that productive areas of mature forest yield 2.3 Mℓ/ha/year.

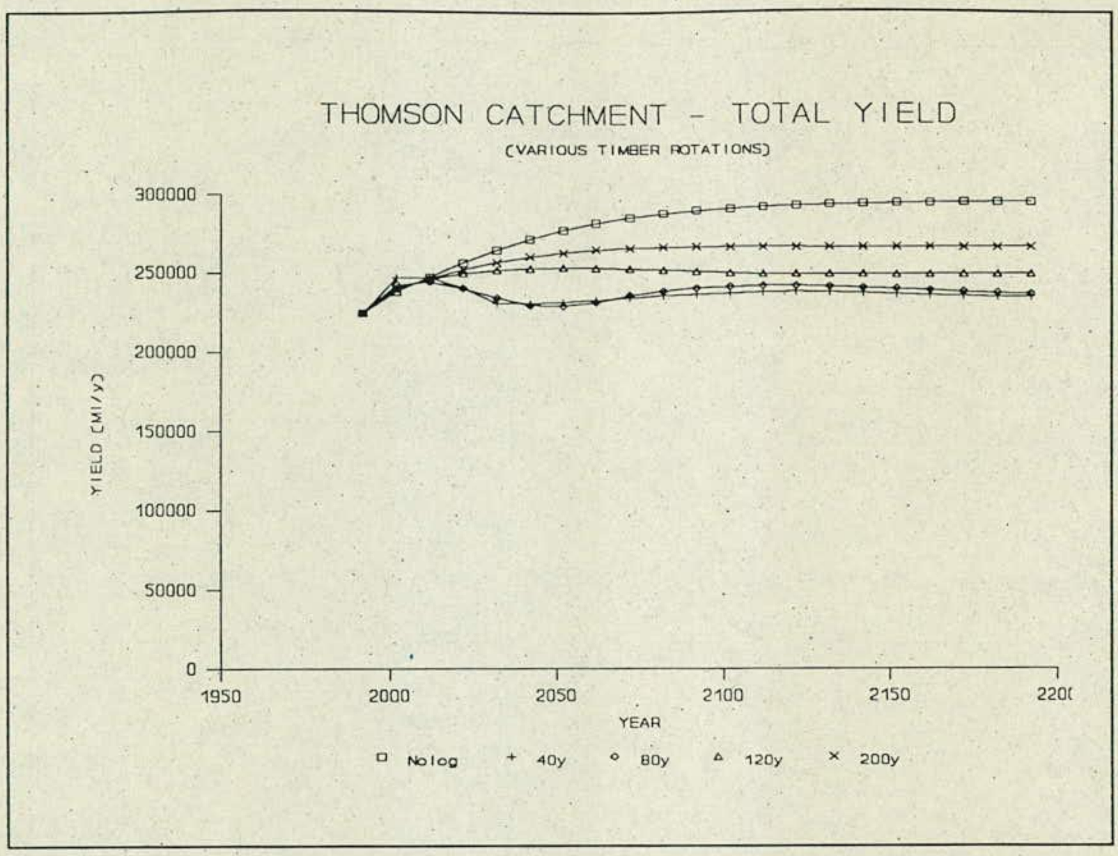


FIGURE 3.3: EFFECT OF HARVEST ROTATION LENGTH (OPTIONS 1 TO 5).

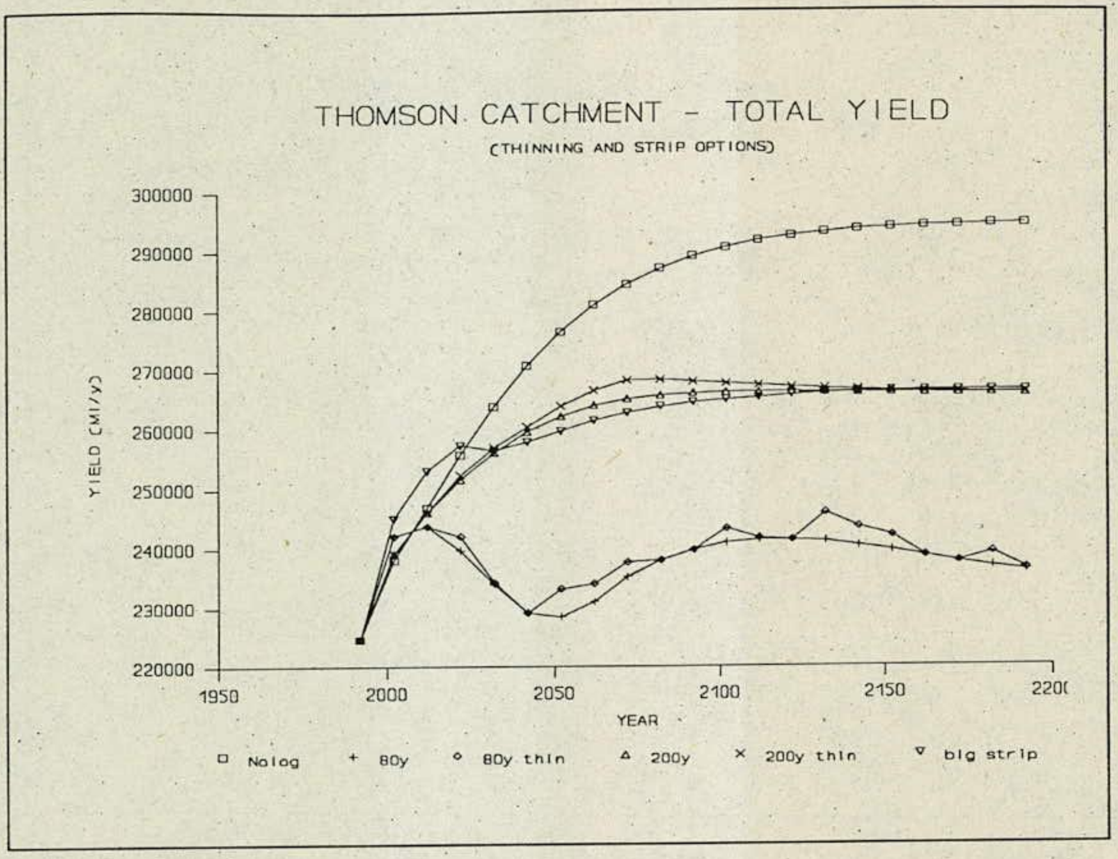


FIGURE 3.4: EFFECT OF COMBINED THINNING AND CLEAR FELLING OPTIONS.

Figure 3.3 shows total yield for the standard rotations, in addition to no logging. It can be clearly seen that, as rotations become shorter, less water is available at the Thomson Dam.

Yields from the thinning scenarios together with the no-logging scenario are shown in Figure 3.4. Several comments are worth making.

1. yield from the 80 year thinning option is due to increased flows, although these are small and variable with time;

2. the 200-year thinning option on 1785 ha gives more consistent increases in flows, although these increases are less than for the 80-year thinning option;

3. the 6000 ha strip thinning option gives higher yields initially due to the clearing of 3000 ha in the early years. The ultimate yield, however, is similar to the 200-year rotation-(rather than higher); this is because the remaining forest was logged at the same rate for both options. The proportionately heavier logging on the ash forest for the 6000 ha stripping option is about equivalent to a 150 year forest rotation;

4. Figure 3.5 shows the water yield from the ash areas for the rotation options. When compared with Figure 3.3, it is clear that about 60 per cent of the total yield from the catchment is generated from ash covered areas. (The slight inconsistency in the 80-year yield is due to the current cutting schedule.)

5. Yield from the mixed species area varied little between scenarios. The maximum difference over all years and all scenarios was only 8 Gl/y (Appendix D). In contrast, yields from ash differed by as much as 54 Gl/y between scenarios.

3. for regrowth, after clearfelling a relationship similar to Eqn. 3.1 applies, but with M = 2.3, L = 1.15, K = 0.039.

Assumption 3. was used by Moran (1988, p.139), in a similar study to this one, for the Otway Ranges. There are no "hard" data to support the assumption, although it can be noted that water yield from regeneration of a mixture of ash and mixed species on the 53 hectare Picaninny Catchment behaved in a way consistent with Eq. 3.1 (O'Shaughnessy and Jayasuriya, 1991). Recent work on the correlation between sapwood area and transpiration (Dunn and Connor, 1991), combined with knowledge of the sapwood/age relationship for growing trees, also supports the above relationship (O'Shaughnessy, pers. comm.).

3.2.3 Alpine vegetation (other than Ash)

These species occupies only a small portion (7 per cent) of the catchment, mainly in the high and exposed areas. A yield of 10 Mℓ/ha/year has been assumed.

3.2.4 Scrub species

Pockets of scrub occur in the ash forest area; they represent about 1% of the total catchment. Yield from them is assumed to be the same as unregenerated areas in the forest, i.e. 11.9 Mℓ/ha/year.

3.2.5 Water surface

The water surface area of the Thomson Reservoir is about 2400 ha when full. The yield from precipitation falling directly onto the water body is estimated as follows:

Average annual rainfall = 1000 mm.

Average annual evaporation (Section 2.2) = 440 mm

Average yield = 560 mm

Say, 5.5 Mℓ/ha/year.

3.2.6 Summary of adopted unit yields

The unit water yields adopted for the various types of land cover on the Thomson catchment are summarised below:

Ash-type : as given by Eqn. 3.1, but for

Clearfelling (short rotations): add 2 Mℓ/ha/year for first 5 years.

Thinning 50% of forest at age 20 years: add 2 Mℓ/ha/year declining to zero after 15 years.

Strip Thinning 50% of forest area: for the strip itself, add 13.9 Mℓ/ha/year for 5 years, 11.9 Mℓ/ha/year after than until the whole area is regenerated.

Mixed Species :

Productive areas: Eqn. 3.1, with M = 2.3, L = 1.1.5, K = 0.039.

Unproductive areas: 1.9 Mℓ/ha/year.

Alpine Vegetation (other than Ash) : 10 Mℓ/ha/year (constant)

Scrub Species : 11.9 Mℓ/ha/year (constant)

Water Surface : 5.5 Mℓ/ha/year (constant).

These values have been used in subsequent calculations to estimate total catchment yield for a number of timber management scenarios.

3.3 EXPECTED FUTURE CATCHMENT YIELD FOR DIFFERENT SCENARIOS

This Section gives the methodology used for total catchment yield calculations, a definition of the timber harvesting scenarios, and the calculated yields for each of them.

3.3.1 Methodology

Using the areas, vegetation type and ages given in Appendix B, together with the unit yields (Section 3.2.6), the total catchment yield can be calculated.

Projected catchment yields in future years can be similarly obtained using updates of the area statement. For this study, total yields were calculated for each of the scenarios listed in Section 2.1 at each 10 year interval beginning in 1992 and finishing in 2192.

It is important to note that such calculations give the *expected* yield for the year concerned; fluctuations due to departures from average conditions (e.g. unusually wet or dry periods) are not considered. Another assumption made here is that bushfires will not occur in the next 200 years. Such events would require a re-assessment of the computed flow sequences.

3.3.2 Results

The 200-year sequences of expected yield for each scenario are given in Appendix D. Figures 3.3 and 3.4 display this information graphically.

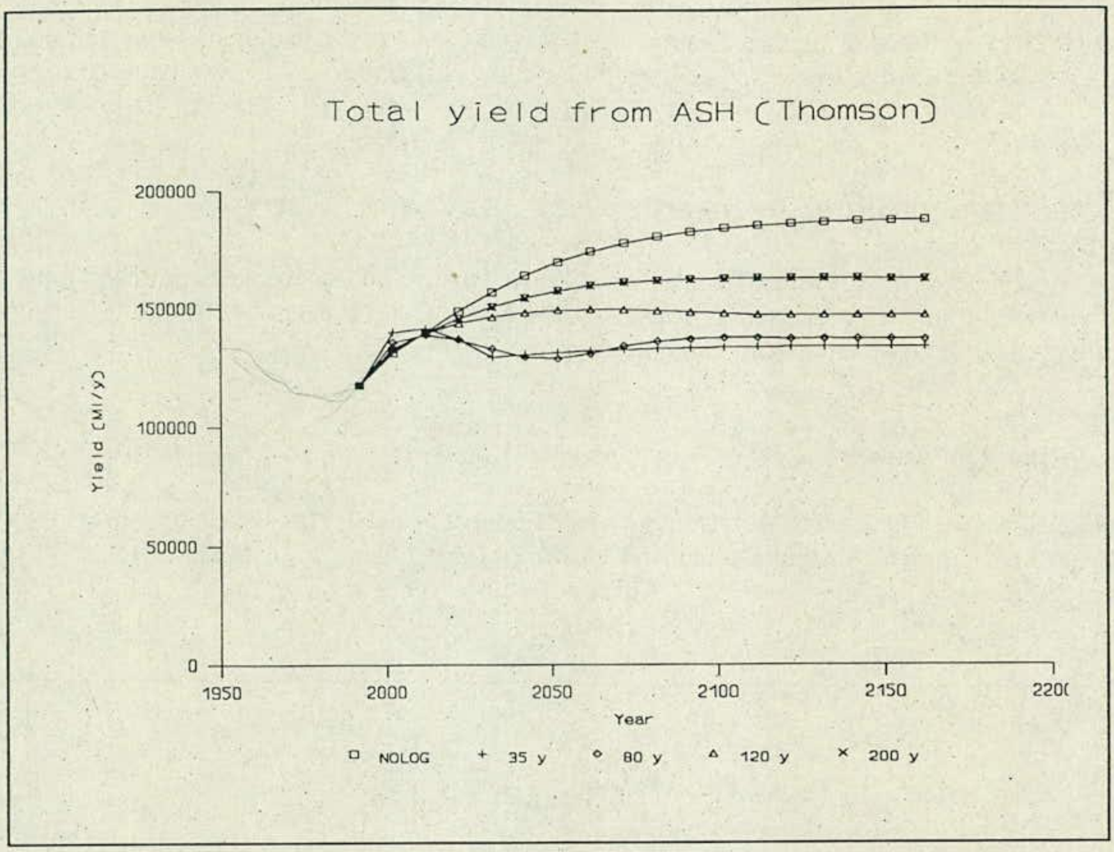


FIGURE 3.5: EFFECT OF HARVESTING ROTATION ON YIELD FROM ASH.

3.3.3 Accuracy of yield forecasts

As in all calculations of this kind, the expected yields for each of the scenarios are subject to uncertainties. A number of points on accuracy can be made:

1. Kuczera (1985) gave 90 per cent confidence limits for Eqn. 3.1. These varied in width; at their widest (age ~ 60 years), they represent an uncertainty of ± 30 per cent in *absolute* terms. However, this uncertainty applies in the same manner to <u>all</u> scenarios. Hence, the accuracy of *relative* estimates is much less than ± 30 per cent; more like ± 5 per cent.

2. For all scenarios, the 1992 estimate of total flow is the same, consistent with the area statement (Appendix B). The computed flow (225 Gℓ/year) is within one standard error of the mean of the recorded flows (241 Gℓ/year, s.e. = 20 Gℓ/year; from 27 years of data listed in SRWSC (1984, p.319)), i.e. not significantly different.

3. No allowance has been made for climatic fluctuations, or trends in climatic variables. It is well known that the former give rise to considerable variability in recorded yields; so much so that the latter are quite difficult to detect. The flows calculated here are *expected* flows for *average* climatic conditions; actual future flows for any scenario would fluctuate about these expected values.

4. Similar uncertainties apply in demand forecasting. For this study it is important that the *same* demand has been used for each scenario to allow for direct comparisons.

For the purposes of this study, i.e. an assessment of the *relative* merits of one scenario versus another, the accuracy of the estimated flows is believed to be quite sufficient to distinguish between options.

3.4 EXPECTED REQUIREMENTS FOR SYSTEM AUGMENTATION

The expected yield sequences for each scenario can be used to estimate the expected timing of required augmentations for the Melbourne supply system. In this Section, the demands on the Thomson storage itself are used to forecast augmentation requirements.

3.4.1 Demand on Thomson storage

Figure 3.6 shows the projected consumption for the Melbourne water system. It features strong growth initially (~ 2 per cent p.a.), declining to a lower growth (~ 0.2 per cent p.a.) at the end of the 100 year forecast period.

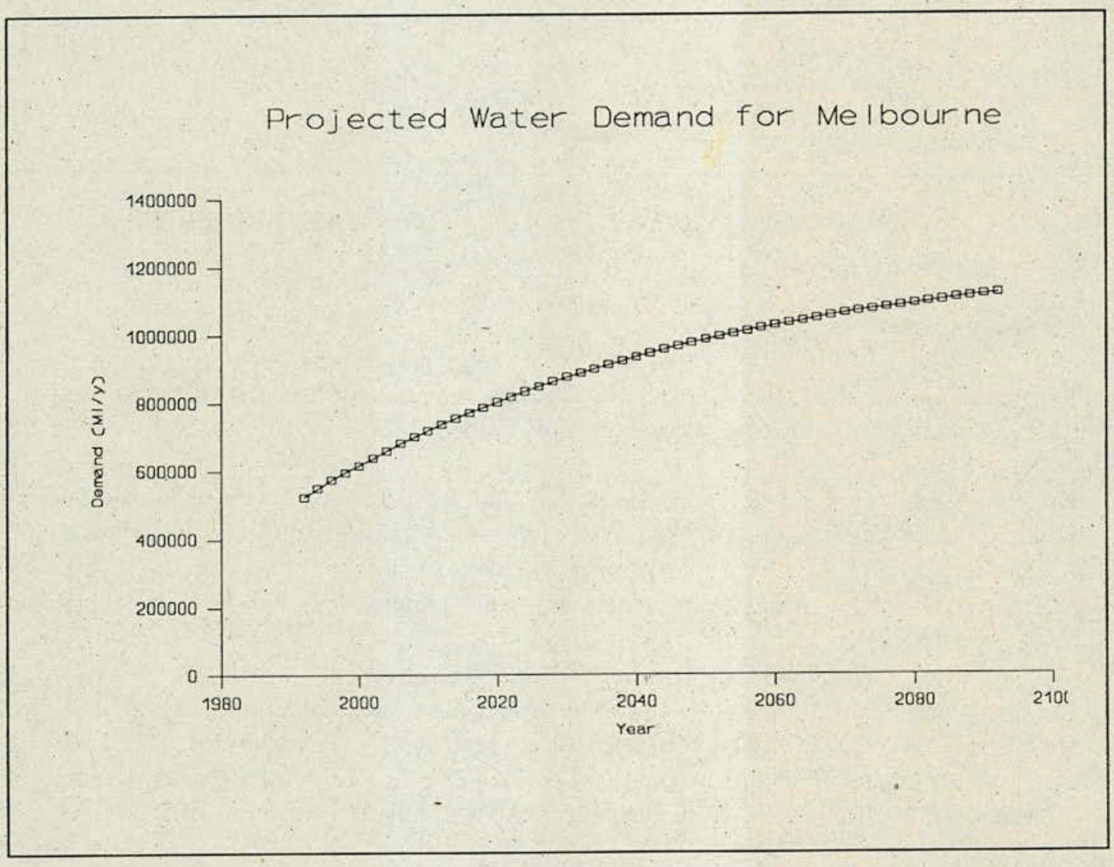


FIGURE 3.6: TOTAL FORECAST DEMAND ON THE MELBOURNE WATER SUPPLY SYSTEM (DATA SUPPLIED BY MELBOURNE WATER).

Calculations of the Melbourne demand on the stored water in the Thomson Reservoir were performed as follows:

Let	DT	=	total demand (Figure 3.6)
	DE	=	environmental flows required downstream of the reservoir (= 65 000 Mℓ/year, figure from Melb. Water)
	DI	=	irrigation requirements from Thomson (= 7200 Mℓ/year, figure from Melb. Water)
	YC	=	yield from the Thomson catchment (Section 3.3.2)
	YO	=	yield available to Melbourne from other catchments (425 000 Mℓ/year in 1992, figure from Melb. Water).

Then the expected demand from the Thomson reservoir (DR) is:

Equation 5.1

$$DR = DT + DE + DI - YC - YO$$

Note that, except for DE and DI, all terms in Eqn. 5.1 change with time; the term YO increases as future augmentations are added.

3.4.2 Timing of future augmentations

Figure 3.7 shows the yield (YC) to, and the demand from, the Thomson catchment, assuming no additional augmentation. It is clear that:

1. the consumption curve is far steeper than any of the yield curves, i.e. urban demand is increasing far faster than Thomson yield;

2. the curves cross in 1999, when there is very little difference in yield between scenarios.

To compute the timing of future augmentations, an annual behaviour analysis was carried out for the Thomson Reservoir. When yield exceeds demand, the reservoir fills (and possibly spills); when demand exceeds yield, the reservoir storage is drawn down. The size and sequencing of future augmentations used here has been as provided by Melbourne Water (listed as a footnote to Table 3.2 below).

It has been assumed that the next augmentation is required when the projected "live storage" in the reservoir (951 000 Mℓ max.) would fall below 450 000 Mℓ by the end of the current 2-year calculation period. This operating rule leaves a safety reserve to cope with drier-than-average years, and is consistent with current Melbourne Water strategy.

Examples of these simulations are shown in Figures 3.8 and 3.9. These show that the Thomson Reservoir is expected to spill in the early years for each case. The effect of the different timber management scenarios is noticeable only in later years. For the no-logging case; expected reservoir levels are higher and most increments (augmentations) to the system can be delayed relative to the 80-year rotation. This reflects the lower long-term yield from the latter option.

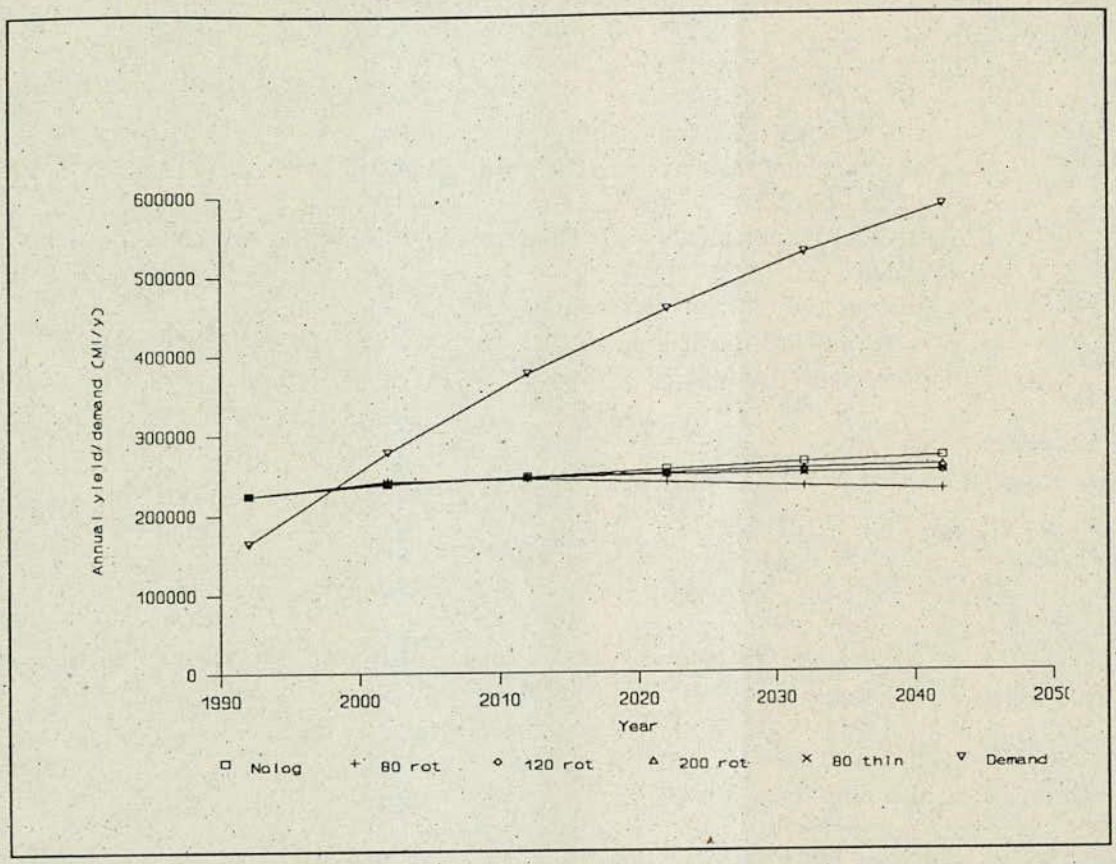


FIGURE 3.7: COMPARISON OF YIELD AND CONSUMPTION FOR THOMSON WATER.

Table 3.2 shows the timing (and source) of the augmentations for all scenarios. For each one, the initial augmentation date is the same. The "big strip" option gives increased flows early, thus delaying the time for augmentation 2 more than other options. Overall, the no-logging case gives the most water; consequently, the timing of augmentation 7 is delayed for the longest period.

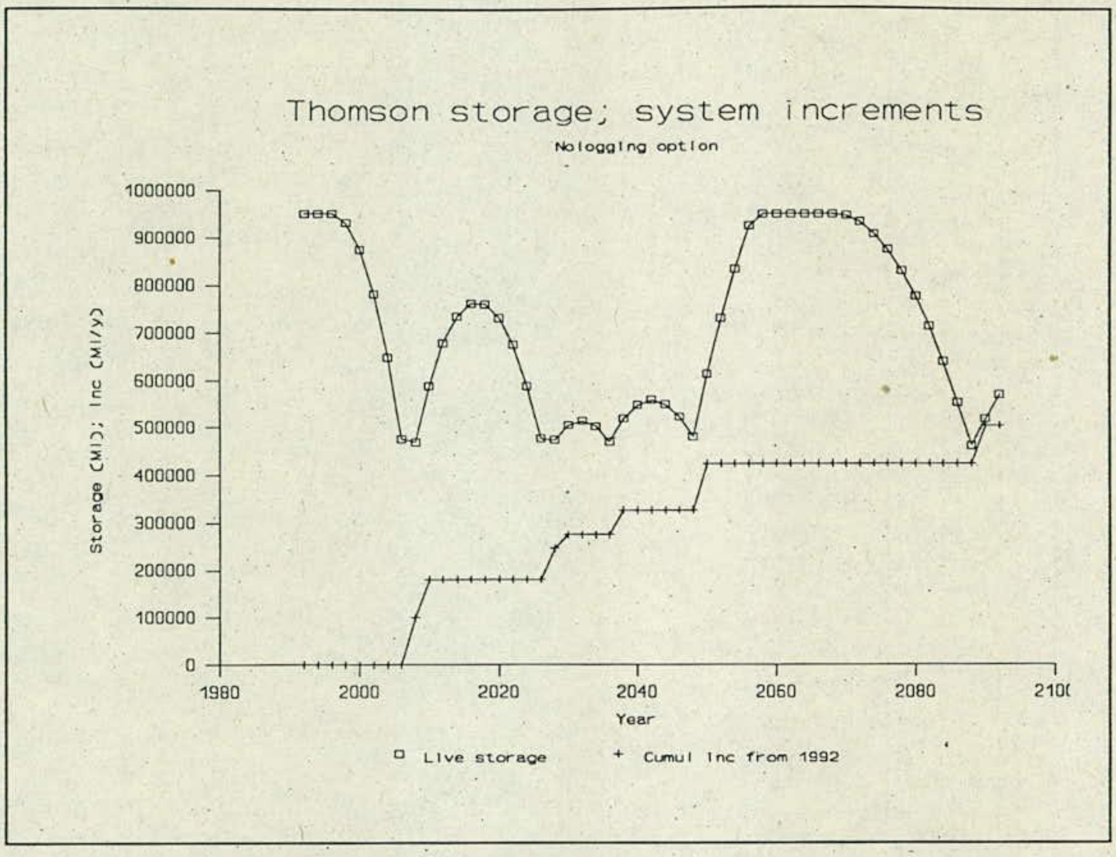


FIGURE 3.8: EXPECTED RESERVOIR BEHAVIOUR DIAGRAM - NO LOGGING OPTION.

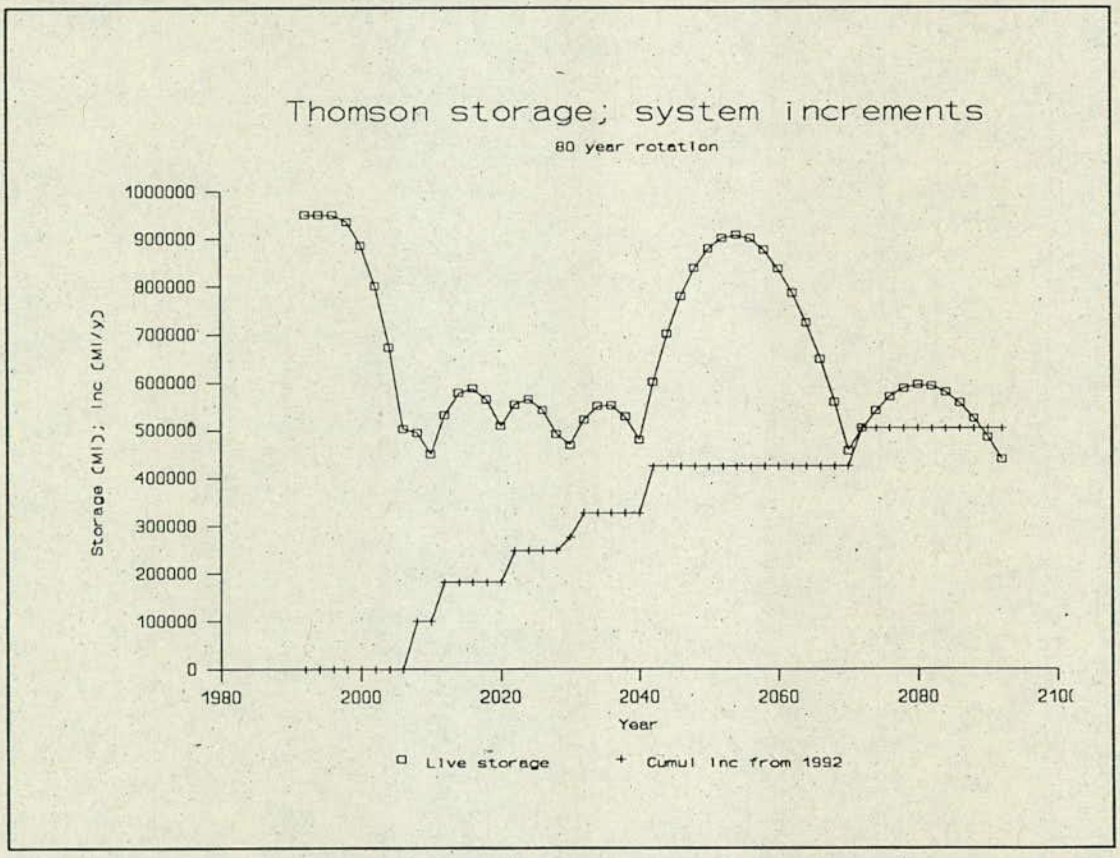


FIGURE 3.9: EXPECTED RESERVOIR BEHAVIOUR DIAGRAM - CURRENT ROTATION.

TABLE 3.2: TIMING OF SYSTEM AUGMENTATIONS CORRESPONDING TO VARIOUS TIMBER SCENARIOS ON THE THOMSON CATCHMENT.

	YEAR																																																			
	1990					2000					2010					2020					2030					2040					2050					2060					2070					2080					2090	
SCENARIO	0	2	4	6	8	0	2	4	6	8	0	2	4	6	8	0	2	4	6	8	0	2	4	6	8	0	2	4	6	8	0	2	4	6	8	0	2	4	6	8	0	2	4	6	8	0	2	4	6	8	0	2
No logging	.	.	.	.	.	.	.	.	.	1	2	.	.	.	.	.	.	.	.	3	4	.	.	.	5	.	.	.	.	.	6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7	.
40y rotation	.	.	.	.	.	.	.	.	.	1	.	2	.	.	.	.	.	3	.	4	5	.	.	.	.	.	.	6	.	.	.	.	.	.	.	.	.	.	.	.	7	.	.	.	.	.	.	.	.	.	.	8
80y rotation	.	.	.	.	.	.	.	.	.	1	.	2	.	.	.	.	3	.	.	.	4	5	.	.	.	.	6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7	.	.	.	.	.	.	.	.	.	8
120y rotation	.	.	.	.	.	.	.	.	.	1	2	.	.	.	.	.	.	.	3	.	.	4	5	.	.	.	.	.	6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7	.	.	.	.	.	.	.
200y rotation	.	.	.	.	.	.	.	.	.	1	2	.	.	.	.	.	.	.	3	.	.	.	4	5	.	.	.	.	6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7	.	.	.	.	.
80y rot. + thin	.	.	.	.	.	.	.	.	.	1	.	2	.	.	.	.	.	3	.	.	4	5	.	.	.	.	6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7	.	.	.	.	.	.	.	.	.	.
200y rot. + thin	.	.	.	.	.	.	.	.	.	1	2	.	.	.	.	.	.	.	3	.	.	.	4	5	.	.	.	.	.	6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7	.	.	.	.	.
6000 ha strip	.	.	.	.	.	.	.	.	.	1	.	.	2	.	.	.	.	3	.	.	.	4	.	5	.	.	.	.	6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7	.	.	.	.	.

1 = Upgraded filters at Winneke Reservoir (100 Gl/y)
2 = Big River diversion (80 Gl/y)
3 = Black River diversion (68 Gl/y)
4 = Black River storage (28 Gl/y)
5 = Lower Yarra Watsons Ck. storage (52 Gl/y)
6 = Macalister Stage 1 (97 Gl/y)
7 = Macalister Stage 2 (80 Gl/y)
8 = Macalister Stage 3 (170 G1/y)

3.5 CONCLUSION

An estimate of the expected water yields was made for each of eight timber harvesting scenarios. The required flow sequences (given in Appendix D) were computed by assuming values, based on research findings, for water yields from the main vegetation species on the catchment.

The expected flow sequences, for each scenario, were used in conjunction with estimated consumption patterns for Melbourne to determine the timing of future augmentations to the Melbourne supply system.

The main findings of this part of the study are:

1. water yield from the Thomson catchment is currently increasing, as the ash forest recovers from the 1939 bushfires. The expected 1992 yield is lowest for all scenarios (Figures 3.3, 3.4).

2. the yield from ash is of the order of 60 per cent of the total (Section 3.2), even though the proportion of ash-area on the catchment is only 33 per cent.

3. Shortening of logging rotations decreases long-term yields. For example, a change from a 200 year to a 40 year rotation would result in a 12 per cent reduction (Tables C.3, C.6).

4. The 1785 ha thinning options for the 80-year and 200-year rotations give small yield increases (~ 1-2 per cent), but these are not sustained for the whole period (Figure 3.4).

5. The 6000 ha stripping option in the ash stands produced higher flows (~ 2-3 per cent) early in the simulation period but fell below, and then finished about equal, to the long-term 200-year rotation level (Figure 3.4).

6. The growth in the Melbourne demand curve is far greater than any increase in possible yield from the catchment (Figure 3.7). Consequently, the expected time to the first yield augmentation is the same for all scenarios (Table 3.2).

7. There are significant differences (of as much as 20 years) in the times to expected augmentations over the next 100 years (Table 3.2).

4. ECONOMIC ANALYSIS

The economic evaluation is undertaken from the viewpoint of maximising economic efficiency for the State of Victoria. The values of timber and water are compared on a common basis; namely, in the catchment. Water is valued in the streams of the catchment and timber is valued standing in the catchment prior to harvest. It would not have mattered where they were valued (e.g. in the catchment, at the point of final consumption, or at any intermediate point), but it is important that either each commodity is valued at the same point, or that account is taken of the differences in costs between the points at which each commodity is valued.

Because the prices of timber and water are administered by Government rather than being determined competitively in a market, the true economic values must be estimated. Central to this process is an assessment of the *willingness of consumers to pay* for timber and water by a process which requires the application of economic theory, empirical observation and judgement. Therefore there can be no single correct answer for either commodity. Consequently the consultants have adopted a range of values for specifying prices for timber and water and then tested the sensitivity of the economic analyses to changes within those ranges.

4.1 VALUING TIMBER

Harvested timber is valued in the year that it is cut, but standing (that is, pre-harvest) values are used. Royalties represent prices for standing timber in the catchment but are administered by Government rather than being determined competitively in a market. Consequently it has been necessary to estimate economic values.

There are numerous published studies which have examined the relationship between royalty values and the true economic value of standing timber in Victoria (see Appendix E). Three approaches have been used in those studies:

1. Residual price calculation where the market prices for processed timber products are taken and the costs of harvesting, transport, processing and marketing are deducted.

2. Imputation of shadow prices from the prices paid for long term harvesting rights.

3. Import/export parity prices with residual price calculations.

A detailed account of the methods employed for valuing timber in this study is presented in Appendix E and summarised below.

4.1.1 Sawlogs

Most studies adopting the residual pricing approach to estimating shadow values for sawlogs in Victoria have concluded that shadow values exceed royalties by between 70 and 200 per cent. However, the consultants recognise conceptual weaknesses with some of the residual pricing approaches adopted. Fortunately there are estimates of prices available from the market in harvesting rights, and timber values can be inferred from these prices.

Victoria has a system of long-term transferable licences which are allocated to saw mills. The bid prices of sawmillers for those licences reflects primarily how much more than royalty rates the standing timber is worth to them. It is not disputed that some part of the prices bid for those licences would reflect a payment to achieve security as well as the value of the wood itself; however, for the purposes of the discounted cash flow analysis, the view is taken that the sum of royalty rates and the values defined from prices bid for licences provide a good indication of true willingness to pay for standing timber.

The Australian Bureau of Agricultural and Resource Economics (ABARE) analysed information for 13 sale prices for licences covering most regions of Victoria and the full range of log grades. They found that, depending on the grade of log, shadow prices were 33 to 61 per cent above royalty rates.

It has been pointed out that the ABARE estimates relate to 1990 economic conditions and that there has since been a considerable downturn in the demand for sawn timber. However, the consultants have decided to take the earlier prosperous period as an indication of the long term rather than the depressed conditions of 1992.

For the purposes of this discounted cash flow analysis, the following prices are adopted:

"high" prices	70 per cent above royalty;
"base" prices	ABARE estimates which represent 33, 41 and 61 per cent above royalty for A and B, C and D class logs respectively;
"low" prices	royalty.

4.1.2 Pulplogs

There are no transferable licences for the pulp wood industry and this means that studies of shadow prices for pulp resources have been restricted to residual price calculations. The economic studies which have examined the economic valuation of pulp supplies in Victoria have nearly all concluded that shadow prices would be very similar to royalty values.

APM has provided the consultants with its estimate that the current average cost of wood delivered to its Mary Vale pulp mill from Upper Thomson is about $46 per cubic metre and wood grown in eucalypt plantations would cost an additional $8 to $10 per cubic metre. This suggests that the shadow price of pulp could not exceed royalty by more than $8 to $10 per cubic metre.

The consultants have adopted the pulp royalty for the base case estimates, but have undertaken a sensitivity analysis using a value of $8 per cubic metre above royalty.

4.2 VALUING WATER

A detailed account of the methods employed for valuing water in this study is presented in Appendix F and summarised below. Not only are the charges for water administered by Government, but they are applied *at the tap* and there are no charges applied in the catchment. As there are no prices set for water in the catchment, the approach adopted is to estimate the shadow retail price of water at the tap in Melbourne, to make allowance for system losses between the streams and final consumption, and to deduct the costs associated with getting that water from the catchment to the customers.

The value of additional water in the streams of the Thomson Catchment must be compared to the value of the timber foregone. Ideally water in the streams of the Thomson would be valued in a competitive market where, through a process of competitive or sealed-envelope bids, competing suppliers of urban water considered the price that they were willing to pay to purchase for water in the streams of the Thomson catchment. They would form their bids on the basis of two considerations; namely (1) how much their consumers would be prepared to pay and (2) the price that they were prepared to accept on the basis of the costs that they required to be recovered.

Urban water is put to a number of different uses; for example, drinking, washing, cooking, watering gardens and filling swimming pools. However, for the purposes of this study, urban water is treated as a single commodity whose demand function represents a variety of components. Unfortunately the demand schedule for Melbourne's urban water supplies is unknown; however, there is some information available which has been of considerable use in forming judgements about that schedule:

1. There have been a number of studies into the demand characteristics for urban water in Melbourne, Perth, a number of centres in NSW and in other countries.

2. Melbourne Water's present tariff structure involves a two-block pricing structure for metered consumption of domestic customers involving charges of 30 cents per KL up to 350 KL and 60 cents per KL above 350 KL. Non-domestic customers pay 60 cents per KL.

3. The average amount paid for water in Melbourne is estimated as the total revenue to Melbourne Water (rate charge plus volume charges) divided by the total consumption. The average amount paid has been calculated as representing more than 80 cents per KL.

4. A major econometric study for Melbourne Water has recently concluded that an optimal single price for all types of water in Melbourne over the next 30 years would lie in the range of 52 to 77 cents per KL in 1992 dollar values.

5. Mornington and Peninsular District Water Board, prior to its incorporation into Melbourne Water, purchased water from the Thomson system and paid a price equivalent to 34 cents per KL at the Cardinia take-off, in 1992 dollar values.

6. The Rural Water Commission supplies water to a number of urban water authorities throughout rural Victoria and it sells that bulk water to the authorities for 37.5 cents per KL.

The consultants have concluded that an appropriate set of shadow prices to use in this preliminary analysis is 30, 60 and 80 cents per KL at the tap. However, every one unit of water delivered to the tap in Melbourne requires about 1.14 units of dam releases, the balance being system losses. Consequently the three prices at the tap need to be divided by 1.14. This leads to the following ex-dam prices:

"low" price	26 cents per KL
"base" price	53 cents per KL
"high" price	70 cents per KL

It is argued in Appendix I that this range of 26 to 70 cents per KL may well be less than the actual willingness of consumers to pay for water. An analysis of the effect of future changes in consumption on the shadow prices for water is incorporated in the dynamic programming model (see Section 4.4 and Appendix I).

Water releases which produce hydro-electricity are valued at the present price paid by the SECV at the Thomson Dam. Irrigation and environmental-flushing values are ignored in this analysis as the quantities used for those purposes is constant across all options.

4.3 DISCOUNTED CASH FLOW OF NOMINATED OPTIONS

The aim of the discounted cash flow analysis is to compare the economic value of catchment outputs between eight discrete options and it is undertaken from the viewpoint of the State of Victoria. Timber and water represent the major catchment outputs and this analysis is restricted to consideration of those outputs. Clearly catchments also provide other outputs including environmental or recreation values but, as required by the brief for this consultancy, these are explicitly excluded from this analysis.

The approach adopted is to identify the option with the highest net economic value of catchment outputs. This implicitly assumes that the objective of the State is to achieve the maximisation of economic advantage from timber and water yields. However, as mentioned earlier, the analysis identifies only the relative merits of the eight discrete options and does <u>not</u> indicate whether the option identified as having the greatest economic advantage out of the eight is, in fact, the one which would maximise economic advantage. This is because there may be other option(s) which are superior to any of those nominated for this aspect of the study. In reality there would be a *continuum of production possibilities* but this discounted cash flow analysis considers only the subset of eight of those possibilities which have been nominated by the Steering Committee for this consultancy.

4.3.1 Level of detail to be included in analysis

Just as the aim of the discounted cash flow analysis is to test for the most economically efficient option(s), equally it is important that the analysis itself is undertaken efficiently. Considerable emphasis should be placed on defining the appropriate level of detail to be pursued in assessing the impact of policy changes.

The gains from painstaking research and evaluation for the purposes of a policy decision are sometimes unlikely to warrant the extra cost. The analysis can be shortened by firstly considering only those revenues and costs which are absolutely necessary and secondly by minimising the level of detail with which they are estimated.

For the purposes of choosing between discrete options it is necessary to consider only those costs and revenues which change between the options under consideration. For example, the various forest management options would result in a range of streamflow yields between about 220 GL and 300 GL per year, but Melbourne Water has advised that none of these options would affect the replacement policies for the Thomson headworks or for any of the urban water distribution system. Consequently it is unnecessary to consider the capital costs associated with the Thomson headworks or distribution system as they would be the same for each option, and as such would not affect the ranking of catchment outputs between those options.

Economics is forward looking and past or committed capital expenditure often becomes irrelevant in economic analyses. The emphasis is rather one of "if something changes now, then what will be the implications thereafter". It cannot be overemphasised that it is conceptually sound to ignore the capital costs of infrastructure which is already in existence with adequate capacity to handle the additional water under the new catchment management option. In economic terms such costs are "sunk" and need not be considered in any economic analysis which examines future uses for existing capital infrastructure which have surplus capacity and no alternative use.

In deciding how much detail to be included, the analysis is best undertaken in an iterative fashion by progressing from a simple to more complex analysis until it is judged that a "robust" solution has been found. A robust solution is defined as one in which further detail would not change the decision as to which is the most efficient option. Further detailed analysis beyond that point would improve only the estimate of the margin by which a particular option was the most efficient, but not the decision as to which is the most efficient option.

This position is adopted because there are always some values for which a preliminary estimate can be made rapidly with wide confidence limits, but it would be extremely time consuming to improve the detail of that estimate. It cannot be overemphasised that orders of magnitude of effects derived from initial and less-complex analysis, coupled with sensitivity analysis of key parameters, can give rise to results which are conclusive and more useable because they are timely. This is particularly so when one is attempting to make predictions over a long period, such as the 200 year period for this analysis.

For example, considerable effort has been made by the consultants to estimate the effect of future changes in quantities of water consumed on the choice of appropriate prices for urban water. However, it is believed that a decisive and robust solution has been identified from a less complex analysis using a sensitivity analysis covering a broad range of urban water prices which were assumed not to vary in response to the quantities consumed.

An analysis of the effect of price on the quantities of urban water consumed is incorporated in the dynamic programming model which has been developed for this study. However, the discounted cash flow analysis presented in this Section, incorporates only that level of detail which has been required to identify a choice based on orders of difference, between the various management options for the Thomson catchment.

It is usual in discounted cash flow analysis of timber operations to treat the final year in the planning horizon by adding to the final year's net income a sum equivalent to the NPV of future income streams to infinity. However, in some of the eight options being considered for this analysis of the Thomson, a repeatable rotation has not been finalised by the end of the 200 year rotation, consequently it would be inappropriate to extrapolate an incomplete rotation to the future. Instead, salvage values are specified for Year 2192 as the value of standing timber left at the end of that year.

In accordance with Victoria's Economic Strategy, the rate of discount in the base-case analysis is that which corresponds to the target real rate of return on public assets; set currently at 4 per cent. The 4 per cent was estimated to reflect the long-term real costs of debt and equity to the public sector, weighted by the extent to which these forms of finance are utilised by public enterprises (Lumley, Mouzakis and Bould 1990).

The Commonwealth Department of Finance has recently issued guidelines which specify that a real rate of 8 per cent should be used in benefit cost analyses to determine the value of projects to the Commonwealth. According to those guidelines, however, a lower rate may be used when the "intended action has a cash flow which is known with virtual or complete certainty". The Industry Commission (1992) has argued that water authorities face no competition and as a result the risk to investors is commensurately lower than in other government enterprises. The Commission, therefore, suggested that the discount rate for evaluating the provision of infrastructure related to water could be set at the long-term bond rate (currently about 5 per cent) "with little risk of encouraging over-investment (in such infrastructure)".

This consultancy concerns both water and timber production in the State of Victoria. Using the same criterion as the Industry Commission, timber production is a more risky venture. Therefore, the sensitivity of base case results is tested at 6 per cent (50 per cent higher than the base rate). For comparative purposes, the sensitivity of results has been tested at a discount rate of 2 per cent (50 per cent lower than the base rate). Because real rates of discount are used, inflation can be ignored and all costs and prices are measured in 1992 dollar values.

4.3.2 Estimation of costs

4.3.2.1 Catchment management costs

DCE is responsible for overall catchment management and has provided estimates of the unit costs associated with its management of non-harvesting activities in the Thomson catchment for 1990-91. DCE provided separate estimates for State Forest and for parks and reserves, and calculated a weighted average across the Thomson catchment of $5.53 per ha for its management of non-harvesting activities in 1990-91. This value has been inflated by 10 per cent to reflect 1992-93 values and has been adopted for all forestry options and applied across the total catchment area of 48,223 ha.

Harvesting costs are excluded from the analysis as the timber is valued as standing in the catchment; that is, prior to harvest. Similarly thinning costs have been excluded as they represent a harvest operation. Harvesting, including thinning, costs could be included in the analysis but then it would be necessary to apply values for harvested timber rather than standing timber.

DCE also provided an estimate of its research and development costs across the State, but the inclusion of this item has been rejected on the basis that DCE's research and development costs across the State would be of a fixed nature and would not be likely to change specifically because of changes in the Thomson catchment which represent less than 2 per cent of approximately 1.3 million ha of productive areas in all State Forests.

DCE provided an estimate that regeneration activities involved costs for site preparation and establishment of $607 per ha in the Thomson catchment for 1990-91. These have been adopted, but not inflated to 1992-93 values as it was considered that, even in 1990-91 dollar values, they would represent an over-estimate as they are based on regeneration from Shining Gum seed which is the most expensive of the ash-type species. In reality regeneration would involve a mixture of ash-type species. The regeneration costs are applied in accordance with the number of hectares clear felled in any time period.

There has been considerable discussion about the likely level of catchment management costs which would be incurred for the no logging option. Some members of the Steering Committee have argued that a cessation of logging would lead to an increased management costs while others have argued that the management costs would be reduced. It has been decided to specify the same management costs for each option but to test the sensitivity of the analysis to a high estimate of $17 per ha.

4.3.2.2 Costs associated with distribution of water

Melbourne Water has advised that varying the volumes of water from the Thomson catchment would affect only its disinfection costs, pumping costs and the timing of future augmentations to its system. It has advised that while some of the distribution and headworks structures may require replacement during the 200 year planning horizon being considered, those replacements would be necessitated strictly by age and would not vary according to varying volumes of water from the Thomson catchment.

All water requires disinfection and Melbourne Water has estimated that its average disinfection cost is presently $7.25 per ML. Most of Melbourne Water's urban distribution system relies on gravity and involves no pumping. However, a small proportion of supplies do need pumping within the urban distribution system and Melbourne Water estimates that this involves an average cost of $18 per ML for that water which is pumped. As Melbourne Water cannot provide an accurate estimate of the proportion of releases from the Thomson catchment which would require pumping, the cost of $18 per ML has been applied to all releases for the Thomson catchment.

The pattern of yields from the Thomson Dam in the future will affect the timing of augmentations to the total urban supply system and that timing will affect the quantities of water which Melbourne Water pumps from the Yarra at its Winneke offtake. Pumping and disinfection costs at Winneke are high and represent $60 per ML owing to the quality of those supplies and substantial lift required from pumping. The quantities required from the Winneke offtake have been simulated for each option (see Section 3) and a cost of $60 per ML has been applied to those quantities and added to the operations and water supply costs for the water supply system.

4.3.2.3 Costs associated with forestry

As explained in Section 4.2.1 above, costs for catchment management by DCE or Melbourne Water have been included for each option and harvest and post-harvest costs have been excluded as timber is valued as standing. However, the representatives of the timber industry on the Steering Committee for this consultancy have argued that some post-harvest costs would change in the event that timber harvesting in the Thomson catchment were reduced. It has been argued that the Mary Vale pulp mill and the sawmills which presently process timber from the Thomson catchment would have to substitute timber from other areas of State Forest and that this would require additional road transport of logs to the various mills.

A preliminary assessment by officers of DCE at Traralgon has indicated that this may not necessarily be the case. DCE officers have indicated that it is likely that those (saw and pulp) mills presently processing Thomson outputs could be re-directed to (nearby) stands within the Erica operations area and/or to stands near Noojee.

The suggestion that sawlogs from other areas of State Forest would require additional road transport is rejected because Victoria has many sawmills and it is more than likely that other sawmills would process logs in close proximity to the areas of State Forest which were used to substitute for timber from the Thomson catchment. However, the situation is not as clear with respect to pulp logs. APM's mill at Maryvale represents the State's largest pulp mill and it would be quite unrealistic to assume that another pulp mill would process pulp logs from the areas of State Forest which were used to substitute for timber from the Thomson catchment.

APM believes that the next parcel of ash to become available to substitute for Thomson supplies would be as far afield as Alexandra and that the additional post-harvest costs would be $14 to $16 per cubic metre relative to costs for timber from the Thomson catchment. For the purposes of this analysis, it has been assumed that any reduction in pulplog volumes relative to the status quo rotation <u>would</u> require the additional road transport from Alexandra and APM's estimate of $14 per cubic metre is applied to all of those volumes.

Representatives of the timber industry on the Steering Committee for this consultancy argued that a reduction in timber harvesting in the Thomson catchment would lead to a lower utilisation of capital invested in timber mills. However, as mentioned above, DCE has advised that existing mills which are presently processing timber from the Thomson catchment would be allocated timber from elsewhere.

Consequently, in the event that timber harvesting was reduced in the Thomson catchment then the harvesting, processing, transport and marketing companies involved would switch their resources to activities associated with the harvesting of timber from elsewhere. The costs associated with those companies would genuinely cease to be attributed to the Thomson but would then apply elsewhere. That is, the capital costs associated with existing timber processing equipment cannot be ignored as they have an alternative use.

Existing licences for sawmills do not expire until the year 2004 and the real impact of a reduction in timber harvest from the Thomson would not occur until the next set of 15-year licences are allocated in 2004. DCE expects that the total volumes to be allocated for the period subsequent to 2004 would be greater than the present volumes specified for licences (applying to the Central Gippsland FMA). That is, the real impact would be a reduction in the potential future increases for the period subsequent to the year 2004.

Consequently it could be argued that the economic analysis should only consider reductions in timber volumes from 2004 onwards. However, the consultants have taken the view that it is appropriate for an analysis, from the viewpoint of the State, to specify reductions in timber harvesting as commencing immediately. That is, the analysis assumes that there is a real opportunity cost incurred henceforth and overlooks the administrative details embodied in the process of licence allocation. This could be seen as resulting in an over-estimate of the cost to the State from a reduction in timber harvesting from the Thomson catchment.

A summary of the prices and costs adopted for this analysis is presented in Table 4.1.

4.3.3 Results

During discussions with the Steering Committee for this consultancy, it became evident that some members of the Steering Committee have conceptual concerns about the consultants' view of the appropriate price to apply to water in the streams of the catchment. Given those concerns, it is useful in the first instance to consider what can be gleaned from the results without estimating such a price.

This can be approached by asking the question "**How high does the value of water in the streams of the Thomson have to be to justify a reduction in timber harvesting?**"

Consider the comparison between the STATUS QUO and the BIG STRIP option which involves an initial corridor thinning treatment for 6000 ha of 1939 ash regrowth to be followed by clear felling on a long rotation. Table 4.2 presents the simulated timber and urban water yields. These reveal that, for the BIG STRIP relative to the STATUS QUO, timber volumes are reduced by more than 50 per cent in most decades and that water yields are increased in every decade. While water yields do not increase greatly over the first 20 years, they are increased by more than 200 GL (per decade) for most of the decades modelled; that is, 20 GL per year which represents about a 10 per cent increase in the average yield of urban water from the Thomson catchment.

The reduction in NPV of standing timber represents about \$52 M (at base case values) and we can estimate that price for the additional water in the streams which equates with an NPV of \$52 M. **That price is about \$150 per ML and tells us that the value of additional water in the streams of the catchment would exceed the value of the timber foregone for any price of water in those streams of greater than \$150 per ML.** So water in the streams of the catchment needs to be worth at least \$150 per ML to warrant a shift from the STATUS QUO to the BIG STRIP option. We can now ask "What value at the tap in Melbourne is commensurate with a value of \$150 per ML in the streams?"

The answer is that water at the tap must be at least \$150 per ML plus the costs of supplying the additional water from the streams to the taps in Melbourne. The decision as to which costs associated with supplying water should be included is an important one. Our decision is influenced largely by the following advice from Melbourne Water and DCE to the Steering Committee for this consultancy; namely that:

> the decision to reduce timber harvesting would not incur any additional capital costs for headworks or distribution infrastructure as it is already in place with adequate capacity to handle the additional water;
>
> the expected life of those assets would not be affected by handling the additional volumes; and

TABLE 4.1 SUMMARY OF PRICES AND COSTS USED

ITEM	LOW ESTIMATE	BASE CASE	HIGH ESTIMATE
Urban water price $/ML	260	530	700
Hydro-elec water price $/ML	25	25	25
Pulp price $/M3	10	10	18
Ash A & B logs $/M3	45	60	77
Ash C logs $/M3	32	46	54
Mixed spp A & B logs $/M3	27	36	46
Mixed spp C logs $/M3	25	35	42
Discount rate %	2	4	6
Catchment management costs $/Ha	6	6	17
Forest regeneration costs $/Ha	607	607	607
Additional transport for pulp to Mary Vale if Thomson cut reduced (relative to status quo) $/M3	0	14	20
Pumping and disinfection costs at Winneke $/ML	60	60	60
O & M costs for supply of Thomson water $/ML	25	25	25

TABLE 4.2 WATER AND TIMBER YIELDS FOR STATUS QUO AND BIG STRIP OPTIONS (decade totals)

Decade ended	Status Quo Water Yield GL	Big Strip Water Yield GL	Status Quo Timber Yield '000 M3	Big Strip Timber Yield '000 M3
2002	1700	1729	1448	581
2012	1716	1809	1615	652
2022	1676	1852	1646	705
2032	1618	1843	1679	637
2042	1570	1858	857	637
2052	1563	1876	1317	533
2062	1588	1894	846	545
2072	1631	1907	870	551
2082	1659	1916	933	560
2092	1676	1923	977	570
2102	1688	1928	1016	577
2112	1693	1931	1268	581
2122	1693	1936	1276	580
2132	1690	1939	1539	581
2142	1683	1941	1121	582
2152	1675	1942	1192	586
2162	1666	1943	1243	588
2172	1656	1943	1289	586
2182	1648	1943	1314	584
2192	1641	1943	1281	579

DCE would allocate timber from elsewhere to those mills presently allocated harvest rights for the Thomson Catchment.

It has been concluded that the only costs involved in transforming the water in the stream to water at the tap in Melbourne are the additional pumping and disinfection required and those costs amount only to about $25 per ML. This is because the capital costs for the existing headworks and distribution infrastructure must be ignored as they have already been committed and would in no way vary because of additional water yield from the catchment.

Consequently we can now say that the value of additional water <u>at the tap</u> would have to be greater than $175 per ML ($150 plus $25 per ML) for it to hold that there would be a real economic advantage to the State by adopting the BIG STRIP option instead of the STATUS QUO. The question now becomes "Does water at the tap in Melbourne really have a value of greater than $175 per ML?". In fact the value would not have to be even that high since this rather simplistic analysis has ignored the effects on future augmentations which is a benefit not considered in determining the estimate of $175 per ML.

The consultants have concluded that water values in the streams are likely to lie in the range $235 to $675 per ML or higher (see Section 4.2 and Appendix F). Even the lower value of $260 per ML is substantially higher than $175 per ML. Consequently it is concluded that the BIG STRIP option would represent an increase in the economic value of catchment outputs relative to the STATUS QUO.

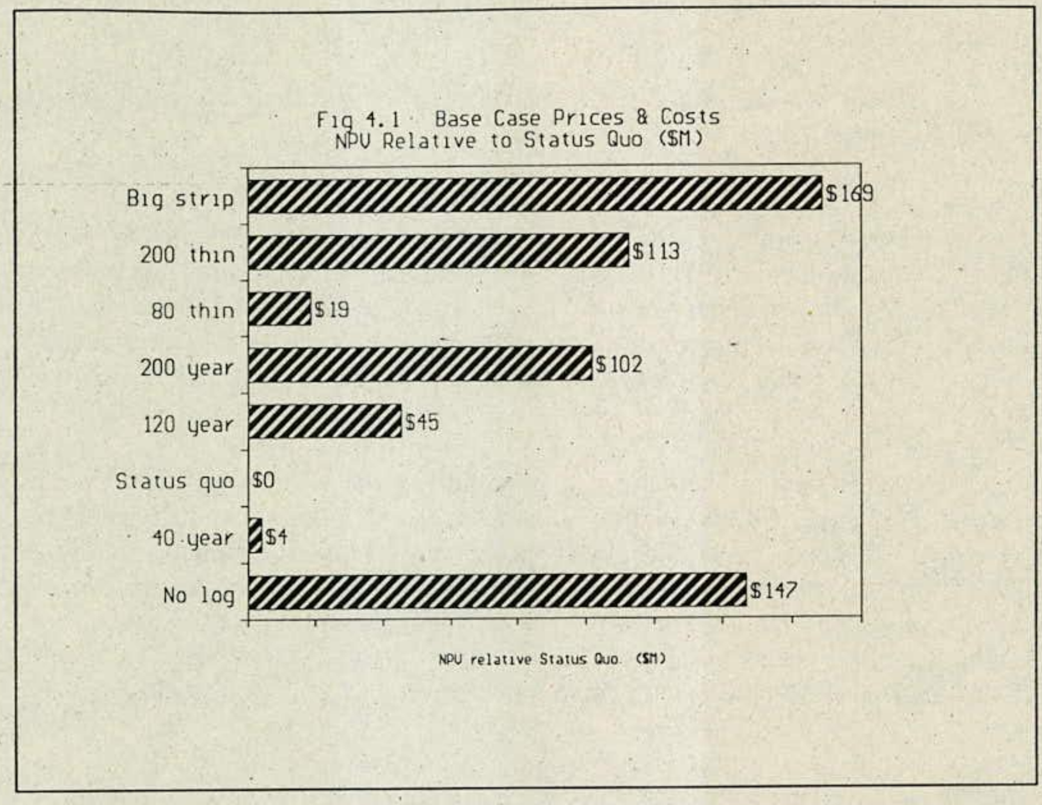
So far only the results for the BIG STRIP have been discussed, but it is not the only option which would represent an improvement over the STATUS QUO. Results for all options are discussed below for the base case which assumes our preferred estimate of water price of $530 per ML at the tap.

4.3.3.1 Base case

A useful way to view the estimates of NPVs which have been estimated is to compare the NPV of each of the hypothetical seven options to the STATUS QUO. The important result is that <u>less</u> timber harvesting than the STATUS QUO results in a greater economic value of catchment outputs. A comparison of the NPV of each option relative to the STATUS QUO for the base case is presented in Figure 4.1. These indicate that the net economic value to the State of Victoria from timber and water yields from the Thomson would be increased by any change, but particularly by either ceasing logging or increasing the rotation length or by an increased use of thinning techniques.

As shown by Figure 4.1, the NO LOG option and those three options which are based on a long rotation provide the greatest NPV of catchment outputs. That is, the NO LOG, 200 YEAR, BIG STRIP and 200 THIN options each involve a NPV of catchment outputs which is about $100 M to $170 M greater than the STATUS QUO.

The 200 YEAR option performs well because of the increased water yield from older forests. The BIG STRIP option performs even better because of the initial increment to water yield which occurs from the clearing of corridors plus the reasonably high returns



from timber cut in the near future. The good performance of the 200 THIN options would appear to result from the fact that, both uniform thinning and corridor thinning lead to increased streamflow yields.

The BIG STRIP option has allowed a clear identification of the economic benefits from corridor thinning with a long rotation. The NPV of catchment outputs for the BIG STRIP exceed that achieved by the 200 YEAR option and the difference must represent the benefit from corridor thinning with long rotations (that is, of managing about half of the area of 1939 regrowth of ash-type forest in the Thomson Catchment to corridor thinning over the next 30 years). However, there is insufficient evidence from the analysis of the eight nominated options to separate out the benefits of uniform thinning from the benefit of corridor thinning with the 80 THIN and 200 THIN options.

This leads us to the conclusion that an increase in rotation length or a cessation of logging would increase substantially the value of catchment outputs, but that a superior option may be to move to an increased rotation length in conjunction with the introduction of corridor thinning. There is no conclusive evidence about the effects of uniform thinning.

Because all options have been evaluated over the very long planning horizon of 200 years, the absolute sizes of the economic values are subject to considerable uncertainty; however, many of the silvicultural, hydrological and economic assumptions are the same across option which suggests that greater confidence can be placed in the estimates of relative changes in economic values. Furthermore, the approach adopted has involved "partial budgets" which do not provide meaningful estimates of the absolute size of economic values for catchment outputs. Consequently, only the relative change in NPV is presented.

Full details of the base case estimates are presented in Appendix G and the sensitivity of the results to changes for a range of parameters are elaborated below. Table 4.3 summarises the results of the sensitivity analyses which have been undertaken.

4.3.3.2 Water prices

As would be expected, the size of the NPV depends on the assumed price of water but in broad terms, the ranking of the options is not very sensitive to changes in water prices above about $300 per ML at the dam (before deducting supply costs).

4.3.3.3 Timber prices

The ranking of options is extremely insensitive to changes in timber prices over the range tested.

4.3.3.4 Discount rate

The discount rate does not affect greatly the ranking of options except that the NO LOG option becomes superior to the BIG STRIP option at the lower discount rate (2 per cent). This is not surprising as the NO LOG option achieves the greatest level of water yield during the latter half of the planning horizon and the effect of a higher discount rate is to reduce the effects of such benefits which occur a long way into the future.

Another way of viewing this result is as reflecting that the non-discounted value of catchment outputs would be by far the highest for the NO LOG option (see Table 4.3), but that this perceived advantage of the NO LOG option occurs a long way into the future and is progressively eroded as the discount rate increases.

4.3.3.5 Species Effect

All the results reported to date represent the effects of options involving the change to harvest schedules for both ash-type and mixed species stands. However, similar results are obtained when examining either changes to the ash-type stands or changes to mixed species stands.

For example, ceasing to log the mixed species stands, but continuing to log the ash-type stands under the STATUS QUO, would represent an improvement in the NPV of catchment outputs of about $27 M. To put this in perspective, the improvement in the NPV of catchment outputs with the NO LOG option, for the base case, was about $147 M. This suggests that about $27 M of the total benefit arose by ceasing to log the mixed species stands and that about $120 M arose by ceasing to log the ash-type forest. Given that the productive areas of ash-type and mixed species stands are about 12,600 ha and

8,000 ha respectively, this demonstrates that the gains from reducing timber harvesting for a given area of ash-type forest exceeds by about three-fold the gains from a similar reduction in the harvesting of mixed species.

TABLE 4.3 RESULTS OF SENSITIVITY ANALYSES

NPV RELATIVE TO STATUS QUO FOR NOMINATED PRICES WHILE ALL OTHER PRICES ARE SPECIFIED AS FOR BASE CASE ($M)

	NO LOG	40 YEAR	120 YEAR	200 YEAR	80 THIN	200 THIN	BIG STRIP
Base Case	147	4	45	102	19	113	169
Water Prices							
High	209	12	75	145	22	158	228
Low	48	-7	-2	34	13	41	74
Timber Prices							
High	113	-4	29	79	21	91	150
Low	167	10	55	116	16	125	180
Catchment Management Costs							
High							
Nil	147	4	45	102	19	113	169
	147	4	45	102	19	113	169
Additional Transport Cost for Foregone Pulp Logs							
High	146	4	45	102	19	112	168
Nil	148	4	46	103	19	114	170
Discount Rate							
High	36	10	5	26	10	31	84
Low	563	-30	183	357	41	387	429
Nil	3792	-407	985	2008	75	2043	2078

4.3.3.6 Effect on Future Augmentation of Urban Water System

Changes to forest management have a significant effect on the timing of future augmentations to the capacity of Melbourne's water supply system. The results of the economic analysis presented above incorporate the changes in the NPV of the capital costs associated with future augmentations.

A detailed examination of the results, which are presented in Appendix G, reveals the extent to which differences in NPV between options reflect the changes in timing of future augmentations. For example, the net increase in NPV from a 200 year rotation, relative to the status quo, has the following main components:

- a saving of about $35 million due to deferred augmentations;
- additional water consumption valued at about $130 million;
- reduced timber production valued at about $60 million

giving a net advantage of about $100 million.

The results presented to date have been based on the timing of augmentations as determined by the behavioural rules which were described in Section 3.4. However, the dynamic programming model has also been used to examine the optimal timing of augmentations from a different viewpoint; namely, how the system would be augmented if water prices were not held constant and under varying scenarios for the rate of growth in Melbourne's water consumption.

An important result from this modelling is the observation that the optimal solution for the Thomson Catchment is influenced considerably by the expected rate of increase in demand for water in Melbourne. The base case solution assumes a rate of growth in water demand of 1 per cent per annum, whereas Melbourne's actual demand growth is presently more than 2 per cent. At a rate of growth in consumption of about 1.5 per cent or higher, the optimal solution of the dynamic programming model involves no logging. At lower rates of growth in consumption, the optimal solution involves the continuation of logging with longer rotations and/or increased use of thinning.

4.3.3.7 Other Results

A number of other sensitivity analyses have been undertaken and the results of these, plus the analyses mentioned in the preceding sections, were summarised in Table 4.3. Overall, the sensitivity analyses undertaken have led the consultants to the conclusion that the ranking of options determined in the base case is a robust ranking over the range of prices and costs tested.

4.4 EFFECT OF WATER VALUES ON OPTIMAL ROTATION

The discounted cash flow analysis and the dynamic programming modelling which are presented in subsequent Sections have required considerable data collection. However, much can be gleaned from a strictly theoretical analysis, using conceptual diagrams and equations, to describe the market setting and identify the characteristics of those combinations of catchment outputs which maximise economic values.

With silvicultural practices and rotation length set, timber and water are "joint" products; that is, they are produced in roughly fixed proportions. Changes in silvicultural practices and rotation length, however, causes the products to become "competitive", that is, more of one product means less of the other. If, under some circumstances, more of both can be produced, this should be exploited fully until the products become competitive.

A conceptual analysis has been undertaken and dynamic programming (DP) models have been specified. A detailed discussion of the conceptual models and DP models, and their implications are presented in Appendix H and I respectively. There is nothing new about conceptual models being used to indicate optimal rotations for timber production, but they have rarely incorporated the impact of forest management on water yields. These models indicate that when water values are ignored, then economically optimal rotations involve forest stands always being cut before they reach their maximum sustainable yield.

Recent work by economists has tried to determine how such cutting rules are influenced by "stock externalities" such as environmental or amenity benefits. For example, as a forest gets older it may provide additional wildlife and recreational benefits. Not surprisingly, a theoretical analysis including such stock benefits makes it optimal to increase the computed Fisher and Faustmann rotations. That is, including such non-timber benefits makes it preferable to cut at later ages.

The problem being considered in the present research is related to but more complicated than these stock externality problems. This is because streamflow benefits have a complex effect on the optimum forest rotation because such benefits do not vary linearly with a forest's age. As explained in Section 3, the benefits accrue at a high rate for forests which are currently "young" or "old" but for an intermediate range of ages these benefits fall off substantially.

What this means for optimal Faustmann rotations can be explained as follows. The optimal choice of rotation is influenced by the state of uniformity of forest age at the beginning of the planning horizon. If a forest has just been cleared then **a priori** it cannot be assumed that it will always be optimal to eventually cut. It will not be optimal to ever cut if the streamflow benefits that are lost in the transition from a young to mature forest outweigh any timber values in present value.

Things are more complex if there is currently a standing forest. Again it may be optimal never to cut if the foregone streamflow benefits are large enough. In other circumstances it may be optimal to keep the forest cleared so as to maximise benefits. Optimal forest practice depends on the current age of the standing forest.

Dynamic programming models have also been used to seek the optimal management option for the Thomson Catchment. The dynamic programming model uses the same data as for the discounted cash flow analysis presented above. Results from the dynamic programming model confirm that the starting position for the catchment affects considerably the optimal rotation. For the situation where the starting position is bare land, the optimal "rotation" would involve keeping the catchment as bare land; that is, to mow forest regrowth as it occurs. However, when the initial situation is one of standing forest, then the optimal rotation depends on the age of forest in the initial situation.

For the base case prices, once trees are aged 140 years and over, it is optimal never to harvest the forest. By contrast, when the initial situation involves younger trees then, at low water prices, the optimal solution is to harvest immediately all trees above 40 years of age or even younger, and to then follow a **40 year or even shorter** rotation.

From a wider perspective such short rotations may not be viewed as optimal. Frequent cuttings may cause excessive soil erosion, reservoir sedimentation, and loss of mature forest for wildlife habitat and recreation. The Victorian Timber Industry Strategy (State Government of Victoria, 1986, p. 33) states that "sustainable volumes of sawlogs from mature forests will be calculated for minimum rotations of 80 to 150 years depending on forest type".

The Steering Committee for this consultancy directed at an early stage that consideration should not be given to such very short rotations because they are so far removed from the constraints of the Victorian Timber Industry Strategy, consequently they are not dwelt on here.

However, it cannot be overlooked that the dynamic programming model developed for this consultancy, albeit highly simplified, suggests strongly that very short rotations may represent an optimal rotation. While this is not a practical rotation, in terms of the Victorian Timber Industry Strategy, the results can be used to indicate the foregone value of catchment outputs by adhering to that strategy.

A useful area of future research would be to compare that foregone value with the benefits from the Strategy's position that rotations should not be shorter than 80 years. These benefits would include increased biodiversity, reduced soil disturbance, increased wildlife habitat and improved recreation opportunities.

When the minimum rotation is specified as 80 years, as defined by the Timber Industry Strategy for ash-type forest, the optimal solution for an existing forest is to never harvest timber. The results for the mixed species stands were qualitatively similar to those for the ash-type stands. These results are similar to the rankings for the eight discrete options considered in the previous Section.

There is always a small risk that the entire forest in the catchment will be subject to an uncontrollable fire. The dynamic programming model has been used also to examine the impact of the risk of fire on the optimal rotation. The best estimate which could be obtained of the annual risk of catastrophic fire was 2 per cent. If all the trees could immediately be collected and processed after the fire, there would be little loss from the fire in terms of timber output. However, problems of access, organising retrieval and "flooding the market" lead to losses and delays. The longer retrieval of dead logs is delayed, the greater will be the deterioration of the logs. Royalty charges typically fall for the removal of fire-damaged timber. As a rough estimate, it is assumed that the salvage value of fire-damaged logs is 67 per cent of undamaged logs. It is concluded that allowing for the risk of catastrophic fire has little effect on optimal rotation periods.

4.5 IMPLICATIONS FOR POLICY

The results are best summarised as indicating that a change in management of the forests in the Thomson Catchment would lead to an increase in the economic value of catchment outputs. The important message is that the status quo does not maximise the total value of timber and water outputs from the catchment and that a range of management options would result in significant economic gains relative to the status quo.

Economic output would be increased most by either ceasing logging or by increasing the rotation length together with an increased use of thinning techniques. There is not enough evidence from this study to determine categorically which of those changes would yield the greatest benefit.

The choice between ceasing to log and adopting long rotations with thinning is a very difficult one. They would each appear to lead to a similar NPV of catchment outputs and each have similar degrees of risk. Either avoids the risk of precluding other options in the future. This is because either option retains the existing standing timber resource for many years to come and as such allows the opportunity to change readily to other options including shorter rotations at some point in the future. This is an advantage of the longer rotations over the short (40 YEAR) rotation where once a decision was made to manage the catchment on a short rotation, it would then be difficult to change at some future date to a longer rotation as the standing timber resource would have been harvested substantially in the meantime.

It must be emphasised that this study has considered the mix of catchment outputs only from the viewpoint of economic efficiency for the State or Nation. Before a final decision can be made for the Thomson Catchment, it would be necessary to consider also the other changes which are not relevant to economic efficiency. For example, consideration would need to be given to:

- implications of various management strategies for recreation values and conservation values of the catchment; for example, environmental values such as flora and fauna reserves, wildlife corridors, areas prone to landslip and erosion, areas of landscape significance, and sites of archaeological, cultural and historic interest;

- implications for employment levels;

- implications for non-consumptive uses of water from Thomson catchment; e.g. flushing for Gippsland Lakes.

The methodology used in this study of the Thomson can be applied to other catchments on a catchment by catchment basis. However, the results which have been identified for the Thomson catchment should not be extrapolated to other catchments. An important finding has been that the optimal strategy depends on the current age of the forest. This must be considered when applying the methodology to other catchments.

4.6 SUGGESTIONS FOR FURTHER STUDY

In hindsight it would have been useful to examine some additional options to the eight options nominated by the Steering Committee. In particular consideration could be given to evaluating the following options:

Revised Status Quo

Specify the status quo as involving the harvest of $1/80^{th}$ of the productive area in every year, thereby avoiding the confusion introduced by the fact that DCE intends varying the rate of harvest between decades.

Corridor Thinning with a Variety of Rotation Lengths

The BIG STRIP option indicates the highest level of catchment outputs, but it is not clear whether this result would vary greatly for options involving 6000 ha being thinned to alternate strips in conjunction with shorter or longer rotations.

It must be remembered that technical aspects of corridor thinning have been predicted based solely on the results of research trials. Further study would be required into aspects such as the appropriate orientation of cleared strips, appropriate layout for roading, environmental impacts for flora and fauna, the extent of regrowth from the cleared strip in the longer term, and the longevity of water yield increases.

Uniform Thinning

There is insufficient evidence from the analysis of the eight nominated options to separate out the benefits of uniform thinning from the benefit of corridor thinning with the 80 THIN and 200 THIN options. Consequently there is no conclusive evidence about the effects of uniform thinning. This is because options including uniform thinning (80 THIN & 200 THIN) also involve corridor thinning.

In order to evaluate the effects of uniform thinning in itself, it would be necessary to specify an option(s) involving uniform thinning alone, preferably for a range of rotation lengths.

Thinning Aimed Specifically at Increasing Water Yields

It has been clearly established for ash-type forests that water yields are lower early in the rotation, that is, when volume growth and sapwood cross-sectional area are at a maximum, usually from about ages 10 to 40 years. This suggests that a non-commercial thinning, say at age 10 years leaving only the best 300 stems, may provide a considerable increase in water yield. Subsequently it would increase the ratio of sawlogs to pulplogs. Such non-commercial thinning options could be readily simulated.

Options of a heavy thinning at an early age should be evaluated for a range of rotation lengths.

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APPENDIX A

TERMS OF REFERENCE FOR CONSULTANCY

Doc Ref: 3180/2

Woori Yallock Complex

Forestry Section

22 January 1992

AN INVITATION AND BRIEF FOR THE EVALUATION OF THE ECONOMIC VALUES OF WOOD AND WATER FOR THE THOMSON CATCHMENT

Offers are called from appropriately qualified groups for a desk top study to be completed by mid May 1992 on the valuation of the economic benefits of wood and water outputs from the Thomson Catchment Victoria. These are required as part of the development of forest management regimes.

The background to the study is that Melbourne Water Research has found that streamflow yields are significantly influenced by the stand condition of the ash type forests of the central highlands. Water yield increases with forest age and after certain types of thinning treatments. Fire and/or management actions which convert oldgrowth forest to a regrowth condition decrease streamflow. The status report on CHR published in 1991 (enclosed) summarises these findings.

The Thomson catchment is an area of public land supplying water for irrigation and domestic use, sawlog under licence agreement, pulpwood to the Maryvale mill, habitat and recreational opportunities.

The Thomson catchment contains about 11 500 ha of 50 year old regrowth ash type forest which is currently used to supply sawlogs and pulpwood to regionally based industries. This ash type forest is part of 48 000 ha of forested catchment draining into a 1.2×10^6 ML storage. This storage is able to hold about five times the average annual flow from the catchment.

The Victorian State Government in the 1986 Timber Industry Strategy set a policy for water production from forested catchments. The following extracts are appropriate;

Water is a product of forest land capable of direct management through thinnings and adoption of longer rotations to increase streamflow yields. The implementation of certain management regimes to favour water production would result in lower timber productivity. Integrated planning will give emphasis to water production in catchments designated for water supply.

Planning for these areas requires considerable foresight as timber production and regeneration particulary in the ash type forests has a major long term effect on water yields. Where there is a reduction of timber yields due to measures taken to enhance water yield and to protect water quality, this would be offset by increases in the quantity and quality of streamflow.

The State Conservation Strategy, in line with the World Conservation Strategy, will emphasise the primary importance of protecting catchments.

In accordance with the Code of Forest Practices the Government will:

** Integrate water production criteria into the planning process and will give emphasis to water production in catchments designated for water supply.*

** Give priority to water production in those catchments with limited streamflows which service regions with high current or potential water demand.*

It has also been stated in the Timber Industry Strategy that "*Central Gippsland contains a diversity of forest types including significant areas of ash regrowth, ... the regrowth resource will form the backbone of the hardwood sawmilling industry in the future ...*"

There is community debate about the priority which should be given to wood and water production in the Thomson catchment. An independent report on the appropriate economic valuation of both outputs is required in order to assist in the development of management strategy for the balance of outputs.

Emphasis should be given in the consultancy to the development of an appropriate methodology for the economic evaluation of wood and water outputs over an extended period. The study should examine the effect of various forest management regimes such as; the cessation of forest harvesting, the continuation of the current regime, the use of longer rotations and the use of silvicultural systems such as thinning.

Sensitivity analysis on the effect of changes in economic parameters such as discount rates and product pricing should form part of the report.

The consultancy group will be advised and provided with data by a steering committee drawn from the staff of Melbourne Water and the Department of Conservation and the Environment assisted by an Australian Conservation Foundation representative and a Victorian Association of Forest Industries representative.

The selection of the consultant group will be based on:

(i) The expertise and experience of the group
(ii) An outline of the methodology to be employed and its' outputs
(iii) Costs of undertaking the consultancy

Accordingly your group is invited to put forward a submission detailing factors (i), (ii) and (iii) above. The submission should include the curriculum vitae of the members who would be involved in the study, their degree of involvement, and the likely team leader.

Further information can be obtained from Pat O'Shaughnessy on (059) 64 7100 or Dasarath Jayasuriya (03) 615 4109, or Kevin Wareing (03) 412 4332.

Yours faithfully

P O'Shaughnessy

P O'Shaughnessy
Convenor
DCE/Melbourne Water Steering Committee

APPENDIX B

DCE ESTIMATES OF RESOURCE BASE IN THOMSON CATCHMENT AND PROPOSED MANAGEMENT FOR THAT RESOURCE

1. AREA STATEMENT

The statement below (Table 1) is the **final area statement** for the Thomson catchment based on the 1992 HARIS statement for the Central Gipplsand FMA.

Table 1, Area statement for the Thomson Catchment

Forest Type	Age class of forest	Total forest area (ha)	Area unavailable for wood production		Net Productive Area (ha)
			within reserves	unproductive /prescription	
Alpine Ash	M/OM	35	0	35	0
-	Unstocked	105	0	9	96
	1930-39	8 319	618	774	6 927
	1970-79	371	0	0	371
	1980-89	171	0	0	171
	1990-99	192	0	0	192
Mountain Ash	M/OM	634	0	634	0
	Unstocked	477	0	43	434
	1930-39	3 866	0	887	2 979
	1980-89	203	0	0	203
	1990-99	103	0	1	102
Shining Gum	Unstocked	12	0	0	12
	1930-39	1 260	0	160	1 100
	1980-89	21	0	0	21
	1990-99	27	0	1	26
Sub total (ASH)	-	15 796	618	2 544	12 634
Mixed species	M/OM	20 991	1 830	15 016	4 145
	Unstocked	11	0	0	11
	1910-19	60	0	0	60
	1930-39	4 730	0	1 095	3 635
	1980-89	180	0	74	106
	1990-99	13	0	0	13
Sub total (MS)	-	25 985	1 830	16 185	7 970
Alpine Vegetation	-	3 386	3 355	31	0
Scrub	-	581	0	581	0
Private Land	-	47	0	47	0
Water Surface	-	2 428	0	2 428	0
Sub total (OTHER)	-	6 442	3 355	3 087	0
Total	-	48 223	5 803	21 816	20 604

Source: HARIS Database, March 1992
DCE Geographic Information Systems

Note: M/OM represents mature/overmature forest.

The figures in this statement assume that there will be no change in land tenure and that no additional areas will be excluded by prescription.

2. THINNABLE AREA

A list of the potentially thinnable areas of ash type forest in the Thomson catchment (ie, areas of forest on slopes < 18^0) are included in Table 2.

Table 2, Potentially thinnable areas of ash type forest in the Thomson catchment

Species Type	Age Class	Net Area < 18^0 (ha)
Alpine Ash	pre 1940	3 762
	post 1940	402
Mountain Ash	pre 1940	1 988
	post 1940	243
Shining Gum	pre 1940	729
	post 1940	16
Total	**All Ages**	**7 140**

Source, Management block assessments and HARIS statement.

Due to the variable stocking levels, debris on the forest floor, limited season for operations and uncertain markets it is considered that the area suitable for thinning may be considerably less than 7,140 ha.

3. THINNING YIELDS

The predicted yields from various thinning regimes that could be adopted in the Thomson catchment are listed in Table 3.

Table 3, Predicted yields from various thinning regimes in the Thomson catchment.

Thinning Regime	Predicted yields (m^3/ha) at nominated ages						
	Year 20	Year 60		Year 80		Year 120	
	Pulpwood	Sawlog	Pulpwood	Sawlog	Pulpwood	Sawlog	Pulpwood
1	80	na	na	350	320	na	na
2	90	na	na	425	400	na	na
3	40	120	250	na	na	420	220
4	100	90	120	na	na	550	210

Regime 1 Strip thin (non commercial) at age 8 - 10 years (cut 4m, leave 16m); strip thin at age 20 years (cut alternate existing strips) and clear fell at age 80 years.

Regime 2 Thin from below at age 8 - 10 years (non commercial - thin to 1,200 stems/ha); thin from below at age 20 years (remove 50% standing basal area) and clear fell at age 80 years.

Regime 3 Strip thin at age 20 years (cut 4m, leave 16m); strip thin at age 60 years (cut alternative existing strips) and clear fell at age 120 years.

Regime 4 Thin from below at age 20 years (remove 50% standing basal area); thin from below at age 60 years (remove 30% standing basal area) and clear fell at age 120 years.

Thinning yields are predicted with some uncertainty because of the limited operational application of these regimes. The predictions have, however, been based on computer simulation using specifications employed in experimental trials. It should be pointed out that assumptions regarding growth responses from thinning, particularly in terms of log quality, are largely untested.

4. MEAN ANNUAL INCREMENT

The predicted growth rates of unthinned stands at various rotation ages for the Thomson catchment are listed in Table 4.

Table 4, Predicted growth rates of unthinned stands at various rotation ages for the Thomson catchment

Forest Type(1)	Product	Mean annual increment ($m^3/ha/yr$) at ages:				
		60 years	80 years	120 years	150 years	200 years
Alpine Ash	Sawlog(2)	3.8	4.3	4.5	4.5	3.5
	Roundwood(3)	4.4	4.0	2.9	2.3	1.5
Mountain Ash	Sawlog(2)	3.5	4.1	4.6	4.6	3.4
	Roundwood(3)	5.6	5.1	3.8	2.2	1.3
Shining Gum	Sawlog(2)	3.1	3.5	3.7	3.6	3.2
	Roundwood(3)	3.9	3.6	2.9	1.6	1.1
Mixed Species	Sawlog(2)	1.5	1.5	1.2	1.1	0.8
	Roundwood(3)	1.5	1.5	1.2	1.1	0.8

Notes 1. Predicted yields from all stand classes within a given forest type have been weighted to provide an average value which applies to all age classes.

2. Yield for grade C and better sawlogs.

3. Yield for residual roundwood including lower graded sawlogs and pulpwood.

It should be noted that yield forecasts for longer rotations, i.e. greater than 100 years, have a wider margin of error because this part of the growth curve in terms of product outturn has not been fully validated.

5. TIMBER HARVESTING SCHEDULE

The area of each forest type forecast to be cut over the next 55 years in the Thomson catchment are shown in table 5. The figures represent the average area to be cut per year in five year increments and are based on the assumption that the harvesting strategy adopted will meet the legislated sustainable yield rate of 183,000 m^3/yr for the Central Gippsland FMA as defined in the *Forests (Timber Harvesting) Act 1990*.

Table 5 Annual area of each forest type forecast to be cut from the Thomson catchment (1992-2046)

Forest Type	Annual area to be cut (ha/yr)										
	1992-1996	1997-2001	2002-2006	2007-2011	2012-2016	2017-2021	2022-2026	2027-2031	2032-2036	2037-2041	2042-2046
Alpine Ash	111	111	147	147	147	129	129	129	74	74	74
Mnt. Ash & Shining Gum	98	98	69	69	69	55	55	55	50	50	50
Mixed species	158	158	154	154	154	198	198	198	12	12	12
Total	367	367	370	370	370	382	382	382	136	136	136

6. ACTUAL VERSUS CALCULATED YIELDS

There is no data available at present comparing actual yields with calculated yields for the Central Gippsland FMA or the Thomson catchment, however preliminary investigation of two representative logging coupes in the FMA have indicated that the actual yields do compare well with calculated yields.

7. PROPORTION OF A,B,C GRADE RECOVERIES

The expected grade recoveries for sawlogs from the Central Gippsland FMA are listed in table 6. The figures have been derived from log sales figures for the period 1989/90 and are considered by regional planners as representative grade recoveries for the FMA.

Table 6 Expected grade recoveries for selected species in the Central Gippsland FMA

Species	Sawlog Grade	Proportion (%)
Ash-type	A	1
	B	42
	C	57
Other species	A	0
	B	12
	C	88

8. SAWLOG TO RESIDUAL ROUNDWOOD RATIOS

The ratios of grade C and better sawlog to pulpwood for each forest type in the Central Gippsland FMA are listed in table 7. The figures have been extracted from the HARIS database and are derived from various timber assessments that have been carried out in the FMA.

Table 7 Ratio of grade C & better sawlog to pulpwood for each forest type in the Central Gippsland FMA

Forest Type	Mature/overmature ratio	Regrowth ratio
Alpine Ash	1:2.2	1:1.5*
Mountain Ash & Shining Gum	1:1.8	1:1.5*
Mountain mixed species	1:2.8	1:1
Foothill mixed species	1:5.1	1:1

* this figure is the current standing volume from HARIS for the 1926 and 1939 stands, it is expected to decrease to 1:1 in around 2001.

Department of Conservation & Environment

240 Victoria Parade
East Melbourne
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Telephone (03) 412 4011

Your Ref.
Our Ref.
Date 26 March, 1992

To: Read Sturgess and Associates

From: Bob McKimm
Manager, Native Forests

ATTENTION: Mike Read

As requested I am pleased to supply cost estimates associated with DCE management in the Thomson catchment. The information has been developed by Native Forests from information provided by Jeff Byrne (Project Manager, Commercial Accounting) and regional staff in the Central Gippsland Region and is provided in three Tables and a statement regarding research and development.

Table 1 describes unit costs associated with DCE's management of **non-harvesting activities** in the Thomson catchment for 1990-1991. It is considered that the data for 1990-1991 is representative for management costs in this type of forest. However your attention is drawn to (a) activity #6 (Fire Protection), the cost of which could increase markedly in the event of a major fire and (b) activity #8 (Administration) where the cost for parks and reserves is inflated by approximately \$0.30 ha^{-1} as a result of a car park constructed at Mount St. Gwinear.

Table 1. Unit costs associated with DCE's management of non-harvesting activities in the Thomson catchment, 1990-1991

Activity	Unit Cost (\$ ha^{-1})		
	State Forest	Parks & Reserves	All Public Land*
1. Policy, Planning, Programming	1.31	0.53	1.21
2. Res Inventory & Info Systems	0.54	0.06	0.48
3. Supervision of Operations	0.39	0.26	0.37
4. Roading	0.10	0.50	0.15
5. Pest Control	0.31	0.35	0.32
6. Fire Protection	2.12	2.12	2.12
7. Training	0.07	0.03	0.07
8. Administration	0.60	2.33	0.81
Total	5.44	6.18	5.53

* weighted average of State Forest and parks & reserves.

Table 2 describes unit costs associated with DCE's management of **harvesting and regeneration activities** in the Thomson catchment for 1990-1991. The data provided are considered to be representative for this type of forest.

Table 2, Unit costs associated with DCE's management of harvesting and regeneration activities in the Thomson catchment, 1990-1991

Activity	Costs	Unit
1. Seed Collection	414	$\$ Kg^{-1}$
2. Regeneration (site prep & estab)	193	$\$ ha^{-1}$
3. Harvesting		
a) harvesting	3.85	$\$ m^{-3}$
b) roading	3.61	$\$ m^{-3}$
c) administration	1.81	$\$ m^{-3}$
Sub-total (harvesting)	9.27	$\$ m^{-3}$

It should be noted that (a) seed is applied to harvested coupes at a rate, depending on seed viability, of approximately 1 Kg ha^{-1}. This means that the cost of site preparation and establishment after harvesting approximates \$607 ha^{-1} and (b) the roading component is expected to decrease in the long term.

Table 3 describes the area of State Forest and parks and reserves in the Central Gippsland Region and the Thomson catchment.

Table 3, Area of State Forest and parks and reserves in the Central Gippsland Region and the Thomson catchment

Location	State Forest (ha)	Parks & Reserves (ha)	Total (ha)
Central Gippsland Region(1)	491 000	317 000	808 000
Thomson Catchment(1,2)	40 700	5 800	46 500

1 figures have been rounded
2 based on the provisional area statement
Source: Resource Assessment Report No. 91/01. Hardwood Timber Resources in the Central Gippsland FMA

Research and development costs of \$2.50 ha^{-1} for 1990-1991 are derived from a total expenditure of \$3.21 M for a net productive area of State Forest of approximately 1.3 M hectares statewide. This present level of expenditure is probably a peak figure due to the impact of the value adding and silvicultural systems program (VSP). It is anticipated that the level of expenditure for research and development would range between \$1 and \$2 ha^{-1} yr^{-1} over the rotation in the long term.

R. J. McKimm.

Copies for information:
Frank Noble, Regional Manager, Central Gippsland
Kevin Wareing, Director, Forest Products Management
Richard Rawson, General Manager, Gippsland (Forest Division)
Pat O'Shaughnessy, Steering Committee, Convenor

APPENDIX C

SIMULATED AREAS OF FOREST TO BE HARVESTED; SOURCE OF DATA FOR DERIVATION OF SAWLOG : PULPWOOD RATIOS

TABLE C.1 TIMBER AREA CLEAR FELLED - STATUS QUO (ha)

DECADE ENDING	ASH STAND				MIXED SPECIES STANDS				
	1939	1970	1980	1990	MATURE	1919	1939	1980	1990
1992	0	0	0	0	0	0	0	0	0
2002	2090	0	0	0	1580	0	0	0	0
2012	2160	0	0	0	1540	0	0	0	0
2022	2000	0	0	0	1025	60	675	0	0
2032	1840	0	0	0	0	0	1980	0	0
2042	1240	0	0	0	0	0	120	9	0
2052	1240	371	395	0	0	0	120	9	0
2062	1376	0	0	0	0	0	120	9	1
2072	1376	0	0	40	0	0	120	9	1
2082	1376	0	0	40	0	0	120	9	1
2092	1376	0	0	40	0	0	120	9	1
2102	1376	0	0	40	0	0	140	9	1
2112	1376	0	0	40	518	8	454	9	1
2122	1376	0	0	40	518	8	454	9	1
2132	1376	371	49	40	518	8	454	9	1
2142	1376	46	49	40	518	8	454	9	1
2152	1376	46	49	40	518	8	454	9	1
2162	1376	46	49	40	518	8	454	9	1
2172	1376	46	49	40	518	8	454	9	1
2182	1376	46	49	40	518	8	454	9	1
2192	1376	46	49	40	518	8	454	9	1

TABLE C.2 TIMBER AREA CUT 40 YEAR (ha)

DECADE ENDING	ASH STAND				MIXED SPECIES STANDS				
	1939	1970	1980	1990	MATURE	1919	1939	1980	1990
1992	2752	0	0	0	0	0	0	0	0
2002	2752	93	99	0	1580	0	0	0	0
2012	2752	93	99	80	1540	0	0	0	0
2022	2752	93	99	80	1025	60	675	0	0
2032	2752	93	99	80	0	0	1980	0	0
2042	2752	93	99	80	0	0	120	9	0
2052	2752	93	99	80	0	0	120	9	0
2062	2752	93	99	80	0	0	120	9	1
2072	2752	93	99	80	0	0	120	9	1
2082	2752	93	99	80	0	0	120	9	1
2092	2752	93	99	80	0	0	120	9	1
2102	2752	93	99	80	0	0	140	9	1
2112	2752	93	99	80	518	8	454	9	1
2122	2752	93	99	80	518	8	454	9	1
2132	2752	93	99	80	518	8	454	9	1
2142	2752	93	99	80	518	8	454	9	1
2152	2752	93	99	80	518	8	454	9	1
2162	2752	93	99	80	518	8	454	9	1
2172	2752	93	99	80	518	8	454	9	1
2182	2752	93	99	80	518	8	454	9	1
2192	2752	93	99	80	518	8	454	9	1

TABLE C.3 TIMBER AREA CUT 120 YEAR (ha)

DECADE ENDING	ASH STANDS				MIXED SPECIES STANDS				
	1939	1970	1980	1990	MATURE	1919	1939	1980	1990
1992	0	0	0	0	0	0	0	0	0
2002	917	0	0	0	345	5	303	0	0
2012	917	0	0	0	345	5	303	0	0
2022	917	0	0	0	345	5	303	0	0
2032	917	31	0	0	345	5	303	0	0
2042	917	31	33	27	345	5	303	9	0
2052	917	31	33	27	345	5	303	9	0
2062	917	31	33	27	345	5	303	9	1
2072	917	31	33	27	345	5	303	9	1
2082	917	31	33	27	345	5	303	9	1
2092	917	31	33	27	345	5	303	9	1
2102	917	31	33	27	345	5	303	9	1
2112	917	31	33	27	345	5	303	9	1
2122	917	31	33	27	345	5	303	9	1
2132	917	31	33	27	345	5	303	9	1
2142	917	31	33	27	345	5	303	9	1
2152	917	31	33	27	345	5	303	9	1
2162	917	31	33	27	345	5	303	9	1
2172	917	31	33	27	345	5	303	9	1
2182	917	31	33	27	345	5	303	9	1
2192	917	31	33	27	345	5	303	9	1

TABLE C.4 TIMBER AREA CUT 200 YEAR (ha)

DECADE ENDING	ASH STANDS				MIXED SPECIES STANDS				
	1939	1970	1980	1990	MATURE	1919	1939	1980	1990
1992	0	0	0	0	0	0	0	0	0
2002	550	0	0	0	207	3	182	0	0
2012	550	0	0	0	207	3	182	0	0
2022	550	0	0	0	207	3	182	0	0
2032	550	19	0	0	207	3	182	0	0
2042	550	19	20	16	207	3	182	5	0
2052	550	19	20	16	207	3	182	5	0
2062	550	19	20	16	207	3	182	5	1
2072	550	19	20	16	207	3	182	5	1
2082	550	19	20	16	207	3	182	5	1
2092	550	19	20	16	207	3	182	5	1
2102	550	19	20	16	207	3	182	5	1
2112	550	19	20	16	207	3	182	5	1
2122	550	19	20	16	207	3	182	5	1
2132	550	19	20	16	207	3	182	5	1
2142	550	19	20	16	207	3	182	5	1
2152	550	19	20	16	207	3	182	5	1
2162	550	19	20	16	207	3	182	5	1
2172	550	19	20	16	207	3	182	5	1
2182	550	19	20	16	207	3	182	5	1
2192	550	19	20	16	207	3	182	5	1

TABLE C.5 TIMBER AREA CLEAR FELLED AND THINNED - 80 YEAR COMBINATION THIN (ha)

DECADE	ASH STANDS						MIXED SPECIES STANDS CLEAR FELL				
	UNIFORM THIN	STRIP THIN	CLEAR FELL	CLEAR FELL							
ENDING	1939	1939	1939	1970	1980	1990	MATURE	1919	1939	1980	1990
1992	0	0	0	0	0	0	0	0	0	0	0
2002	0	0	2090	0	0	0	1580	0	0	0	0
2012	0	0	2160	0	0	0	1540	0	0	0	0
2022	1785	0	2000	0	0	0	1025	60	675	0	0
2032	0	0	1840	0	0	0	0	0	1980	0	0
2042	0	0	1240	0	0	0	0	0	120	9	0
2052	0	1785	1240	371	395	0	0	0	120	9	0
2062	0	0	1376	0	0	0	0	0	120	9	1
2072	0	0	1376	0	0	40	0	0	120	9	1
2082	0	0	1376	0	0	40	0	0	120	9	1
2092	0	0	1376	0	0	40	0	0	120	9	1
2102	1376	0	1376	0	0	40	0	0	140	9	1
2112	409	0	1376	0	0	40	518	8	454	9	1
2122	0	0	1376	0	0	40	518	8	454	9	1
2132	0	1376	1376	371	49	40	518	8	454	9	1
2142	0	409	1376	46	49	40	518	8	454	9	1
2152	0	0	1376	46	49	40	518	8	454	9	1
2162	0	0	1376	46	49	40	518	8	454	9	1
2172	0	0	1376	46	49	40	518	8	454	9	1
2182	1376	0	1376	46	49	40	518	8	454	9	1
2192	409	0	1376	46	49	40	518	8	454	9	1

TABLE C.6 TIMBER AREA CLEAR FELLED AND THINNED - 200 YEAR COMBINATION THIN (ha)

DECADE	ASH STANDS						MIXED SPECIES STANDS CLEAR FELL				
	UNIFORM THIN	STRIP THIN	CLEAR FELL	CLEAR FELL							
ENDING	1939	1939	1939	1970	1980	1990	MATURE	1919	1939	1980	1990
1992	0	0	0	0	0	0	0	0	0	0	0
2002	0	0	550	0	0	0	207	3	182	0	0
2012	0	0	550	0	0	0	207	3	182	0	0
2022	550	0	550	0	0	0	207	3	182	0	0
2032	550	0	550	19	0	0	207	3	182	0	0
2042	550	0	550	19	20	16	207	3	182	5	0
2052	135	550	550	19	20	16	207	3	182	5	0
2062	0	550	550	19	20	16	207	3	182	5	1
2072	0	550	550	19	20	16	207	3	182	5	1
2082	0	135	550	19	20	16	207	3	182	5	1
2092	0	0	550	19	20	16	207	3	182	5	1
2102	0	0	550	19	20	16	207	3	182	5	1
2112	0	0	550	19	20	16	207	3	182	5	1
2122	0	0	550	19	20	16	207	3	182	5	1
2132	0	0	550	19	20	16	207	3	182	5	1
2142	0	0	550	19	20	16	207	3	182	5	1
2152	0	0	550	19	20	16	207	3	182	5	1
2162	0	0	550	19	20	16	207	3	182	5	1
2172	0	0	550	19	20	16	207	3	182	5	1
2182	0	0	550	19	20	16	207	3	182	5	1
2192	0	0	550	19	20	16	207	3	182	5	1

TABLE C.7 TIMBER AREA CLEAR FELLED AND THINNED - BIG STRIP ROTATION (ha)

DECADE	ASH STANDS					MIXED SPECIES STANDS				
	STRIP THIN	CLEAR FELL								
ENDING	1939	1939	1970	1980	1990	MATURE	1919	1939	1980	1990
1992	0	0	0	0	0	0	0	0	0	0
2002	2000	0	0	0	0	207	3	182	0	0
2012	2000	0	0	0	0	207	3	182	0	0
2022	2000	0	0	0	0	207	3	182	0	0
2032	0	550	19	0	0	207	3	182	0	0
2042	0	550	19	20	16	207	3	182	5	0
2052	0	550	19	20	16	207	3	182	5	0
2062	0	550	19	20	16	207	3	182	5	1
2072	0	550	19	20	16	207	3	182	5	1
2082	0	550	19	20	16	207	3	182	5	1
2092	0	550	19	20	16	207	3	182	5	1
2102	0	550	19	20	16	207	3	182	5	1
2112	0	550	19	20	16	207	3	182	5	1
2122	0	550	19	20	16	207	3	182	5	1
2132	0	550	19	20	16	207	3	182	5	1
2142	0	550	19	20	16	207	3	182	5	1
2152	0	550	19	20	16	207	3	182	5	1
2162	0	550	19	20	16	207	3	182	5	1
2172	0	550	19	20	16	207	3	182	5	1
2182	0	550	19	20	16	207	3	182	5	1
2192	0	550	19	20	16	207	3	182	5	1

SOURCE OF DATA FOR DERIVATION OF SAWLOG : PULPWOOD RATIOS

C.1 DEPARTMENT OF CONSERVATION AND ENVIRONMENT

Forest Type	Mature/Overmature Ratio	Regrowth Ratio
Alpine Ash	1:2.2	1:1.5*
Mountain Ash & Shining Gum	1:1.8	1:1.5*
Mountain Mixed Species	1:2.8	1:1
Foothill Mixed Species	1:5.1	1:1

The Department indicated these data were based on "assessed", as distinct from operationally-derived, estimates.

The consultants also recognised that the figures did not reflect changes in market conditions or changes in harvesting operations. Nevertheless the figures were seen as providing a valuable guide.

C.2 OPERATIONALLY DERIVED RATIOS

C.2.1 For regrowth ash-type (1939 Regen)

C.2.1.1 Private grower data for sales over nine years, ranging from 39 years to 47 years.

	Sawlogs		Residual Roundwood (Pulpwood and Paling Logs)
	14830 m^3		16096 m^3
Ratio	1	:	1.08

C.2.1.2 Melbourne Water data for 42 year old mountain ash, strip thinned volumes recovered at age 42.

	Sawlogs		Palings Logs	Pulpwood
	148 m^3/ha		48 m^3/ha	257 m^3/ha
Ratio	1	:	2.06	

C.2.1.3 Department of Conservation and Environment for 19 year old thinning, Little Jim Toolangi, 1988.

	Sawlogs		Pulpwood
	0	:	143 tonnes/ha
Ratio	0	:	1

C.2.1.4 Consultants' simulation models for material aged 25, 30 and 35 years.

	Sawlogs		Pulpwood
Ratio	0	:	1

C.2.2 For mature and over mature ash-type

C.2.2.1 Melbourne water data for ~ 140 year old, Mt. Riddell

	Sawlogs		Pulpwood
	85.7 m^3\ha		85.3 m3/ha
Ratio	1	:	1

C.2.2.2 Melbourne water data for ~ 260 year old, Mt. Monda

	Sawlogs		Pulpwood
	103 m^3/ha		251 m^3/ha
Ratio	1	:	2.5

C.2.2.3 Consultant's "ADA BUSH", recoveries for 165 year old stand, based on:

Sawlogs		Pulpwood
1	:	1

C.3 RATIO APPLIED BY CONSULTANTS IN ASH-TYPE FORESTS, MANAGED ON NO THINNING BASIS

Age (Year)	Sawlog : Pulpwood Ratios
0 Years - 20 Years	0 : 1
21 Years - 39 Years	0 : 1
40 Years - 60 Years	1 : 1.5
61 Years - 200 Years	1 : 1
200 Plus Years	1 : 1 - but with considerable reservations on reliability

C.4 DERIVATION OF DATA FOR THINNED 1 ASH-TYPE FORESTS

C.4.1 For uniform thinning from below at age 20 years

Sawlogs		Pulpwood
0	:	1

Source: Department of Conservation and Environment, Little Jim Toolangi - see previous.

C.4.2 For yields from 20 year old uniform thinned stand subsequently strip thinned at 50 years

Source: Melbourne Water Data reported previously viz sawlogs (148 m^3) and resid. round wood of 305 m^3.

Consultants made the assumption that, as age 20 thinning had removed suppressed and intermediate class steams, from all the stand, codominant and dominant stems would be removed in strip thinning of the remaining stand. This would yield a higher ratio of sawlogs to pulpwood than would be achieved at age 50 years. In unthinned stand - it was therefore assumed that a 1:1 ratio was applicable at for strip thinned yield.

C.4.3 For subsequent clear felling at age 80 years and 200 years for stands previously uniform and strip thinned

Age 80 years and 120 years of strip thin in the absence of any field data, the consultants assumed a ratio of 1 of sawlog : 1 pulpwood for yields from clear felled thinned stands at 80 years and 200 years.

APPENDIX D

EXPECTED WATER YIELD TABLES

TABLE D.1: EXPECTED FUTURE YIELDS FROM THOMSON CATCHMENT FOR VARIOUS MANAGEMENT SCENARIOS.

SCENARIO	TOTAL THOMSON YIELD (Gl/year)																				
Year	1992	2002	2012	2022	2032	2042	2052	2062	2072	2082	2092	2102	2112	2122	2132	2142	2152	2162	2172	2182	2192
Nolog	225	238	247	256	264	271	277	281	285	287	289	291	292	293	293	294	294	294	294	295	295
40y rotn	225	246	247	240	230	230	231	232	234	235	236	237	238	238	238	237	236	236	235	235	234
80y rotn	225	242	244	240	234	229	228	231	235	238	240	241	242	242	241	240	240	239	238	237	236
120y rotn	225	240	246	249	251	252	253	253	252	251	250	250	249	249	249	249	249	249	249	249	249
200y rotn	225	239	246	252	256	260	262	264	265	266	266	266	266	266	266	266	266	266	266	266	266
80y thin	225	242	244	242	234	229	233	234	238	238	240	243	242	242	246	244	242	239	238	239	237
200y thin	225	239	246	252	257	261	264	267	268	268	268	268	267	267	267	267	266	266	266	266	266
6000 ha strip	225	245	253	257	257	258	260	262	263	264	265	265	265	266	266	266	266	267	267	267	267

TABLE D.2: THOMSON YIELD (NOLOGGING) (GL/Y)

YEAR	1992	2002	2012	2022	2032	2042	2052	2062	2072	2082	2092	2102	2112	2122	2132	2142	2152	2162	2172	2182	2192
Ash	118	131	140	149	157	164	170	174	178	180	182	184	185	186	186	187	187	187	188	188	188
Mix Species	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53
Alpine Vegetation	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34
Scrub	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Water Surface	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
Private land	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
TOTAL YIELD (Gl/y)	225	238	247	256	264	271	277	281	285	287	289	291	292	293	293	294	294	294	294	295	295

TABLE D.3: THOMSON YIELD (40Y ASH + 80Y MIXED ROTATION) (Gl/y)

YEAR	1992	2002	2012	2022	2032	2042	2052	2062	2072	2082	2092	2102	2112	2122	2132	2142	2152	2162	2172	2182	2192
Ash	118	140	142	137	129	131	132	132	133	133	133	133	134	134	134	134	134	134	134	134	134
Mix Species	53	52	51	49	47	45	45	46	47	48	49	49	50	50	50	49	48	47	47	46	46
Alpine Vegetation	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34
Scrub	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Water Surface	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
Private land	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
TOTAL YIELD (Gl/y)	225	246	247	240	230	230	231	232	234	235	236	237	238	238	238	237	236	236	235	235	234

TABLE D.4: THOMSON YIELD (80 YEARS ROTATION) (GL/Y)

YEAR	1992	2002	2012	2022	2032	2042	2052	2062	2072	2082	2092	2102	2112	2122	2132	2142	2152	2162	2172	2182	2192
Ash	118	136	139	137	133	130	129	131	134	136	137	138	138	137	137	137	137	137	137	136	136
Mix Species	53	52	51	49	47	45	45	46	47	48	49	49	50	50	50	49	48	47	47	46	46
Alpine Vegetation	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34
Scrub	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Water Surface	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
Private land	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
TOTAL YIELD (Gl/y)	225	242	244	240	234	229	228	231	235	238	240	241	242	242	241	240	240	239	238	237	236

TABLE D.5: THOMSON YIELD (120 YEARS ROTATION) (GL/Y)

YEAR	1992	2002	2012	2022	2032	2042	2052	2062	2072	2082	2092	2102	2112	2122	2132	2142	2152	2162	2172	2182	2192
Ash	118	133	140	144	147	148	149	150	149	149	148	148	147	147	147	147	147	147	147	147	147
Mix Species	53	52	52	51	50	50	49	49	48	48	48	48	48	48	48	48	48	48	48	48	48
Alpine Vegetation	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34
Scrub	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Water Surface	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
Private land	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
TOTAL YIELD (Gl/y)	225	240	246	249	251	252	253	253	252	251	250	250	249	249	249	249	249	249	249	249	249

TABLE D.6: THOMSON YIELD (200 YEARS ROTATION) (GL/Y)

YEAR	1992	2002	2012	2022	2032	2042	2052	2062	2072	2082	2092	2102	2112	2122	2132	2142	2152	2162	2172	2182	2192
Ash	118	133	140	146	151	155	158	160	161	162	162	162	162	163	163	162	162	162	162	162	162
Mix Species	53	52	52	52	51	51	50	50	50	50	50	50	50	49	49	49	49	49	49	49	49
Alpine Vegetation	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34
Scrub	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Water Surface	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
Private land	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
TOTAL YIELD (Gl/y)	225	239	246	252	256	260	262	264	265	266	266	266	266	266	266	266	266	266	266	266	266

TABLE D.7: THOMSON YIELD (80 YEARS THINNING) (GL/Y)

YEAR	1992	2002	2012	2022	2032	2042	2052	2062	2072	2082	2092	2102	2112	2122	2132	2142	2152	2162	2172	2182	2192
Ash	118	136	139	139	133	130	134	134	137	136	137	140	138	137	142	140	140	137	137	139	136
Mix Species	53	52	51	49	47	45	45	46	47	48	49	49	50	50	50	49	48	47	47	46	46
Alpine Vegetation	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34
Scrub	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Water Surface	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
Private land	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
TOTAL YIELD (Gl/y)	225	242	244	242	234	229	233	234	238	238	240	243	242	242	246	244	242	239	238	239	237

TABLE D.8: THOMSON YIELD (200 YEARS THINNING) (GL/Y)

YEAR	1992	2002	2012	2022	2032	2042	2052	2062	2072	2082	2092	2102	2112	2122	2132	2142	2152	2162	2172	2182	2192
Ash	118	133	140	147	152	155	159	162	164	164	164	164	164	163	163	163	163	163	163	163	162
Mix Species	53	52	52	52	51	51	50	50	50	50	50	50	50	49	49	49	49	49	49	49	49
Alpine Vegetation	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34
Scrub	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Water Surface	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
Private land	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
TOTAL YIELD (Gl/y)	225	239	246	252	257	261	264	267	268	268	268	268	267	267	267	267	266	266	266	266	266

TABLE D.9: THOMSON YIELD (6000 HA "BIGSTRIP") (GL/Y)

YEAR	1992	2002	2012	2022	2032	2042	2052	2062	2072	2082	2092	2102	2112	2122	2132	2142	2152	2162	2172	2182	2192
Ash	118	138	147	152	151	153	155	157	159	160	161	161	162	162	162	163	163	163	163	163	163
Mix Species	53	52	52	52	51	51	50	50	50	50	50	50	50	49	49	49	49	49	49	49	49
Alpine Vegetation	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34
Scrub	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Water Surface	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
Private land	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
TOTAL YIELD (Gl/y)	225	245	253	257	257	258	260	262	263	264	265	265	265	266	266	266	266	267	267	267	267

APPENDIX E

VALUING TIMBER

VALUATION OF HARDWOOD LOGS

The terms 'royalty' and 'stumpage' are applied widely in the Australian forestry sector to describe the price per cubic metre of standing trees or logs sold by State forestry agencies. A log quota (also called an allocation or a licence) is a right granted by a state forest agency to a log buyer to annually harvest (or have delivered) a specified volume of logs over a specified period of typically fifteen years.

In addition to royalties, a licence (quota) holder in Victoria must pay an annual licence fee (indexed annually) of $1.20/m^3$ of quota held. The fee is set to cover administrative costs. In all states, including Victoria, the estimated cost-of-production appears to be the main determinant of base royalties for sawlogs. In Victoria, the 'royalty equation system' (a form of residual pricing) is then used to ensure that 'royalties are applied equitably and fairly across the state'. Details of the royalty system are provided in Government of Victoria (1986). Recently, the royalty equation system has been the subject of a review by the Department of Conservation and Environment (Ford, 1991).

Use of the cost-of-production method to determine product prices has some serious theoretical and practical shortcomings. The main problem with this system of price determination is that it does not take into account the linkage between supply and demand in the market (Byron and Douglas, 1981).

The way in which logs are priced and allocated by State agencies in Australia, has led many commentators to argue that prices charged for public forest logs have been lower than their competitive market prices (Byron and Douglas 1981; Senate Standing Committee on Trade and Commerce 1981; Government of Victoria 1983; Leslie 1985; Industries Assistance Commission 1987; Department of the Arts, Sport, the Environment, Tourism and Territories 1988, Cameron and Penna 1988; Industry Commission 1990; O'Regan and Bhati 1991).

Any underpricing of logs from native forests could convey a misleading impression that the use of forests for log production is a low value activity relative to the value of non-wood uses of these forests. Thus it is important to attempt to establish the true social value of the hardwood logs produced from publicly-owned forests. Before proceeding with this evaluation it is interesting to note that over the period 1979-80 to 1988-89 log royalties for hardwood sawlogs rose by 117 per cent in Victoria and by 187 per cent in New South Wales. Over the same period the consumer price index increased by 105 per cent. That is to say log royalties in Victoria were increased at a slightly higher rate than the rate of rise in the consumer price index, whereas in New South Wales the rate of increase in log royalties was substantially higher than the increase in the consumer price index. This suggests that the state forestry agencies recognise that log royalties have historically under-valued the market value of wood and that there are political goals and constraints which vary from state to state that determine how rapidly royalties can be increased.

Market (Shadow) Price Criterion

Two approaches have been used to compare recent royalties with prices that it is predicted could have been realised by a competitive market for hardwood logs in Victoria:

- residual price calculation
- estimation of prices paid for long-term harvesting rights.

A third approach would be to examine any auction or tender prices for log allocation. It appears that this system has been used to some extent in Victoria, but information is not publicly available.

Residual Price Calculation

Residual prices for logs may be estimated by deducting estimates of all distribution, processing and harvesting costs from the market prices of final products. Based on broad industrywide costs used in the report commissioned by the Forestry and Forest Products Industry Council on the competitiveness of Australia's forest industries (Jaakko Poyry 1986), O'Regan and Bhati (1991)) calculates a series of residual prices. The relevant results for hardwood logs for sawnwood are:

Actual Royalty (1984-85 dollars)		Estimated Residual Values in Victoria Log Prices ($/m³) Low	High
Existing mill	16.65	39	63
New mill	16.65	53	79

For the low estimate of residual log prices O'Regan and Bhati calculates that in 1984-85 the residual log price was 134 per cent above the royalty value for existing mills and 218 per cent above the royalty value for new mills.

The Industry Commission (1990) has also published a series of residual price calculations for sawlogs using two different approaches to capital cost estimation. The Industry Commission analysis is also based on the Jaakko Poyry (1986) costs, but differs from the O'Regan and Bhati study in that it makes allowance for risk premiums on sawmilling investments. The results which are given over the years 1981-82 to 1984-85 do not separate costs for hardwood and softwood processing. For Victoria, the average excess of residual values over royalties was found to be around 73 per cent.

Residual pricing, if it could be calculated perfectly for each parcel of logs, would generate the same price as a competitive sealed-bid auction. However, the above results should be interpreted with caution for a number of reasons. Firstly, the data on which the results are based is necessarily generalised across entire industries and relies on 1984-55 cost data. Secondly, residual pricing accepts the existing structure of the sawmilling/wood processing industry. However, the existing structure of the industry has been significantly influenced by the particular system of royalties and log quota allocation. A system of competitive sealed-bid auctions (if it could be achieved) would over time provide a continuous incentive toward adjustment and increased efficiencies in the industry. That is to say, the overall cost structure of the industry would be lower. Another way of viewing the situation is to argue that a portion of the rent has been captured by factors of production throughout the sawmilling/wood processing chain. Thirdly, it is extremely difficult for anyone other than the individual mills themselves to know their actual costs of wood processing. Clearly, if the mills believe that any information they divulge on their costs will be used to determine future royalties they have an incentive to provide inflated cost estimates.

In estimating residual log values a crucial consideration is whether or not the industry cost structure in Victoria for sawn hardwood influences final product price. In other words, does Victoria have any market power in the sawn hardwood industry? The answer to this question would appear to be 'yes' given the size of the Victorian industry and the importance of transport costs for a bulky commodity such as sawn timber. It then follows that the unobserved counterfactual world of a competitive market for sawn timber in Victoria would be one in which both the cost structure and the final product price would be lower. In this respect, the results reported by O'Regan and Bhati (1991) for existing and new mills for dressed hardwood for the Australian industry as a whole are erroneous insofar as the same final product price is assumed for both types of mills. If the unobserved competitive market situation is one in which the industry would be dominated by low cost new mills, the final product price would be lower than that currently observed. Consequently, the residual log prices for a 'new mill' industry would be lower than those calculated by ABARE.

Estimating prices paid for long-term log harvesting rights

If log royalties are below what could be realised in a competitive market then a quota right to an annual volume of logs would have a positive value over and above the royalty value. However, it should be recognised that some part of the value of a log allocation could be attributed to the value of long term access rather than the value of wood itself. If long-term access effectively reduces the amount of risk faced by a mill it could be expected to have some positive value.

Outside Victoria, there is clear evidence that the resale price of a mill generally involves a substantial capitalisation of the value of the quota allocation after royalty payments have been deducted (e.g. Department of the Arts, Sport, the Environment, Tourism and Territories 1988). An early notable example of the capitalisation phenomenon is documented by Byron and Douglas (1981). They found that the sale price of the Tasmanian Pulp and Forest Holdings woodchipping facilities was more than double an independent capital valuation.

Victoria is the first state to introduce long-term transferable licences (from 1987) and these provide an alternative means of assessing the value of log allocations in this state. In 1990, ABARE (O'Regan and Bhati 1991) obtained information for thirteen transferable quota sale prices covering most regions of Victoria and the full range of log grades.

For confidentiality reasons, prices for the individual sale transfers from one mill to another, of the rights to a specified volume of logs for a specified period, could not be published. However, the responses indicated that the values of hardwood sawlog transferable licences in Victoria was in every case both positive and substantial. It should be noted that the purchaser of the licence pays royalties on logs at the time of delivery by the state agency.

The following results can be derived from the ABARE study assuming a 4 per cent discount rate are shown below.

SUMMARY OF QUOTA PRICES AND VALUATIONS FOR HARDWOOD LOGS IN VICTORIA

Hardwood Sawlog Grade[a]	Log Royalty (1989-90)	Quota Value	Shadow Price	Excess of Shadow Price Over Royalty Value (%)
A,B	36.43	12.04	48.47	33
C	23.03	9.36	32.39	41
D	8.65	5.26	13.91	61

[a] An average for A and B grade logs was necessary because there were insufficient examples of prices and valuations of these logs to preserve confidentiality if each grade was explicitly valued (O'Regan and Bhati 1991)

The following points can be made about the above study:

- the number of transfer sales (13) is small and they occurred over a period of favourable market conditions for sawmilling;
- the shadow prices may contain a 'security value' component as the licence guarantees a long-term (up to 15 years) supply of a specified volume. O'Regan and Bhati (ABARE) compared long-term (15 years) and short-term (3 to 4 year) licences and found little difference in values. If security value is an important factor the longer term licences would be expected to be worth more;
- it is implicit in the ABARE results that the market price for quota transfer represents a competitively determined price. This appears to be a dubious assumption. The spatial dispersal of mills relative to forests is likely to be frequently such that log haulage costs (always a significant component of log values of mill) significantly favour one or two close sawmillers and effectively prevent competitive bids from other more distant mills. Consequently, some element of bilateral monopoly power is likely to exist between seller and buyer of a log quota. In these circumstances, the market price at which a particular transfer sale takes place will depend upon the relative bargaining strengths of the parties. All that is known for certain is that the market price will be bounded by the minimum amount the seller is willing to accept and the maximum amount the buyer is willing to pay and it would only be a coincidence if the observed market price equalled the competitive market price.

Observations for 13 transferable quota sales would appear to be a small sample from which to derive shadow prices for different grades of logs. Presumably, there was sufficient variation in the mix of grades between individual quota sales (some quota sales for dominantly high grade logs and others dominantly low grade logs) to allow estimation of the premiums for each grade. The fact that ABARE found A, B grade logs to have a lower premium than C grade logs which in turn had a lower premium than D grade logs could be related to several issues:

- more informed setting of royalties for high grade logs
- insecure tenure of high grade logs under VAUS
- more secure market for low grade log products e.g. scantling
- more secure supply of low grade logs if conservation pressures cause mature forests to be 'locked-up'.

It is important also to note that the ABARE values embrace a range of hardwood forest types which may limit the application to a single species or mix of species in the Thomson Dam catchment. Nevertheless it is the only information publicly available and we now apply the ABARE results to royalty values for the Thomson Dam catchment made available by the Department of Conservation and Environment.

The estimated shadow prices for A, B logs, C logs and D logs, adopting values above royalty values of 33, 41 and 61 per cent respectively are shown in Table E.1. In addition, for the purpose of sensitivity testing, low and high shadow prices for all grades of logs of actual royalties and 70 per cent above royalty values are shown.

Pulpwood

The ABARE residual pricing analysis for pulpwood was inconclusive. Pulpwood prices are negotiated under bilateral monopoly conditions, but with strong competition for domestic pulp from imported pulp. Given that domestically produced pulpwood has a close import substitute it is reasonable to assume that the unadjusted royalty values of pulpwood logs fairly closely approximate a competitive market price. For the Thomson catchment the average royalty value over all grades of pulpwood is $\$10.15m^3$. This figure could be adjusted upward by, say, 10 per cent to allow for the natural protection domestically produced pulpwood logs acquire from the transport costs of import substitutes.

APM has provided the consultants with its estimate that the current average cost of wood delivered to its Mary Vale pulp mill from Upper Thomson is about $46 per cubic metre and wood grown in eucalypt plantations would cost an additional 8 to 10 dollars per cubic metre. This suggests strongly that the shadow price of pulp could not exceed royalty by more than 8 to 10 dollars per cubic metre. The consultants have adopted the pulp royalty for the base case estimates, but undertake a sensitivity analysis using value of $8 per cubic metre above royalty.

TABLE E.1 ESTIMATED ROYALTY RATES AND SHADOW PRICES FOR LOGS FROM THE THOMSON DAM CATCHMENT

Product	Grade	1991-92 Royalty Rate $/m^3 (inclusive of all charges)	Shadow prices[a] (ABARE based)	Shadow prices 70% above royalty values
Alpine Ash	A, B	45.13	60.02	76.72
	C	34.56	48.73	58.75
	D	18.87	30.33	32.08
Mountain Ash	A, B	45.03	59.89	76.55
	C	30.18	42.55	51.31
	D	14.98	24.12	25.47
Other Species	B	27.22	36.20	46.27
	C	24.47	34.50	41.60
	D	12.70	20.45	21.59
Shining Gum	A, B	42.99	57.18	73.08
	C	32.64	46.02	55.49
	D	17.72	28.53	30.12

[a] These shadow prices are based on ABARE estimates that competitive market prices would exceed royalty values for A, B grade logs, C logs and D logs by 33, 41 and 61 per cent, respectively.

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APPENDIX F

VALUING MELBOURNE'S WATER

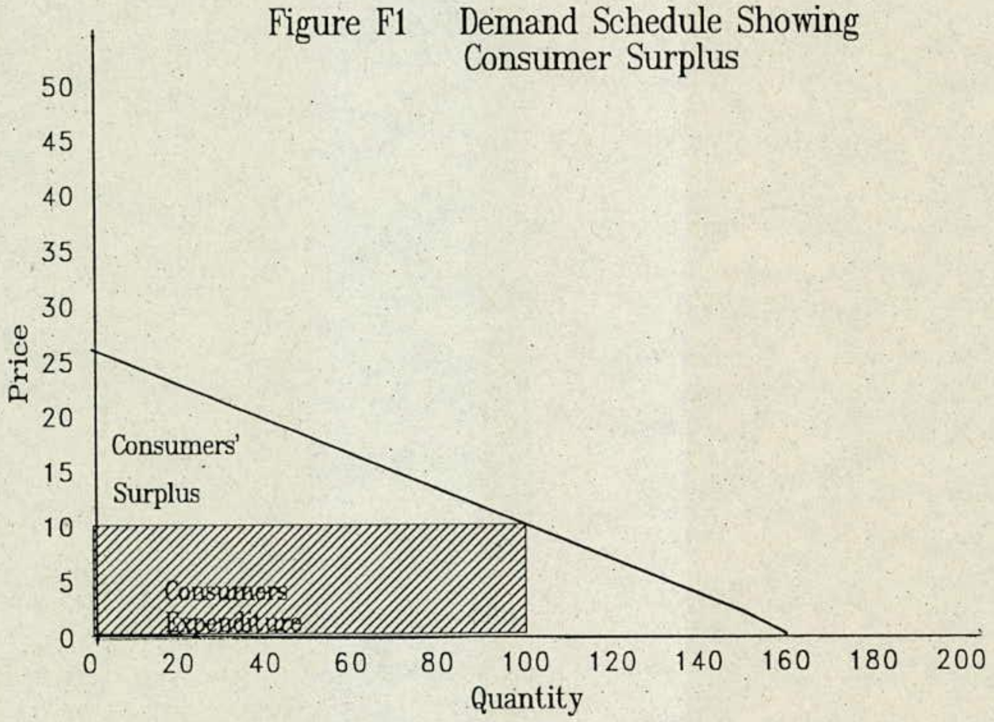
To maximise the economic benefit of the catchment to the State of Victoria it is necessary to specify the economic values, as opposed to the financial or administered values, of both timber and water. Because the prices of the two products are administered by government, rather than determined by the interaction of supply and demand in the market place, the true economic values cannot be observed and must be estimated by a process which involves the application of economic theory, empirical observation and judgement. Therefore, there can be no one correct answer. Any valuation must be judged by the soundness of the method used to obtain it, taking into account any constraints on the application of the method. In this study, water consumption in Melbourne is valued by employing the theoretical construct of a demand schedule for water.

F.1 DEMAND SCHEDULES AND VALUE

The notion of a demand schedule is understood by most people. There are, however, some attributes of the schedule which are overlooked in everyday usage and some useful measures of consumer welfare which can be obtained from the schedule.

A demand schedule (or curve) shows the amounts of a good that would be purchased at various prices during some specified period of time, **all other things held constant**. If price is measured on the vertical axis of a graph and the quantity purchased on the horizontal axis (as in Figure F.1), the curve is generally downward-sloping -- a greater quantity is purchased during the specified time period the lower the price. Because we are interested only in the relationship between price and the quantity

Figure F1 Demand Schedule Showing Consumer Surplus



purchased, the other things which must remain constant so as not to confuse the relationship include incomes, population, tastes, the prices of other goods, and, in the case of water, climate. Thus, for example, it is to be expected that the demand curve for television sets will be higher (shifted to the right) if population increases, incomes rise, if people become less interested in reading or if the price of movie tickets rises.

The demand curve observed for the entire market is, of course, built up from the demand curves expressed by individuals. One reason the demand curve slopes downwards is thought to result from the so-called "law of diminishing marginal utility". Simply stated this law says that as more units of the good in question are consumed, the value of each succeeding one decreases. Or, stated another way, a consumer's willingness to pay for the tenth cake purchased in the specified time period will be lower than for the ninth cake which will be lower than the eighth cake and so on. If the demand curves for the given good were known for all individuals these could be added horizontally to obtain the market demand curve. That curve will have negative slope due to all individuals displaying diminishing utility and because new consumers enter the market and existing consumers purchase more as price decreases.

The market demand curve can be used to express the value to the community of any quantity of the good or service. Total willingness to pay for a given quantity is nearly always greater than what people actually have to pay. The balancing item of value is called consumers' surplus. This can be demonstrated with the aid of Figure E1. At a price of $10 per unit, 100 units would be exchanged in the market during the relevant time period. Total willingness to pay for this quantity is the area under the demand curve from zero to 100 units. Total expenditure by consumers (price times quantity), that part of the total value which is transferred from consumers to producers, would be $1000. This is equivalent to the shaded area under the demand curve. Producers of the commodity, of course, have a clear interest in this amount since it represents their gross revenue. Nevertheless, from the standpoint of the whole economy, it is not the total valuation of the commodity.

The remaining (unshaded) triangular area under the demand curve is called the consumers' surplus because it represents the value in excess of what they had to pay. Those consumers who were prepared to pay any price higher than $10 per unit to obtain the quantity they wanted have benefited -- gained a surplus in value -- because they only had to pay $10 per unit. The idea of consumers' surplus can be likened to getting a bargain. Indeed, getting a bargain means paying less than we would be willing to pay and, by the nature of a demand curve, some consumers always get bargains. Those consumers can now spend the money so saved on other things. Consumers' surplus is not only a legitimate form of economic value but one of the most important forms which must be counted in the economic analysis of public policy.

It is sometimes considered that expenditure in the market is a reliable guide to total value of a good or service. The reason this view is mistaken can be demonstrated if we redefine the demand curve in Figure F.1 so that it is the demand curve for an individual rather than the aggregate demand curve. The total value (measured in money) of the good to the individual is the whole area under the demand curve. When this consumer buys 100 units at the market price ($10/unit), $1000 is spent and the buyer gains a consumer's surplus equal to the unshaded area. If the market price falls to $2/unit, her **total valuation does not change** but now the consumer buys 150 units, spends only $300 and gains a much larger consumer's surplus. Expenditures, therefore, do not reveal the real worth of an activity, service or commodity, namely, what people would be prepared to pay over and above their cash outlays.

Expenditure by consumers is the total valuation of the commodity if the demand schedule is horizontal. Such a situation can arise when a given group of consumers (say, in a small country) is so small relative to the entire (world) market that the buying decisions of the group have no effect on the world price. Such consumers (like the individual consumer in most markets) are price takers and must make their decisions according to the prevailing price. In this situation, consumers' surplus is zero.

The price elasticity of demand (hereafter called simply the elasticity of demand) is a measure of the way the quantity of water purchased by consumers responds to changes in the price of water. It is measured as the percentage change in quantity consumed divided by the percentage change in price. Thus, for example, an elasticity of demand of -0.4 means that a change of 10 per cent in price leads to a four per cent change in the quantity consumed. The negative sign, which is sometimes omitted in common usage, indicates the inverse relationship between price and quantity. Knowledge of the elasticity enables the prediction of either prices or quantities consumed, provided the demand schedule does not change. Clearly, changes in incomes, tastes and other prices, will lead to a change in the demand curve and possibly a change in the elasticity.

F.2 THE NATURE OF THE DEMAND FOR URBAN WATER

Metropolitan water is put to a number of different kinds of use depending on where and when the water is used. For example, water use can be characterised as domestic, industrial and commercial or institutional. Water used for domestic purposes can be further categorised depending on whether it is used indoors (for example, drinking, cooking and washing) or outdoors (for example, used in gardening, swimming pools and car washing). In places like Melbourne where the climate is markedly seasonal, water consumption may differ between summer and winter. At times, it may be appropriate to consider such uses as defining separate types of water or "products", each characterised by its own demand schedule and, therefore, price elasticity of demand (see, for example, Dixon and Baker 1992). For this study, however, metropolitan water is viewed as a single product whose demand function reflects a variety of components.

The market demand schedule for water in Melbourne is unknown and would be difficult to determine because of the way prices have been fixed in the past. While Melbourne's demand schedule is unknown, there is some information available which can be used to approximate the price elasticity of demand.

F.2.1 The elasticity of demand

Most studies of the price elasticity of demand for urban water have been conducted outside Australia (see Gibbons (1986) for a review of such studies). These studies, therefore, can provide only a guide to the situation in Melbourne since they embody a range of conditions (climates, incomes, and adjustment periods) which are not necessarily met in Melbourne. Generally, these studies have demonstrated that the elasticity for total water is greater than -1.0 but that the seasonal elasticities may alter from a low figure (say, around -0.2) in winter to an elasticity greater than -1.0 (say, around -1.3) in summer.

A review by Hanke, undertaken for the Perth MWSS in 1977, also highlighted the different elasticities between water used inside residences and that used outside. From the studies he reviewed, Hanke indicated a range of elasticities for inside water from -0.1 to -0.25 and from -0.5 to -1.0 for outdoor water. In selecting elasticities for an analysis of water pricing options for Perth, Hanke chose -0.2 for inside water and -0.7 for outdoor water. A subsequent review by the Perth Metropolitan Water Authority in 1985 estimated a price elasticity of -0.04 for inside use and -0.31 for outside use.

Using an experimental approach with 14 households in Nowra, NSW, Gallagher and Robinson (1977) obtained elasticities for inside water ranging from -0.24 to -0.894. A review by Melbourne Water ("Pricing to Conserve Water") indicates estimated elasticities for total domestic use range from -0.11 to -0.18 in Perth, -0.15 to -0.20 in the Hunter River district and from -0.11 in Finland to -0.40 in Victoria (BC), Canada.

Hanke's review of elasticities for non-residential users (estimates ranged from -0.25 to -0.63) led him to believe that such users were probably slightly more responsive to price than residential users for indoor water. His best estimate for Perth in the mid-1970s was -0.35. Melbourne Water ("Pricing to Conserve Water"), on the other hand, implies that the elasticity of demand in non-domestic use is very low, citing a study in the Netherlands which estimated an elasticity of zero.

The definition of the price variable in demand studies can also influence the estimated elasticity. For example, the use of an average price may lead to incorrect estimates when consumers face block-pricing regimes. In these circumstances, estimating equations require variables accounting for the both the marginal price facing the average consumer and the income effect resulting from the intramarginal part of the rate schedule.

Overall, it appears that the demand for water is relatively inelastic with respect to price and that the lowest elasticity is for water used inside residences. Given that about 32 per cent of all water consumed in Melbourne falls into this category, the above reviews of studies leads us to conclude that the overall price elasticity of demand for water is likely to be less than -0.50. In the absence of specific studies for Melbourne, we must rely on the judgement and experience of those with an intimate knowledge of the city's water system in order to improve this estimate. H Rose and H Duncan of Melbourne Water (pers. comm.) suggested that -0.5 would be too high and both drew attention to a recent study of the intended behaviour of domestic consumers under various pricing regimes. That study has revealed intentions which are consistent with a very inelastic response to price. It was also noted that many of the elasticity estimates were made prior to any interventions, such as advertising campaigns directed at saving water, whereas Melbourne has had several such campaigns. The frequency of billing (once per year) is also an important consideration in the way users respond to price signals.

F.2.2 Shifts in the demand schedule

Over time, the demand schedule will shift as there is change in such items as population, the number of houses, incomes and the number and type of water-using appliances. If price were held constant in real terms, knowledge of all such parameters and their future values would enable forecasts of consumption for future time periods.

Duncan (1991) has estimated the growth in Melbourne's consumption to the year 2021 under various assumptions about the rate of growth in such parameters and various "demand management" scenarios. Some of these scenarios embody some use of water pricing as a rationing device and, therefore, do not provide an estimate of future consumption under constant prices.

F.3 EFFECTS OF CHANGING COSTS ON WATER VALUES

Ideally water would be valued in a competitive market where consumers would form their bids based on their willingness to pay for the satisfaction or utility gained from using the water and suppliers would decide whether or not to sell on the basis of what it costs to supply. The net contribution to the State economy represents the economic value to the State and this would be expressed by the degree to which willingness to pay exceeded the costs of supplying the water. That is, the economic value of water equals the willingness to pay less the costs of supplying the water.

However, there is no single value of water in streams or elsewhere; rather the values change through time and between different management scenarios. For example, the value of water can vary depending on whether the particular augmentation necessitates additional costs associated with the distribution of that water or depending on the relative costs of the next best augmentation.
To demonstrate this point more clearly, lets follow through a simplified and hypothetical development of the Melbourne water system, but stick with 1992 dollar values and pretend that the Thomson dam and tunnel represented only the second increment; that is, that the system prior to the Thomson was built all at once a long time ago.

Long ago

Melbourne relied on rain water tanks and carting of water supplies, but it now required a reticulated supply and secure storages. A distribution system was constructed throughout Melbourne and it connected to the cheapest available headworks at say a total capital cost of about $3000 M to provide an annual water yield of 200 GL per year; that is, a capital cost of about $15000 per ML ($3000 M divided by 200,000 ML). Assuming a discount rate of 4 per cent, this is equivalent to an annual cost of about $600 per ML. Operations and maintenance costs were $150 per ML so the total cost of supplying water was equivalent to $750 per ML.

So water in the streams would have been valued at the willingness to pay (WTP) less the costs of supplying the water; that is:

WTP less 750

1980

Melbourne required additional water and there were two technically and politically acceptable options; namely, the Thomson or Lower Yarra dams.

The Thomson project had a capital cost of about $900 M to provide an annual water yield of 220 GL per year; that is, a capital cost of about $4100 per ML ($900 M divided by 220,000 ML). Assuming a discount rate of 4 per cent, this is equivalent to an annual cost of about $160 per ML.

The Lower Yarra project had a capital cost of about $260 M to provide an annual water yield of 52 GL per year; that is, a capital cost of about $5000 per ML ($260 M divided by 52,000 ML). Assuming a discount rate of 4 per cent, this is equivalent to an annual cost of about $200 per ML.

The city chose the Thomson because it represented the cheaper cost per ML and because it represented a larger increment to supplies.

The distribution system was there already with adequate capacity to handle the additional water, so the only costs attributable to the water in the streams of the Thomson at the time of building the dam and tunnel were the the capital costs (equivalent to about $160 per ML of yield), and pumping and disinfection costs of $30 per ML; that is, a total cost equivalent to $190 per ML. So water in the streams of the Thomson would have been valued at the willingness to pay (WTP) less the costs of supplying the water; that is:

WTP less $190

199?

Melbourne needs more water again, and political events have changed and the city now has two new options to consider in addition to Lower Yarra; namely Big River (which can use Thomson tunnel) or less timber harvesting in the catchment.

The cost of getting extra water by less timber harvesting is represented by the value of timber foregone and consulting economists are employed to assess that value. They conclude that the value of the additional water exceeds the value of the timber harvesting foregone and the State adopts such a policy of reducing the level of timber harvesting in the Thomson in order to gain additional streamflow yield.

However, not many years later Melbourne requires more water again. The Big River project has a capital cost of about $110 M to provide an annual water yield of 80 GL per year; that is, a capital cost of about $1375 per ML ($110 M divided by 80,000 ML). Assuming a discount rate of 4 per cent, this is equivalent to an annual cost of about $55 per ML.

The distribution system was there already with adequate capacity to handle the additional water, so the only costs attributable to the water in the streams of the Big River at the time of building the project were the pumping and disinfection costs of $30 per ML and the capital costs and any amount paid to purchase water entitlements from irrigators north of the divide; that is, a total cost equivalent to $85 per ML plus any amount paid to purchase water entitlements from irrigators.

Implications

For the purposes of this discussion the monetary equivalent of WTP can be ignored. The important point is that at various stages during the development of Melbourne's water system, the economic value of water varied through time.

Date	**Value of water in various streams 1992 values**
Long ago	WTP less 750
1980	WTP less $190
199?	WTP less $85 less irrigation value

At the time of building the original system the (net) value of water in the catchment streams was low owing to the high costs required to build and maintain the distribution system. However, since those original builders had the foresight to build plenty of surplus capacity in the distribution system, the costs of supplementing supplies with water from other catchments was low and consequently in economic terms the water in the streams of those other catchments had a correspondingly higher value at the point in time of commanding those supplies.

At the time of building the Thomson Dam it seemed that the next augmentation would be the Lower Yarra Dam and at a capital investment of $5000 per ML, but political events changed and it became a feasible option to access water from north of the divide in the Big River for a capital investment of $1375 per ML. Similarly it became politically feasible to consider reducing timber harvesting in order to increase water supplies.

This discussion has concentrated on showing how the changing costs of supply lead to changes in the economic value of water in streams, but equally there are other factors which cause the value of water to change through time. See for example, the discussion of shifts to the demand schedule in F.2.3. The value of water varies depending on its end-use. Similarly the value of water varies depending on whether the particular augmentation necessitates additional costs associated with the distribution of that water.

F.3.1 Choice of Price and Quantity

In this Section we discuss the initial price and quantity settings which are specified for the demand schedule in the base case for the dynamic programming model. Those same prices are adopted for the discounted cash flow analysis of the eight discrete options which have been nominated by the Steering Committee. However, for simplicity, those prices are held constant throughout the planning horizon for the analysis of the eight options.

The starting quantity of water is taken as the current quantity of ex-dam consumption. As indicated above, the true willingness to pay for this quantity is unknown and must be approximated. There are a number of figures which could be used for this purpose but we need to employ a figure which is consistent with the use of a demand schedule, that is, it should be indicative of the aggregate willingness to pay for the last KL of water consumed in the base year.

If we assume that the price paid for the last KL is independent of the charge based on property NAV, which seems reasonable at any point in time, then the willingness to pay is related to the prices of the (now) two-block pricing structure for metered consumption, namely 30c per KL up to 350 Kl and 60c per Kl above 350 KL.

It is estimated (H Rose pers.com.) that about 80 per cent of domestic consumers will pay 30c per KL at the margin under the new tariff structure while the remaining 20 per cent will pay 60c per KL. Industrial and commercial users, accounting for about 22 per cent of all water, pay 60c at the margin. This suggests that the current weighted average of willingness to pay for the last KL lies between 30c and 60c per KL or higher. We say "or higher" in recognition of the consumer surplus referred to above. For the analyses in this study, a current marginal willingness to pay at 30c and 60c per KL is adopted for values at the tap.

By way of contrast, the average price actually paid for water is the total revenue from water received by Melbourne Water (rate charges plus volume charges) divided by consumption. With consumption at metered connections at about 370 GL and revenue in 1989-90 at $326 M, the average price for metered connections is more than 80 cents per KL.

The choice of 30c and 60c per KL is supported by the work of Dixon and Baker (1992) who estimated that an optimal single price for all types of domestic water over the next 30 years would lie in the range from 40c to 60c per KL (measured in 1987 dollars) -- about 52c to 77c in 1992 dollars. Dixon's and Baker's innovative study employed a powerful general equilibrium model which predicted water prices for a 100-year period commencing in 1987. Because their's is the only detailed study of pricing levels which is based firmly on economic principles, the findings of Dixon and Baker cannot be ignored. In terms of selecting a range of prices in current dollars for demand simulation, their finding suggests that a "high" value of, say, 80c per KL might also be used.

Further support for the proposition that the current marginal willingness to pay lies within this range is provided by the agreement for the purchase of water by the Peninsula and District Water Board prior to its incorporation into Melbourne Water. The agreed annual price to purchase up to 60,000 ML per year was $4.9 million plus $200 per ML. The charge per ML was to be inflated by the Consumer Price Index. Assuming the Board had purchased its full entitlement in 1992 the price would have been about 34c per KL for water at the Cardinia off-take. Similarly, the Rural Water Commission supplies water to a number of urban water authorities throughout rural Victoria and it sells that bulk water to the authorities for 37.5 cents per KL.

The prices suggested so far, 30c, 60c and 80c per KL are marginal prices of metered consumption in Melbourne. Every 1.00 KL of consumption requires about 1.14 KL of dam releases because of losses from the system due to leakage. Therefore it is argued that every 1.0 KL of **useable** water requires about 1.14 KL of streamflow. Therefore, marginal prices of 30c, 60c and 80c at the tap correspond to prices "in the stream" of 26c, 53c and 70c.

Now to determine the prices appropriate for valuing water in the streams, these values must also be adjusted by the costs of providing water from the dam to taps in Melbourne. These matters are dealt with in the Main Report (Section 4.3)

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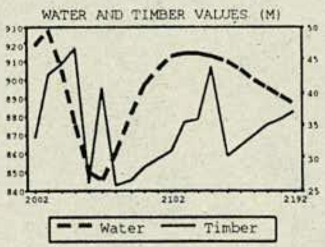
APPENDIX G

DETAILED RESULTS OF DISCOUNTED CASH FLOW ANALYSIS FOR BASE CASE ASSUMPTIONS

APPENDIX TABLE G.1 STATUS QUO (55 to 80 YEAR) ROTATION DISCOUNTED CASH FLOW ANALYSIS FOR "BASE CASE" ASSUMPTIONS

PRICE ASSUMPTIONS		COST ASSUMPTIONS	
Discount rate	0.04		
P pulp	$10	Forest management $/Ha	$6.10
P ash sawlog A&B	$60	Regeneration costs $/Ha	$607.00
P ash sawlog C	$46	Urban supply costs $/ML	$25.25
P mixed sawlog A&B	$36	Winneke $/ML	$60.00
P mixed sawlog C	$35		
P urban	$530		
P hydro	$25		



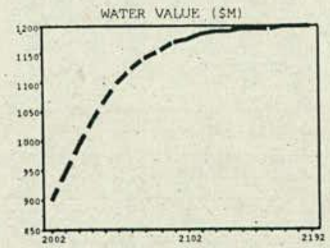
DECADE TOTALS

DECADE ENDED	TIMBER VOLUMES HARVESTED ('000 cubic metre) Ash log A & B	Ash log C	Mixed log A & B	Mixed log C	Total pulp	STANDING VALUE OF HARVESTED TIMBER ($M)	FOREST MANAGEMENT COSTS INCLUDING REGEN-ERATION ($M)	EXTRA PULP LOG TRANSPORT ($M)	URBAN WATER YIELD (GL)	HYDRO WATER YIELD (GL)	VALUE WATER YIELD ($M)	O&M COSTS WATER SUPPLY ($M)	CAPITAL COSTS WATER SUPPLY ($M)
2002	171	226	9	67	975	33	-5.2	n.a.	1700	722	919	-43	
2012	250	331	9	66	958	43	-5.2	n.a.	1716	722	927	-73	-110
2022	253	336	14	105	938	44	-5.2	n.a.	1676	722	906	-102	-160
2032	251	332	25	181	891	46	-5.3	n.a.	1618	722	876	-101	-400
2042	177	235	2	12	432	26	-3.8	n.a.	1570	722	850	-100	-600
2052	276	365	2	12	662	41	-4.2	n.a.	1563	722	846	-99	
2062	174	231	2	13	427	26	-3.9	n.a.	1588	722	860	-100	
2072	179	238	1	6	446	26	-3.9	n.a.	1631	722	882	-101	-500
2082	193	256	1	6	478	28	-3.9	n.a.	1659	722	897	-102	
2092	202	268	1	6	500	30	-3.9	n.a.	1676	722	907	-102	
2102	209	277	1	7	522	31	-3.9	n.a.	1688	722	913	-103	
2112	213	283	9	65	698	35	-4.4	n.a.	1693	722	915	-103	
2122	215	285	9	66	700	36	-4.4	n.a.	1693	722	915	-103	
2132	271	360	9	67	832	44	-4.7	n.a.	1690	722	914	-103	
2142	180	239	6	41	655	30	-4.5	n.a.	1683	722	910	-102	
2152	192	255	6	42	696	32	-4.5	n.a.	1675	722	906	-102	
2162	202	268	6	42	727	33	-4.5	n.a.	1666	722	901	-102	
2172	209	289	6	42	743	35	-4.5	n.a.	1656	722	896	-102	
2182	220	291	6	42	756	36	-4.5	n.a.	1648	722	891	-102	
2192	223	296	11	82	669	37	-4.5	n.a.	1641	722	888	-101	
Salvage						141							
NPV						95	-13	0			2288	-193	-291

Net present value	1887

LOGGING DETAILS OF DISCOUNTED CASH FLOW ANALYSIS FOR "BASE CASE" ASSUMPTIONS

ASSUMPTIONS		COST ASSUMPTIONS	
Discount rate	0.04		
P pulp	$10	Forest management $/Ha	$6.10
P ash sawlog A&B	$60	Regeneration costs $/Ha	N.A.
P ash sawlog C	$46	Urban supply costs $/ML	$25.25
P mixed sawlog A&B	$36	Addit pulplog cart $/M3	$14.00
P mixed sawlog C	$35	Winneke $/ML	$60.00
P urban	$530		
P hydro	$25		



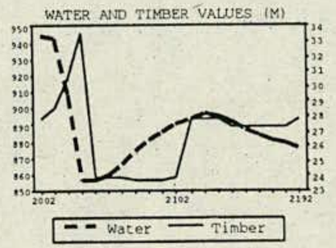
DECADE TOTALS

DECADE ENDED	TIMBER VOLUMES HARVESTED ('000 cubic metre)					STANDING VALUE OF HARVESTED TIMBER ($M)	FOREST MANAGEMENT COSTS INCLUDING REGEN-ERATION ($M)	EXTRA PULP LOG TRANSPORT ($M)	URBAN WATER YIELD (GL)	HYDRO WATER YIELD (GL)	VALUE WATER YIELD ($M)	O&M COSTS WATER SUPPLY ($M)	CAPITAL COSTS WATER SUPPLY ($M)
	Ash log A & B	Ash log C	Mixed log A & B	Mixed log C	Total pulp								
2002	0	0	0	0	0	0	-2.9	0.0	1659	722	900	-42	
2012	0	0	0	0	0	0	-2.9	0.0	1748	722	944	-74	-110
2022	0	0	0	0	0	0	-2.9	0.0	1836	722	991	-106	
2032	0	0	0	0	0	0	-2.9	0.0	1917	722	1034	-108	-300
2042	0	0	0	0	0	0	-2.9	0.0	1986	722	1071	-110	-260
2052	0	0	0	0	0	0	-2.9	0.0	2043	722	1101	-112	-600
2062	0	0	0	0	0	0	-2.9	0.0	2088	722	1125	-102	
2072	0	0	0	0	0	0	-2.9	0.0	2123	722	1143	-109	
2082	0	0	0	0	0	0	-2.9	-13.7	2150	722	1158	-114	
2092	0	0	0	0	0	0	-2.9	-13.4	2170	722	1168	-115	-500
2102	0	0	0	0	0	0	-2.9	-13.1	2185	722	1176	-115	
2112	0	0	0	0	0	0	-2.9	-12.5	2197	722	1182	-115	
2122	0	0	0	0	0	0	-2.9	-6.0	2205	722	1187	-116	
2132	0	0	0	0	0	0	-2.9	-9.3	2211	722	1190	-116	
2142	0	0	0	0	0	0	-2.9	-6.0	2215	722	1192	-116	
2152	0	0	0	0	0	0	-2.9	-6.2	2218	722	1194	-116	
2162	0	0	0	0	0	0	-2.9	-6.7	2220	722	1195	-116	
2172	0	0	0	0	0	0	-2.9	-7.0	2222	722	1196	-116	
2182	0	0	0	0	0	0	-2.9	-7.3	2223	722	1196	-116	
2192	0	0	0	0	0	0	-2.9	-9.8	2224	722	1197	-116	
Salvage						294							
NPV						0	-7	-1			2484	-201	-241

Net present value	2034

APPENDIX TABLE G.3 40 YEAR ROTATION DISCOUNTED CASH FLOW ANALYSIS FOR "BASE CASE" ASSUMPTIONS

PRICE ASSUMPTIONS		COST ASSUMPTIONS	
Discount rate	0.04		
P pulp	$10	Forest management $/Ha	$6.10
P ash sawlog A&B	$60	Regeneration costs $/Ha	$607.00
P ash sawlog C	$46	Urban supply costs $/ML	$25.25
P mixed sawlog A&B	$36	Winneke $/ML	$60.00
P mixed sawlog C	$35		
P urban	$530		
P hydro	$25		



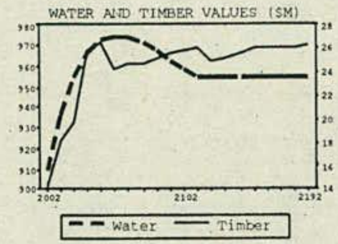
DECADE TOTALS

DECADE ENDED	TIMBER VOLUMES HARVESTED ('000 cubic metre)					STANDING VALUE OF HARVESTED TIMBER ($M)	FOREST MANAGEMENT COSTS INCLUDING REGEN-ERATION ($M)	EXTRA PULP LOG TRANSPORT ($M)	URBAN WATER YIELD (GL)	HYDRO WATER YIELD (GL)	VALUE WATER YIELD ($M)	O&M COSTS WATER SUPPLY ($M)	CAPITAL COSTS WATER SUPPLY ($M)
	Ash log A & B	Ash log C	Mixed log A & B	Mixed log C	Total pulp								
2002	0	345	9	67	917	28	-5.7	n.a.	1742	722	944	-44	
2012	0	357	9	66	934	29	-5.7	n.a.	1743	722	942	-74	-110
2022	0	369	14	105	920	30	-5.9	n.a.	1679	722	908	-102	
2032	0	379	25	181	877	33	-6.0	n.a.	1582	722	857	-100	-560
2042	0	379	2	12	589	24	-4.9	n.a.	1581	722	856	-100	
2052	0	379	2	12	590	24	-4.9	n.a.	1589	722	860	-100	-600
2062	0	379	2	13	590	24	-4.9	n.a.	1602	722	867	-100	
2072	0	379	1	6	598	24	-4.9	n.a.	1615	722	874	-101	-500
2082	0	379	1	6	598	24	-4.9	n.a.	1628	722	881	-101	
2092	0	379	1	6	599	24	-4.9	n.a.	1639	722	887	-101	
2102	0	379	1	7	605	24	-4.9	n.a.	1647	722	891	-102	
2112	0	379	9	65	771	28	-5.4	n.a.	1654	722	895	-102	
2122	0	379	9	66	768	28	-5.4	n.a.	1658	722	897	-102	
2132	0	379	9	67	770	28	-5.4	n.a.	1655	722	895	-102	
2142	0	379	6	41	804	27	-5.4	n.a.	1649	722	892	-102	
2152	0	379	6	42	806	27	-5.4	n.a.	1642	722	888	-101	
2162	0	379	6	42	805	27	-5.4	n.a.	1635	722	885	-101	
2172	0	379	6	42	809	27	-5.4	n.a.	1629	722	881	-101	
2182	0	379	6	42	806	27	-5.4	n.a.	1624	722	879	-101	
2192	0	379	11	82	710	28	-5.4	n.a.	1620	722	877	-101	
Salvage						67							
NPV						71	-14	0			2313	-194	-285

Net present value	1891

APPENDIX TABLE G.4 120 YEAR ROTATION DISCOUNTED CASH FLOW ANALYSIS FOR "BASE CASE" ASSUMPTIONS

PRICE ASSUMPTIONS		COST ASSUMPTIONS	
Discount rate	0.04		
P pulp	$10	Forest management $/Ha	$6.10
P ash sawlog A&B	$60	Regeneration costs $/Ha	$607.00
P ash sawlog C	$46	Urban supply costs $/ML	$25.25
P mixed sawlog A&B	$36	Addit pulplog cart $/M3	$14.00
P mixed sawlog C	$35	Winneke costs $/ML	$60.00
P urban	$530		
P hydro	$25		



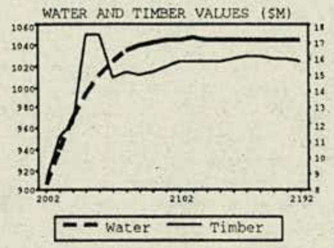
DECADE TOTALS

DECADE ENDED	TIMBER VOLUMES HARVESTED ('000 cubic metre)					STANDING VALUE OF HARVESTED TIMBER ($M)	FOREST MANAGEMENT COSTS INCLUDING REGEN-ERATION ($M)	EXTRA PULP LOG TRANSPORT ($M)	URBAN WATER YIELD (GL)	HYDRO WATER YIELD (GL)	VALUE WATER YIELD ($M)	O&M COSTS WATER SUPPLY ($M)	CAPITAL COSTS WATER SUPPLY ($M)
	Ash log A & B	Ash log C	Mixed log A & B	Mixed log C	Total pulp								
2002	75	99	2	34	384	14	-3.9	0.0	1677	722	909	-42	
2012	106	141	5	39	373	18	-3.9	0.0	1734	722	937	-74	-110
2022	116	154	5	40	396	20	-3.9	0.0	1768	722	955	-105	-160
2032	155	205	6	43	525	26	-3.9	0.0	1789	722	966	-105	-140
2042	159	211	6	44	532	26	-4.0	0.0	1800	722	972	-105	-260
2052	145	193	6	45	475	24	-4.0	0.0	1805	722	975	-106	-600
2062	150	198	6	45	483	25	-4.0	0.0	1804	722	974	-102	
2072	152	201	4	28	508	25	-4.0	0.0	1798	722	971	-105	-500
2082	154	204	4	28	517	25	-4.0	-6.4	1791	722	967	-105	
2092	158	209	4	29	525	26	-4.0	-6.1	1782	722	963	-105	
2102	160	212	4	28	530	26	-4.0	-5.7	1775	722	959	-105	
2112	161	214	4	28	534	26	-4.0	-5.0	1768	722	955	-105	
2122	153	203	4	27	512	25	-4.0	0.0	1768	722	955	-105	
2132	156	206	4	27	517	25	-4.0	-2.0	1768	722	955	-105	
2142	159	210	4	28	528	26	-4.0	0.0	1768	722	955	-105	
2152	161	213	4	29	536	26	-4.0	0.0	1767	722	955	-105	
2162	162	214	4	28	534	26	-4.0	0.0	1767	722	955	-105	
2172	162	214	4	28	535	26	-4.0	0.0	1767	722	955	-105	
2182	161	214	4	28	534	26	-4.0	0.0	1767	722	955	-105	
2192	163	216	4	28	538	26	-4.0	-2.2	1767	722	955	-105	
Salvage						184							
NPV						49	-10	-1			2382	-197	-291

Net present value	1932

APPENDIX TABLE G.5 200 YEAR ROTATION DISCOUNTED CASH FLOW ANALYSIS FOR "BASE CASE" ASSUMPTIONS

PRICE ASSUMPTIONS		COST ASSUMPTIONS	
Discount rate	0.04		
P pulp	$10	Forest management $/Ha	$6.10
P ash sawlog A&B	$60	Regeneration costs $/Ha	$607.00
P ash sawlog C	$46	Urban supply costs $/ML	$25.25
P mixed sawlog A&B	$36	Addit pulplog cart $/M3	$14.00
P mixed sawlog C	$35	Winneke $/Ml	$60.00
P urban	$530		
P hydro	$25		



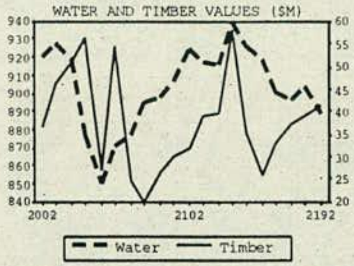
DECADE TOTALS

DECADE ENDED	TIMBER VOLUMES HARVESTED ('000 cubic metre)					STANDING VALUE OF HARVESTED TIMBER ($M)	FOREST MANAGEMENT COSTS INCLUDING REGEN-ERATION ($M)	EXTRA PULP LOG TRANSPORT ($M)	URBAN WATER YIELD (GL)	HYDRO WATER YIELD (GL)	VALUE WATER YIELD ($M)	O&M COSTS WATER SUPPLY ($M)	CAPITAL COSTS WATER SUPPLY ($M)
	Ash log A & B	Ash log C	Mixed log A & B	Mixed log C	Total pulp								
2002	45	60	1	24	237	9	-3.5	0.0	1670	722	905	-42	
2012	64	84	5	28	231	11	-3.5	0.0	1739	722	940	-74	-110
2022	70	92	4	29	245	12	-3.5	0.0	1795	722	969	-105	
2032	104	137	4	31	361	17	-3.5	0.0	1840	722	993	-106	-160
2042	104	138	4	31	359	17	-3.6	0.0	1875	722	1012	-107	-400
2052	87	116	4	32	294	15	-3.6	0.0	1900	722	1025	-108	-600
2062	90	119	4	32	299	15	-3.6	0.0	1919	722	1035	-99	
2072	91	121	3	19	317	15	-3.6	0.0	1930	722	1041	-109	
2082	93	123	3	19	323	15	-3.6	-9.1	1936	722	1044	-109	-500
2092	95	125	3	19	328	16	-3.6	-8.8	1939	722	1046	-109	
2102	96	127	3	19	331	16	-3.6	-8.5	1940	722	1046	-109	
2112	97	128	3	19	334	16	-3.6	-7.8	1941	722	1047	-109	
2122	97	129	3	19	333	16	-3.6	-1.4	1941	722	1047	-109	
2132	97	128	3	19	334	16	-3.6	-4.6	1940	722	1046	-109	
2142	98	129	3	19	334	16	-3.6	-1.3	1940	722	1046	-109	
2152	98	130	3	19	336	16	-3.6	-1.5	1939	722	1046	-109	
2162	98	130	3	19	338	16	-3.6	-2.0	1939	722	1046	-109	
2172	98	130	3	19	337	16	-3.6	-2.3	1938	722	1045	-109	
2182	97	129	3	19	335	16	-3.6	-2.6	1938	722	1045	-109	
2192	96	128	3	19	333	16	-3.6	-5.1	1938	722	1045	-109	
Salvage						141							
NPV						31	-9	-1			2423	-198	-256

Net present value	1989

APPENDIX TABLE G.6 COMBINATION THINNING FOR 80 YEAR ROTATION DISCOUNTED CASH FLOW ANALYSIS FOR "BASE CASE" ASSUMPTIONS

PRICE ASSUMPTIONS		COST ASSUMPTIONS	
Discount rate	0.04		
P pulp	$10	Forest management $/Ha	$6.10
P ash sawlog A&B	$60	Regeneration costs $/Ha	$607.00
P ash sawlog C	$46	Urban supply costs $/ML	$25.25
P mixed sawlog A&B	$36	Addit pulplog cart $/M3	$14.00
P mixed sawlog C	$35	Winneke $/ML	$60.00
P urban	$530		
P hydro	$25		



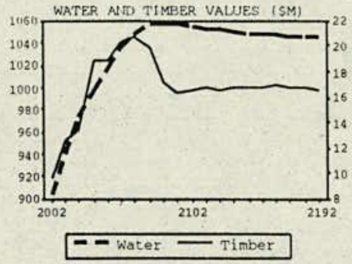
DECADE TOTALS

DECADE ENDED	TIMBER VOLUMES HARVESTED ('000 cubic metre) Ash log A & B	Ash log C	Mixed log A & B	Mixed log C	Total pulp	STANDING VALUE OF HARVESTED TIMBER ($M)	FOREST MANAGEMENT COSTS INCLUDING REGEN-ERATION ($M)	EXTRA PULP LOG TRANSPORT ($M)	URBAN WATER YIELD (GL)	HYDRO WATER YIELD (GL)	VALUE WATER YIELD ($M)	O&M COSTS WATER SUPPLY ($M)	CAPITAL COSTS WATER SUPPLY ($M)
2002	171	226	9	67	975	37	-5.2	0.0	1700	722	921	-43	
2012	250	331	9	66	958	46	-5.2	0.0	1716	722	927	-73	-110
2022	253	336	14	105	1002	51	-5.2	0.0	1700	722	919	-103	-160
2032	251	332	25	181	891	56	-5.3	0.0	1621	722	877	-101	-400
2042	177	235	2	12	432	27	-3.8	0.0	1570	722	850	-100	-600
2052	369	489	2	12	880	55	-4.2	0.0	1611	722	872	-91	
2062	159	211	2	13	391	24	-3.9	0.0	1620	722	877	-101	
2072	132	176	1	6	338	20	-3.9	0.0	1655	722	895	-102	
2082	175	232	1	6	437	26	-3.1	-7.5	1659	722	897	-102	-500
2092	202	268	1	6	501	30	-3.6	-6.4	1676	722	907	-102	
2102	209	277	1	7	572	32	-3.9	-5.1	1712	722	925	-103	
2112	213	283	9	65	713	39	-4.4	-2.5	1696	722	917	-103	
2122	215	285	9	66	700	39	-4.4	0.0	1693	722	915	-103	
2132	344	456	9	67	1000	58	-4.7	0.0	1738	722	939	-104	
2142	202	268	6	41	704	35	-4.5	0.0	1714	722	927	-103	
2152	132	176	6	42	557	26	-4.5	0.0	1700	722	919	-103	
2162	181	240	6	42	679	33	-3.6	0.0	1666	722	901	-102	
2172	209	289	6	42	743	37	-4.2	0.0	1656	722	896	-102	
2182	220	291	6	42	805	39	-4.5	0.0	1671	722	904	-102	
2192	223	296	11	82	684	42	-4.5	-0.2	1644	722	889	-102	
Salvage						52							
NPV						107	-12	-1			2300	-192	-295

Net present value	1907

APPENDIX TABLE G.7 COMBINATION THINNING FOR 200 YEAR ROTATION DISCOUNTED CASH FLOW ANALYSIS FOR "BASE CASE" ASSUMPTIONS

PRICE ASSUMPTIONS		COST ASSUMPTIONS	
Discount rate	0.04		
P pulp	$10	Forest management $/Ha	$6.10
P ash sawlog A&B	$60	Regeneration costs $/Ha	$607.00
P ash sawlog C	$46	Urban supply costs $/ML	$25.25
P mixed sawlog A&B	$36	Add pulplog cart $/M3	$14.00
P mixed sawlog C	$35	Winneke $/ML	$60.00
P urban	$530		
P hydro	$25		



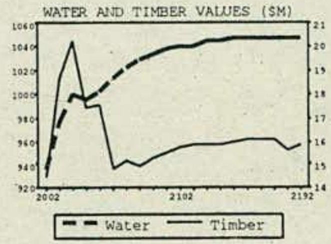
DECADE TOTALS

DECADE ENDED	TIMBER VOLUMES HARVESTED ('000 cubic metre) Ash log A & B	Ash log C	Mixed log A & B	Mixed log C	Total pulp	STANDING VALUE OF HARVESTED TIMBER ($M)	FOREST MANAGEMENT COSTS INCLUDING REGEN-ERATION ($M)	EXTRA PULP LOG TRANSPORT ($M)	URBAN WATER YIELD (GL)	HYDRO WATER YIELD (GL)	VALUE WATER YIELD ($M)	O&M COSTS WATER SUPPLY ($M)	CAPITAL COSTS WATER SUPPLY ($M)
2002	45	56	1	24	230	10	-3.5	0.0	1670	722	905	-42	
2012	63	80	4	28	243	13	-3.5	0.0	1739	722	940	-74	-110
2022	69	88	4	29	257	13	-3.5	0.0	1802	722	973	-106	
2032	103	132	4	31	373	19	-3.5	0.0	1848	722	998	-107	-300
2042	104	133	4	31	355	19	-3.6	0.0	1883	722	1016	-108	-260
2052	115	148	4	32	352	20	-3.6	0.0	1918	722	1034	-108	-600
2062	118	152	4	32	357	21	-3.6	0.0	1944	722	1048	-108	
2072	120	157	3	19	372	20	-3.6	0.0	1962	722	1058	-110	
2082	99	130	3	19	327	17	-3.6	-9.1	1962	722	1058	-110	-500
2092	94	123	3	19	315	16	-3.6	-9.0	1959	722	1056	-109	
2102	96	125	3	19	318	17	-3.6	-8.7	1956	722	1055	-109	
2112	96	126	3	19	321	17	-3.6	-8.0	1953	722	1053	-109	
2122	97	126	3	19	320	17	-3.6	-1.6	1949	722	1051	-109	
2132	96	126	3	19	321	17	-3.6	-4.8	1947	722	1050	-109	
2142	97	127	3	19	321	17	-3.6	-1.5	1944	722	1049	-109	
2152	98	128	3	19	323	17	-3.6	-1.7	1943	722	1048	-109	
2162	98	128	3	19	325	17	-3.6	-2.1	1941	722	1047	-109	
2172	98	127	3	19	323	17	-3.6	-2.5	1940	722	1046	-109	
2182	97	127	3	19	322	17	-3.6	-2.8	1939	722	1046	-109	
2192	96	125	3	19	320	17	-3.6	-5.3	1939	722	1046	-109	
Salvage						52							
NPV						35	-9	-1			2430	-199	-256

Net present value	2000

APPENDIX TABLE G.8 CORRIDOR THINNING DISCOUNTED CASH FLOW ANALYSIS FOR "BASE CASE" ASSUMPTIONS

PRICE ASSUMPTIONS		COST ASSUMPTIONS	
Discount rate	0.04		
P pulp	$10	Forest management $/Ha	$6.10
P ash sawlog A&B	$60	Regeneration costs $/Ha	$607.00
P ash sawlog C	$46	Urban supply costs $/ML	$25.25
P mixed sawlog A&B	$36	Addit pulplog cart $/M3	$14.00
P mixed sawlog C	$35	Winneke $/ML	$60.00
P urban	$530		
P hydro	$25		



DECADE TOTALS

DECADE ENDED	TIMBER VOLUMES HARVESTED ('000 cubic metre)					STANDING VALUE OF HARVESTED TIMBER ($M)	FOREST MANAGEMENT COSTS INCLUDING REGEN-ERATION ($M)	EXTRA PULP LOG TRANSPORT ($M)	URBAN WATER YIELD (GL)	HYDRO WATER YIELD (GL)	VALUE WATER YIELD ($M)	O&M COSTS WATER SUPPLY ($M)	CAPITAL COSTS WATER SUPPLY ($M)
	Ash log A & B	Ash log C	Mixed A & B	Mixed C	Total pulp								
2002	82	108	1	24	366	14	-3.2	0.0	1729	722	937	-44	
2012	116	153	4	28	352	19	-3.2	0.0	1809	722	977	-76	
2022	127	168	4	29	378	20	-3.2	0.0	1852	722	1000	-107	-110
2032	104	137	4	31	361	17	-3.5	0.0	1843	722	995	-107	-300
2042	104	138	4	31	359	17	-3.6	0.0	1858	722	1003	-107	-260
2052	87	116	4	32	294	15	-3.6	0.0	1876	722	1012	-107	-600
2062	90	119	4	32	299	15	-3.6	0.0	1894	722	1022	-96	
2072	91	121	3	19	317	15	-3.6	0.0	1907	722	1029	-108	
2082	93	123	3	19	323	15	-3.6	-9.1	1916	722	1034	-108	-500
2092	95	125	3	19	328	16	-3.6	-8.8	1923	722	1037	-109	
2102	96	127	3	19	331	16	-3.6	-8.5	1928	722	1040	-109	
2112	97	128	3	19	334	16	-3.6	-7.8	1931	722	1042	-109	
2122	97	129	3	19	333	16	-3.6	-1.4	1936	722	1044	-109	
2132	97	128	3	19	334	16	-3.6	-4.6	1939	722	1046	-109	
2142	98	129	3	19	334	16	-3.6	-1.3	1941	722	1047	-109	
2152	98	130	3	19	336	16	-3.6	-1.5	1942	722	1048	-109	
2162	98	130	3	19	338	16	-3.6	-2.0	1943	722	1048	-109	
2172	98	130	3	19	337	16	-3.6	-2.3	1943	722	1048	-109	
2182	95	126	3	19	331	16	-3.6	-2.7	1943	722	1048	-109	
2192	97	128	3	19	334	16	-3.6	-5.1	1943	722	1048	-109	
Salvage						155							
NPV						43	-8	-1			2476	-201	-253

Net present value	2056

APPENDIX H

CONCEPTUAL APPROACH

SUMMARY

Economists conventionally treat the problem of determining a forest stand's "optimal rotation" in two ways. First they determine the rotation which will maximise the present value of the stand over a single forest rotation - this is called the **Fisher rotation** and, second, they determine the rotation which will maximise the present value of all future forest rotations assuming that once a stand is cut it will be allowed to regenerate as a new forest - this is the **Faustmann rotation**.

While the Faustmann rotation is theoretically preferable to the Fisher rotation for forests which will regenerate the Fisher rotation is often used because of its relative simplicity and because of its good approximation properties as an estimator of the Faustmann rotation for forests which are harvested with long rotations.

The basic qualitative properties of these economically optimal rotations are (i) that forest stands should always be cut before they reach their maximum sustainable yield since when a forest gets old it tends to grow slowly, and (ii) that the Faustmann rotation is always shorter than the Fisher rotation because when ongoing rotations are accounted for it makes sense from an economics viewpoint to remove slow-growing old trees to make way for more rapid-growing young trees.

Recent work by economists has tried to determine how such cutting rules are influenced by "stock externalities" such as environmental or amenity benefits. For example as a forest gets older it may provide additional wildlife or recreational benefits. Not surprisingly, including such stock benefits makes it optimal to increase the computed Fisher and Faustmann rotations. That is including such benefits makes it preferable to cut at later ages.

The problem being considered in the present research is related to but more complicated than these stock externality problems. Basically streamflow benefits have a complex effect on the optimum forest rotation because such benefits vary nonlinearly with a forest's age. The benefits accrue at a high rate for forests which are currently "young" or "old" but for an intermediate range of ages these benefits fall off substantially.

What this means for optimal Faustmann rotations can be explained as follows. If a forest has just been cleared (for whatever reason) then **a priori** it cannot be assumed that it will always be optimal to eventually cut. It will not be optimal to ever cut if the streamflow benefits that are lost in the transition from a young to mature forest outweigh any timber values in present value. All that can be said is that including streamflow benefits will always act to increase the desired rotation although this increase may be very large. Thus including such benefits may in fact make it never optimal to cut.

Things are more complex if currently there is a standing forest. Again it may be optimal never to cut if the foregone streamflow benefits by so doing are large enough. In fact even should the optimal age of the forest exceed the optimal Faustmann rotation for a just-cleared forest it may still be non-optimal to ever cut again because of sacrificed water benefits. Clearly optimal forest practice here depends on the current age of the standing forest. To be specific: if a forest is currently young it may make sense for it to be harvested in perpetuity using Faustmann rotations while if it is old the same forest may optimally never be harvested.

Of course once a forest is clear felled it may not regenerate in its original state. Also it could in certain circumstances be possible to keep the forest cleared so as to maximise forest benefits. These

"endpoint" policy options need to also be considered in any comprehensive assessment of alternative joint water-timber management strategy.

Although the introduction of streamflow benefits complicates the analysis of optimal management policies provided data is available on timber benefits as a function of age and streamflow benefits as a function of age it is straightforward to work out the optimal management policy simply by plotting the various present values under the different management options (for given discount rates, clearing costs and current stand ages). The analysis illustrates this procedure for a Kuczera water yield function and a simple timber value function and establishes, for this particular instance, that the forest should never be harvested.

Generally the strongly divergent views that are associated with forestry and water management specialists (harvesting with quick rotations, never harvesting respectively) can be explained as reflecting self-interested myopia. An alternative explanation is that because of the nature of the relationship between water benefits with forest age, there well may be a case for extreme types of policy response on purely theoretical grounds. Good forest management may well correspond to the extremes of quick or very slow harvests simply because it is in the mid-range of forest ages that benefits are lost in significant quantities.

Choice between these extreme options may well depend on environmental considerations that are not taken up in this analytical review of appropriate policies.

H.1 INTRODUCTION

This paper provides a conceptual and practical computational guide to the relation between the length of a forest's rotation and streamflow water yields when forest stands of different ages have distinctive effects on such yields. The objective of managers is taken to be the joint optimisation of economic advantage from timber and water yields.

The approach largely follows the classic Faustmann analysis of optimal forest rotations (see e.g. Samuelson (1976, pp.466-492)) as it has been adapted to deal with stock and flow externalities by Hartman (1976, pp.52-58), Strang (1983, pp.575-583) and others. Most importantly, the analysis shows how the role of water benefits can be introduced into forestry models in a reasonably elementary way which avoids the use of advanced mathematics: the only complication is that economically optimal policies need not be interior because of the way streamflow benefits impact on the appropriate harvest decision. It is thus impossible to rule out the optimality of either never harvesting or harvesting with very quick rotations. Regardless of these complications, numerical estimation procedures are provided that are very simple to use to determine optimal forest rotations when water benefits are present.

The perspective adopted is small scale. Thus forest harvest and streamflow management strategies are discussed for small areas of forest which have only a relatively marginal impact on aggregate timber and water supplies. It therefore makes sense to always view the manager of the resources considered as a price-taker.

There are three basic components to the modelling approach utilised:

1. a hypothesised relationship between water output in the form of streamflow (e.g. ml/hectare) and the age of a forest stand.

2. A hypothesised relationship between the age of a forest stand and its value as timber or timber products.

3. The evaluation of alternative management strategies from the viewpoint of maximising (expected) discounted present values of returns.

H.2 WATER YIELD AND FOREST ROTATION

Letting w(T) be the net dollar value of water yields in terms of streamflow in ml/hectare/period (after any marginal water distribution costs are accounted for) when a forest stand has age T the relation between w(T) and T can be graphed as in Figure H.1.

The intuition behind the shape of this-graph is that at very young ages trees absorb very little water which is "lost" as transpiration but that water usage increases up to age about 25 years whereupon it decreases with age. The main point is that quite high water yields are generated at both low, and high forest stand ages. Note that, as drawn, the function w(T) is initially concave then convex and then concave again so it must have two inflection points.

H.3 STAND AGE AND TIMBER VALUES

Let v(T) denote the final product value net of all royalty, harvest and timber processing costs of a forest stand of age T once it has been processed into

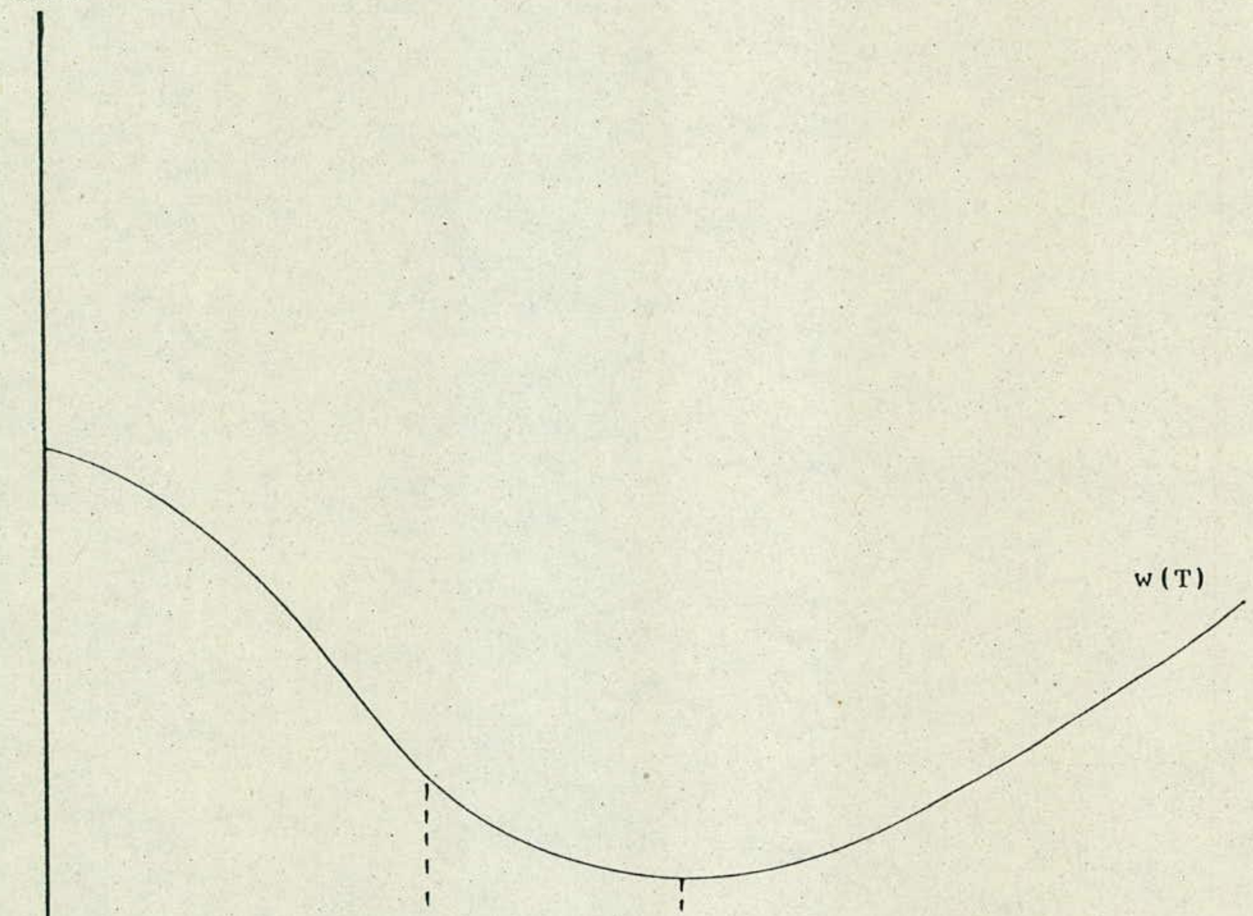


FIGURE H.1: STAND AGE AND VALUE OF STREAMFLOW YIELD IN DOLLARS

($w(T)$ is minimum at $T=25$ and has an inflection at T_i)

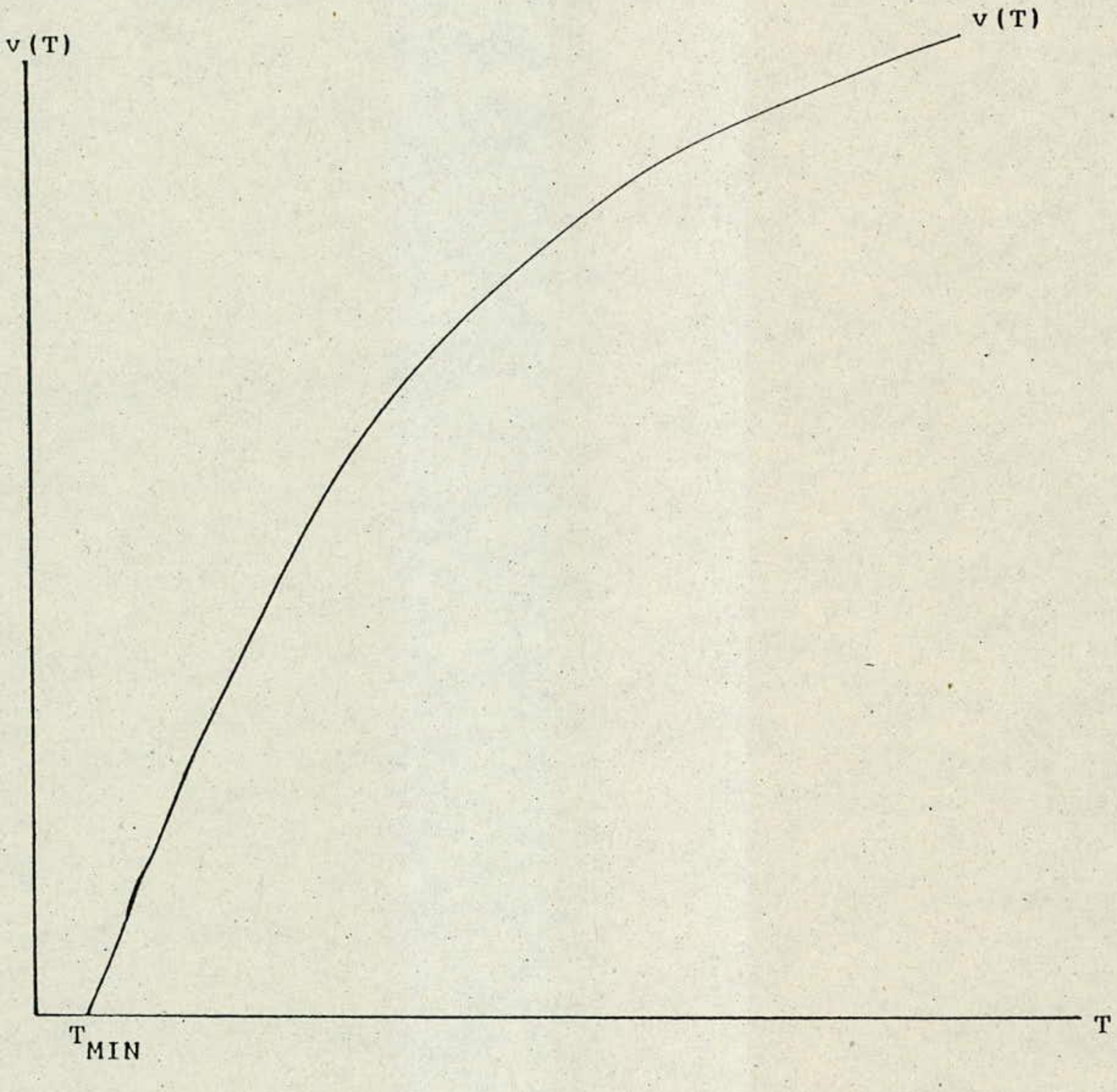


FIGURE H.2: STAND AGE AND TIMBER VALUES

(note $v(T) > 0$ only for $T \geq T_{MIN}$)

timber products. Suppose v(T) can be generated as the product of the estimated forest volume at each age T times the estimated value per unit at each age.

Following standard theory v(T) is supposed to be a non-decreasing function of T which is concave for $T \geq T_{MIN}$ as illustrated in Figure H.2.

H.4 FOREST MANAGEMENT STRATEGIES

Suppose the forest is managed to maximise the present value of benefits from streamflow yields as well as timber values.

Further suppose the forest's current age is known and uniform at T_0 years. An important question is whether it is **ever** optimal to harvest trees. This is by no means self-evident: to take an extreme example for illustration, suppose trees are currently "old" and yield good streamflow benefits but because of their extreme age have relatively low timber benefits. If the trees are also relatively slow-growing then it might make sense purely from an economic viewpoint never to harvest them and thereby enjoy the water benefits in perpetuity. Equally, if trees are currently "young" it may make sense to harvest them young and continue harvesting at frequent rotations in order to gain substantial streamflow benefits. In simple terms, optimal harvest policies may depend crucially on the **initial** age of a forest stand.

H.4.1 Single rotation problems

Although forests are typically managed as renewable resources which are exploited over "ongoing rotations", the optimisation of benefits over a single rotation (the so-called **Fisher solution**) is also often analysed. The Fisher solution is much simpler than optimising cutting ages over ongoing rotations (the Faustmann solution) and is a very accurate approximation to the latter for forests harvested with long rotations with empirically reasonable discount rates (e.g. greater than 4 per cent p.a.). The analysis begins therefore by examining the Fisher solution (when streamflow benefits are present) as a precursor to discussing exact Faustmann-type solutions.

Suppose future benefits and costs are discounted at the instantaneous rate δ. Also assume, initially, that the forest in question has just recently been harvested (for whatever reason). Then if w(t)dt denotes the water benefits during the interval dt and v(T) denotes the forest stand's value at age T (if cut), then the discounted value of the water and timber benefits up to the conclusion of the first (and only) rotation are:

$$PV(T) = \int_0^T w(z)e^{-\delta z} + e^{-\delta T} v(T) \qquad (1)$$

and the decision-maker's optimisation task is to select T to maximise this present value. Assuming that v(T) is eventually "concave enough" to ensure a unique **interior** global optimum (this is by no means an innocuous assumption), a necessary first-order condition for a maximum here is that:

$$\mathbf{PV'(T) = 0}$$

$$\Rightarrow \mathbf{w(T)\, e^{-\delta T} - \delta e^{-\delta T}\, v(T) + e^{-\delta T}\, v'(T) = 0} \tag{2}$$

which in turn implies that:

$$\frac{w(T) + v'(T)}{v(t)} = \delta \tag{3}$$

or, in words, that **the forest should be cut at the age where the growth in timber v′(T) and stream flow benefits w(T) relative to the standing forest value v(T) is equal to the discount rate.**

It can be seen immediately that **the existence of streamflow benefits always makes it optimal to delay an interior forest harvest beyond the level that would obtain in the absence of such benefits.** Thus in **Figure H.3**, log v(T) is graphed against T and the optimal cutting age in the absence of water benefits T_{NWB} is compared to the optimal age with such benefits T_{WB}. T_{NWB} is determined when the slope of logv(T) equals δ (i.e. when $v'(T) / v(T) = \delta$) while T_{WB} is determined where $v'(T) / v(T) = \delta - w(T)/v(T) < \delta$. Geometrically with v(T) concave it is obvious that $T_{NWB} < T_{WB}$ as claimed.

It is also worth noting from (3) that while streamflow benefits may greatly increase desired cutting ages **there will definitely exist an increased (though finite) optimal cutting age in the presence of such benefits if there exists an optimal cutting age in the absence of such benefits.**

Assuming there does exist an optimal cutting age in the absence of streamflow benefits **what should be done with trees currently standing and aged T_o years?** If the objective again is to maximise the value of benefits from the current stand of trees (inclusive of water benefits) then the policy prescription is simple. If $T_o < T_{WB}$ then it is optimal to wait $T_{WB} - T_o$ years and then cut while if $T_o \geq T_{WB}$ the trees should be cut immediately.

Finally, the **sensitivity properties** of the harvest model can be analysed. A proportional increase in timber values from v(T) to α v(T), with $\alpha \geq 1$, or an increase in discount rates is shown to increase the LHS of (3) namely, $\delta - w(T)/v(T)$, while leaving the growth in timber values $v'(T)/v(T)$ unchanged. **This type of increase in timber values therefore acts to shorten the optimal interior cutting age.**

A key shortcoming of all this analysis is the unrealistic neglect of water benefits beyond the age at which the standing forest is cut - an issue taken up in 4.3). The simple results are useful but it is necessary to generalise them into a more realistic "ongoing rotations" setting.

H.4.2 Ongoing rotations

Again suppose the forest is managed to maximise the stream of benefits from stream flows and timber. Now however consider the case of "ongoing rotations" so that as the first forest rotation is completed the second is initiated and so on.

To begin, again suppose the forest has just been cleared so $T_o = 0$. The present value at time zero of forest and streamflow benefits at discount rate δ is:

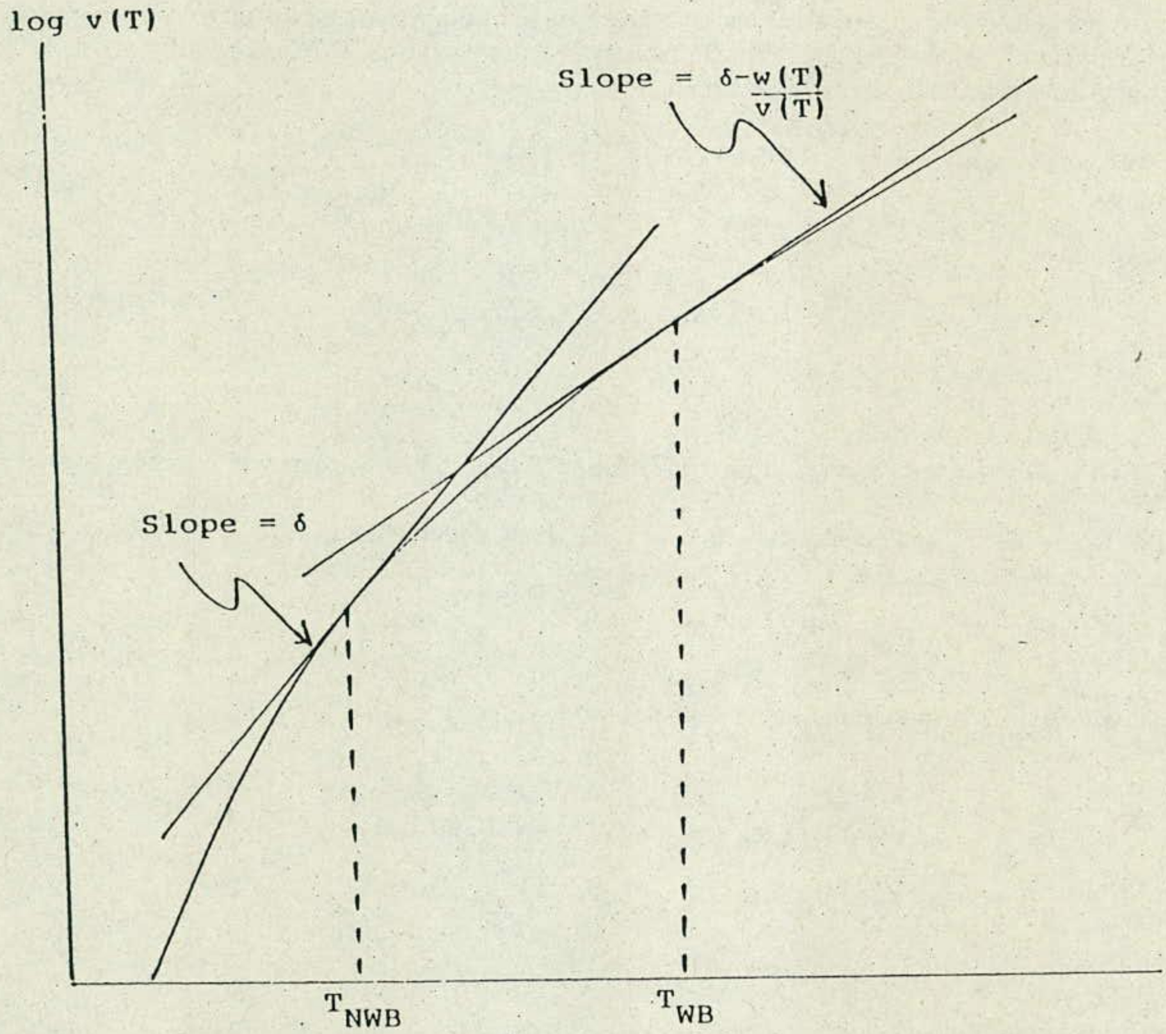


FIGURE H.3 STREAMFLOW BENEFITS RESULT IN A LONGER INTERIOR OPTIMAL FISHER ROTATION

$$PV(T) = \int_o^T w(z)e^{-\delta z}dz + e^{-\delta t}\{v(T) + \int_o^T w(z)e^{-dz}dz\}$$
$$+ e^{-2\delta T}\{v(T) + \int_o^T w(z)e^{-\delta z}dz\} + ... \qquad (4)$$

The first unbracketed term here gives the discounted value of the water benefits up to the time where the next rotation begins. The next term (in braces) gives the value, at T, of the next timber harvest and water flow benefits to the next rotation and so on.

The series (4) is easily summed:

$$PV(T) = -v(T) + \frac{v(T) + \int_o^T w(z)e^{-\delta z}dz}{1 - e^{-\delta T}} \quad . \qquad (5)$$

If v(T) and w(T) are concave enough for large enough T then PV(T) will have an interior maximum at $T = T^F_{WB} = T^F$. A necessary condition for such a maximum is that:

$$PV'(T) = 0 \qquad (6)$$

which, with some manipulation, implies that at $T = T^F$:

$$[v'(T) + w(T)]\,(1 - e^{-\delta T}) = \delta(v(T) + \int_o^T w(z)e^{-\delta z}dz) \quad . \qquad (7)$$

In the case w(z) = 0 (no streamflow benefits) from (7) the standard Faustmann formula for the optimal rotation of a forest is recovered while, if $v(T) \equiv 0$, (7) never has a solution and the forest should never be cut. To summarise:

Proposition 1. For forest land which has just been cleared the optimal rotation of forests yielding both timber and streamflow benefits is $T = T^F < \infty$ which solves (7) provided that such a $T = T^F$ exists.

It will definitely **not** always be the case that such a T^F exists. As mentioned, if timber benefits are low relative to streamflow benefits there is no T^F solving (7). **In this event one should never harvest.**

In practice the forest will invariably **not** just have been cleared as supposed but will be a standing forest of age T_o. Using the ideas contained in Proposition 1 optimal harvest policies for such a forest can be formulated.

If the current forest age T_o is such that $T_o > T^F$ (a case we refer to as the **"old growth"** forestry case) and if additionally:

$$\int_{T_o}^{\infty} w(z)e^{-\delta z}dz > v(T_o) + PV(T^F) \tag{8}$$

then the forest should **never** be harvested.

When (8) is satisfied, the forest should never be harvested since appropriately discounted streambenefits exceed the sum of timber benefits derived now and over ongoing rotations.

If $T_o > T^F$ and the inequality in (8) is reversed it is optimal to cut standing trees immediately and then cut at the constant optimal rotation T^F.

If $T_o < T^F$ and if

$$\int_{T_o}^{\infty} w(z)e^{-\delta z}dz > \int_{T_o}^{T^F} w(z)e^{-\delta z}dz + e^{-\delta(T^F - T_o)}\{v(T^F) + PV(T^F)\} \tag{9}$$

i.e. if
$$\int_{t^F}^{\infty} w(z)e^{-\delta z}dz > e^{-\delta(T^F - T_o)}\{v(T^F) + PV(T^F)\} \tag{10}$$

then it is again nonoptimal to ever cut since appropriately discounted streamflow benefits exceed timber benefits. If (10) is reversed then it is optimal to harvest after $(T^F - T_o)$ years and then to continue rotations at intervals T^F years thereafter.

We can summarise our results concisely as follows:

Proposition 2. For a standing forest of age T_o if $T_o > T^F$ and if

$$\int_{o}^{\infty} w(z)e^{-\delta z}dz > v(T_o) + PV(T^F)$$

then the forest should never be cut.

If however for $T^F < \infty$, $T_o > T^F$

$$\int_{o}^{\infty} w(z)e^{-\delta z}dz < v(T_o) + PV(T^F)$$

then the forest should be cut now and thereafter at rotations of length T^F.

If $T_o < T^F$ and $\int_{T^F}^{\infty} w(z)e^{-\delta z}dz > e^{-\delta(T^F - T_o)}\{v(T^F) + PV(T^F)\}$ then the forest should never be harvested.

If however for $T^F < \infty$, $T_o < T_F$

$$\int_{T^F}^{\infty} w(z)e^{-\delta z}dz < e^{-\delta(T^F - T_o)}\{v(T^F) + PV(T^F)\}$$

then the forest should be harvested after T^F - T_o years and thereafter at rotations of T^F years.

How does this version of the Faustmann rule compare with the earlier Fisher rule? The Fisher rule requires cutting at T_{WB} where:

$$w(T) + v'(T) = \delta v(T). \tag{11}$$

The Faustmann rule involves cutting at T^F where:

$$w(T) + v'(T) = \frac{\delta}{1-e^{-\delta T}}\{v(T) + \int_{o}^{T} w(z)e^{-\delta z}dz\} \ . \tag{12}$$

Comparing (11) and (12) it can be seen that the Faustmann rule involves harvesting **earlier** than the Fisher rule if

$$e^{-\delta T^F}v(T^F) > \int_{o}^{T^F} w(z)e^{-\delta z}dz \tag{13}$$

For example, if $w(t) \equiv 0$ (no water benefits), the standard result that the Faustmann rule involves an **earlier** cut is recovered. More generally, **if discounted timber values at the end of the rotation exceed the discounted value of water benefits during the rotation this standard result obtains. If the reverse holds however (i.e. if water benefits are significant) the traditional result is reversed and the Faustmann rotation will be longer than the Fisher rotation.**

It is also worth examining the relation between the Faustmann rotation in the presence and in the absence of water benefits namely (call the latter T^F). The relation determining T^F is

$$\frac{v'(T)}{v(T)} = \frac{\delta}{1-e^{-\delta T}} \tag{14}$$

while that determining T^F is

$$\frac{v'(T)}{v(T)} = \frac{\delta}{1-e^{-\delta T}} - \frac{w(T)}{v(T)} + \frac{\delta \int_0^T w(z) e^{-\delta z} dz}{v(T)(1-e^{-\delta T})} \tag{15}$$

The harvest will be later in the presence of water benefits if when $T = T^F$:

$$\frac{-w(T)}{v(T)} + \frac{\delta \int_0^T w(z) e^{-\delta z} dz}{v(T)(1-e^{-\delta T})} < 0 \tag{16}$$

If $w(z)$ is maximised over $z \in (0, T^F]$ when $T = T^F$, so, as Figure H.1 suggests, the oldest standing forests yield maximum water benefits, then (16) is readily seen to hold. In this event

$$\frac{\delta \int_0^T w(z) e^{-\delta z} dz}{1-e^{-\delta T}} \le \frac{\delta \int_0^T w(T) e^{-\delta z} dz}{1-e^{-\delta T}} = w(T)$$

on integration so (16) holds. Hence - analogously to the Fisher rule case - **inclusion of streamflow benefits lengthens the optimal interior Faustmann rotation.**

An argument analogous to that examined for the Fisher case shows that **if there exists an optimal harvest rule without streamflow benefits there will always exist such a rule in the presence of such benefits** (provided, naturally, that streamflow benefits remain bounded).

Finally, the comparative static properties of the Faustmann rule with waterflow benefits can be checked. **A proportionate increase in timber values increases the value of the last two terms in (15) and hence hastens the optimal rotation.** Conversely it can be seen that **a proportionate increase in water benefit values acts to slow down the optimal rotation.**

H.4.3 Other single cut policies

Now consider situations where a single cut is optimal followed by a policy of either (1) keeping forest cover cleared by spending an ongoing (although perhaps small) clearing cost, or (2) allowing the forest to regenerate perhaps as woodland or as cleared landscape with light vegetation.

In both cases the optimal harvest rule is of the Fisher-type however the traditional formulation of this rule needs to be modified to account for the streamflow benefits which occur **after** the single cut.

The optimisation task for the case where clearing permanently after the cut is the preferred option is analysed in two stages. First we consider the case where the forest has just been cleared. Then the optimal date of cut T^{SC} must maximise:

$$PV(T)^{SC} = \int_0^T w(z)e^{-\delta z}dz + \int_T^\infty (w(0) - C)e^{-\delta z}dz + e^{\delta T}v(T) \qquad (17).$$

where C is the constant ongoing instantaneous clearing cost.

Integrating the second term in (17) one can write this expression as

$$PV(T)^{SC} = \int_0^T w(z)e^{-\delta z} + e^{-\delta T}\left\{v(T) + \frac{w(0) - C}{\delta}\right\}. \qquad (18).$$

It is straightforward to adapt the analysis of Section 4. a) to maximise (18). The optimal cutting age T^{SC} is the solution in T to:

$$\frac{w(T) + v'(T)}{v(T) + (w(0) - C)/\delta} = \delta\ . \qquad (19).$$

This suggests that including ongoing streamflow benefits beyond the cut decreases the optimal age of cutting while including clearing costs increases the optimal cutting age.

If trees of age T_O are currently standing then what are the optimal cutting rules? If it is always optimal to cut then provided $T_O < T^{SC}$ it is optimal to wait T^{SC} - T_O years and then cut. If $T_O \geq T^{SC}$ the trees should be cut immediately.

Suppose the alternative management strategy envisaged is to allow the forest to regenerate as a woodland with a new streamflow benefits function q(z) describing the relevant instantaneous benefits when the woodland's age is z. Maximising present values then involves estimating the $T = T^W$ which maximises for an initially clear area:

$$PV(T)^W = \int_O^T w(z)e^{-\delta z}dz + \int_T^\infty q(z - T)e^{-\delta z}dz + e^{-\delta T}\ v(T) \qquad (20).$$

Straightforward computation implies this T^W must solve:

$$\frac{v'(T) + w(T) - q(0)}{v(T)} = \delta \qquad (21).$$

so that if, as seems plausible, $q(0) > w(T^W)$, the inclusion of such woodland-generated streamflow benefits will bring forward the timing of the optimal cut compared to the situation where such ongoing benefits are ignored.

The advantage of allowing a woodland to regenerate naturally rather than maintaining cleared land is the avoidance of land-clearing costs. On the other hand as the woodland does regenerate the level of streamflow benefits will diminish for some time. It thus becomes an empirical matter whether permanent clearing or regeneration as woodland is the better long-term management policy.

Of course if the forest regenerates naturally to its original state following a cut then, assuming stable cost and demand conditions, if it ever was optimal to cut it will certainly become optimal to cut again in the standard ongoing rotations fashion.

H.5 EMPIRICAL ISSUES

A simple procedure for empirically applying the above analysis is now detailed. The data needed to check on all the management possibilities discussed above includes:

$w(T)$ = instantaneous streamflow benefits as a function of stand age T,
$v(T)$ = timber value of a stand age T,
$q(T)$ = instantaneous streamflow benefits from a regenerating woodland of age T,
δ = appropriate discount rate,
C = instantaneous cost of maintaining cleared land,
T_o = current stand age.

Much of the consequent analysis centres on the behaviour of two derived functions that can be defined as:

$$PV(T) = -v(T) + \frac{v(T) + \int_0^T w(z)e^{-\delta z}dz}{1 - e^{-\delta T}} \qquad (22).$$

$$W(T) = \int_T^\infty w(z)e^{-\delta z}dz \ . \qquad (23).$$

A plot of (22) is very useful since it is a transparent way of determining the optimal Faustmann rotation T^F as well as the overall sensitivity of present values to variation in rotation length. It also clarifies whether "corner solutions" will be optimal or not. (23) gives the present value now of streamflow benefits which occur after a single forest harvest at time T in the future.

Suppose T^F, the optimal Faustmann rotation, has been calculated.

There are two management possibilities depending on whether $T_O \le T^F$ or $T_O > T^F$.

<u>Case $T_O \le T^F$</u> (an initially "young" forest).

Here if

$$W(T^F) > e^{-\delta(T^F - T_O)} (v(T^F) + PV(T^F))$$

then the forest should **never** be cut and the analysis ends. If the inequality is reversed then the forest should be cut. There are then three management possibilities:

(a) The forest should be cut at the single cutting age where it is thereafter optimal to keep the land permanently cleared. This age is:

(i) T_O if $T_O \geq T^{SC}$ when the present value generated is $PV(T_O)^{SC}$.

(ii) T^{SC} if $T_O < T^{SC}$ when the present value generated is

$$PV(T^{SC})^{SC} \cdot e^{-\delta(T^{SC} - T_O)}.$$

(b) The forest should be cut at the single cut age where it is thereafter optimal to allow the cleared land to regenerate as woodland. This cutting age is:

(iii) T_O if $T_O \geq T^{SC}$ when the present value generated is $PV(T_O)^W$

(iv) T^W if $T_O < T^W$ when the present value generated is

$$PV(T^W)^W \cdot e^{-\delta(T^W - T_O)}.$$

(c) An ongoing rotations policy of cutting in $T_F - T_O$ years is initiated and then followed by rotations at T^F years. This yields present value $e^{-\delta(T^F - T_O)} PV(T^F)$.

The present value functions $PV(T)$, $PV(T)^W$ and $PV(T)^{SC}$ are presented in the paper. The optimal harvest strategy for the case $T_O \leq T^F$ depends on which of the relevant alternatives in a), b), c) gives the highest present value.

<u>Case $T_O > T^F$</u> (the "old-growth" forest case).

This can be dealt with analogously. Thus if:

$$w(O) > v(T_O) + PV(T^F)$$

then the forest should never be cut. If this inequality is reversed then harvesting should occur although these are again three management possibilities.

(a) The permanent clearing possibility. Here a single cut is optimal at age:

(i) T_O if $T_O \geq T^{SC}$ when the present value generated is $PV(T_O)^{SC}$.

(ii) T^{SC} if $T_O < T^{SC}$ when the present value generated is

$$PV(T^{SC})^{SC} \cdot e^{-\delta(T^{SC} - T_O)}.$$

(b) Cut once and then allow to regenerate as woodland. The optimal cutting age is:

(iii) T_O if $T_O \geq T^{SC}$ when the present value generated is $PV(T_O)^W$.

(iv) T^W if $T_O < T^W$ when the present value generated is

$$PV(T^W)^W e^{-\delta(T^W - T_O)}.$$

(c) Managed as a Faustmann rotation forest and cut immediately and thereafter at rotations of T^F years. The present value generated is $v(T_O) + PV(T^F)$.

Again the optimal harvest strategy depends on which of the relevant alternatives in a), b), c) maximises present value.

For numerical illustration consider the **Kuczera** water yield function for Alpine Ash and Mountain Ash in the Thompson River catchment (see Section 3). In this formulation water yields y in mℓ/ha/year are the function of stand-age t given by:

$$\left.\begin{aligned} \mathbf{y(t)} &\mathbf{= 11.9 \text{ for } t < 2} \\ &\mathbf{= 11.9 - .2379(t-2)e^{1.078-.039t} \text{ for } t \geq 2 .} \end{aligned}\right] \qquad (24)$$

Suppose, for illustration, that the value of this water is \$250 per mℓ/ha/year. Then with a continuous discount rate of 4 per cent the discounted water benefits function $t \geq 2$ is:

$$\int_0^t w(t)dt = 250 \text{ x } 11.9 \text{ x } \int_0^2 e^{-.04z}dz + 250 \int_2^t y(z)\, e^{-.04z}dz \ . \qquad (25)$$

We evaluated this (and all the functions to follow) using the DERIVE mathematical software. The computations were very straightforward and yielded the results sought with only a few minutes programming. Simplifying (25):

$$\int_0^t w(t)dt = 44743.9 - 74375e^{-.04t} + 28.0059e^{-.079t}(79t + 842)$$

The sawlog values discussed in Appendix E (we ignored the role of pulpwood) were used and we took the value per cubic metre of sawlog at \$35. This led to the timber value function:

$$\mathbf{v(t) = 35(-16211.9 + 7836.1\ell ogt - 436.4982(\ell ogt)^2)}$$

Computing (22) showed that the present value function for a just-harvested area was an increasing concave function of stand age which would be maximised at a boundary. Specifically, for this data, the present value of the forest would be maximised by **never** again harvesting the forest. This is a very strong result and shows that for a forest of current age $T_0 > 0$ it is likewise never optimal to harvest.

These results illustrate the extreme complexity of including streamflow benefits in an analysis of optimal forest rotations. While the results do not (because of data inadequacies) indicate any specific case for a particular management practice, they do indicate that an effect of including such benefits can be to make it essential to analyse carefully non-interior types of management policies.

H.6 RATIONALE FOR STRONGLY DIVERGENT MANAGEMENT VIEWS

Some commentators argue for a policy of actively logging water catchment areas while others argue for a policy of harvesting, if at all, over very long rotations. These alternative viewpoints can be rationalised in terms of the shapes of the economic benefit schedules that describe timber and streamflow benefits. In what follows we argue that these shapes make possible the optimality of non-interior policies that involve either harvesting on the basis of a very rapid rotation or in never harvesting.

Consider timber benefits $v(t)$ first since these are simple. If these are generated by a logistic growth function over empirically sensible harvest ages, then the $v(t)$ is a strict concave function of t so that $v(t)\exp(-\delta t)$, where δ is the discount rate, is a single-humped function with a maximum at say $t=t^*$ which provides an upper bound for the optimal Faustmann rotation.

The discounted value of intra-rotation water benefits is however increasing at rate $w(t)\exp(-\delta t)$. If δ is very low then the value of this function changes in accord with the "low" discount case illustrated in Figure H.4. If δ is large then the function corresponds to the "high" discount case.

We can now see clearly what is happening. If analysts place a high weight on streamflow benefits then they can select one of two options. First, seldom harvest for timber so as to seldom impose severe streamflow losses, or second, harvest frequently in order to limit tree demands on water resources.

At first sight here it appears that water flow benefits will always be maximised by the shorter rotation policy but this is an incorrect impression. The outcome depends crucially on the current age of standing trees. If they are already very old then it will pay to keep them old, while if they are young the policy switches to a very rapid rotation.

It is worth emphasising that the analysis here does exclude environmental considerations which may prove crucial in practice (fire risks alone might provide a strong basis for very long rotations or policies of never cutting).

It is only if the major source of benefits is timber that we can give much serious consideration to the idea of a regular interior Faustmann-type harvesting solution. Otherwise aggregating such a problem with one involving streamflow benefits may turn a straightforward single-humped type of maximisation problem into one that may resemble that of maximising a convex function. Such a function will generally take its maximum at boundary points hence motivating the concern by those who place weight on streamflow benefits, for policies of either frequently harvesting or never harvesting. Hence sensible policy choice (with consideration for environmental benefits) would involve either never harvesting or harvesting on the basis of very long rotations.

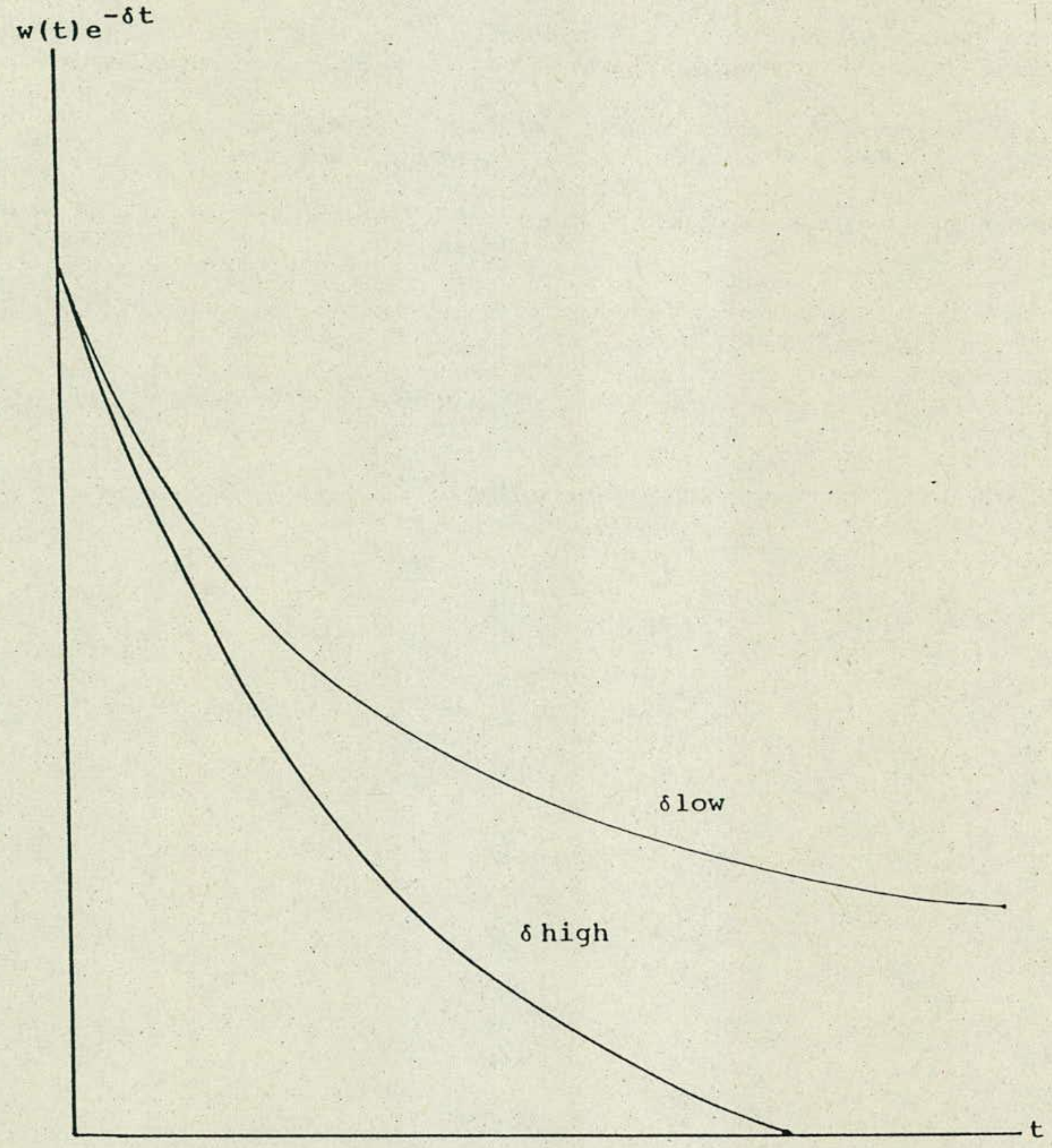


FIGURE H.4 **DISCOUNTED INTRA-ROTATION STREAMFLOW BENEFITS WITH LOW AND HIGH DISCOUNT RATES**

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TABLE I.3: AGE OF ASH-TYPE FOREST SUBJECT TO RISK OF FIRE BEYOND WHICH WOULD NOT FELL

Annual risk of fire (%)	Salvage value percentage	Age beyond which would not fell (years)
2	67	150
2	50	150
5	67	160
5	50	170
10	67	190
10	50	-

The results for a mixed-species even-aged stand were qualitatively similar to those for an Ash-type stand. For the base data, the minimum possible rotation age of 10 years was optimal. For trees aged 120 years and over, trees should not be felled. The price of water had to fall to $90/ML and below to obtain an optimal rotation of 50 years.

The optimal rotation period with risk of fire

There is always a small risk that the entire forest in the catchment will be subject to an uncontrollable fire. How is the optimal rotation period affected when allowance is made for this risk?

It is a standard result for the timber only rotation problem that if the probability of trees surviving from one year to the next, for all years, is p, so that the risk of loss is (1−p), the optimal rotation period can be obtained by calculating the optimal rotation period for the no-risk case, but using (1+r−p)/p instead of the discount rate, where r is the actual discount rate (see, e.g., Reed, 1984, pp.180-190, and Kennedy, 1986, Ch. 9). Thus if the probability of annual survival is 98 per cent, and the actual discount rate is 4 per cent, the optimal rotation for the stochastic problem is obtained by solving the deterministic problem with a discount rate of 6.12 per cent. The result is a shorter rotation period for the stochastic case.

The case of Ash-type forest in the catchment is more complex, both because of streamflow being an additional output, and because the trees still retain their market value immediately after the fire. If all the trees could immediately be collected and processed, there would be little loss from the fire in terms of timber output. However, problems of access, organising retrieval and "flooding the market" lead to losses and delays. The longer retrieval of dead logs is left, the greater will be the deterioration of the logs. Royalty charges typically fall for the removal of fire-damaged timber. As a rough estimate it is assumed that the salvage value of fire-damaged logs is 67 per cent of undamaged logs.

The best estimate which could be obtained of the annual risk of catastrophic fire was 2 per cent. There was little evidence to suggest the risk varied with the age of the trees except perhaps for very young trees. Stochastic DP results for the base case gave the same rotation policy as optimal as the DP results gave for the deterministic base case, except that trees over 150 years of age instead of 140 years should not be felled. Stochastic DP results for other combinations of risk of fire and salvage value proportion are shown in Table I.3.

It would appear that allowing for the risk of catastrophic fire has little effect on optimal rotation periods.

APPENDIX I

DETAILS OF DYNAMIC PROGRAMMING

I.1 OPTIMAL ROTATION LENGTHS FOR EVEN-AGE STANDS

A starting point in determining socially efficient rotation and thinning regimes for Ash and Mixed-species stands in the Thomson catchment is to determine optimal rotations for even-aged stands treated in isolation from other stands. In practice, management decisions must encompass the scheduling of all output from the catchment over time, taking account of the desirability of maintaining a roughly even flow over the years to prevent swings in timber prices and harvesting and processing costs. However, it is of interest to start by considering the simple stand problem of the optimal rotation period, both ignoring the value of streamflow, and also including the value of streamflow for various water prices.

The optimal rotation period starting with bare land

If timber prices, regeneration costs, timber growth functions and streamflow functions remain unchanged for all future years, the net present value of $V\{t'\}$ of following rotations of length t' years in perpetuity, starting with bare land is:

$$V\{t'\} = \left(-k + \sum_{t=1}^{t'} w\{t\}(1+r)^{1-t} + s\{t'\}(1+r)^{1-t'} \right) / \left(1 - (1+r)^{-t'}\right)$$

where

k = planting or regeneration costs

$w\{t\}$ = value of streamflow over the year at the end of which trees are t years old

$s\{t\}$ = stumpage value for trees of age t

r = annual rate of interest

Values of $s\{t\}$, $w\{t\}$ and $V\{t\}$ are shown in Table I.1 at ten-year intervals for Ash-type forest, for the base data presented in Table I.2. The values are summarised in the bar chart, Figure I.1. The optimal rotation period appears as the minimum possible (i.e.) at 10 years. However, 10 years can hardly be described as a rotation because no timber is harvested. The high value for $V\{10\}$ merely reflects the large streamflow which can be obtained immediately and then indefinitely if there are no trees to diminish streamflow. It would be preferable to find some vegetation with a lower water requirement than trees to be maintained in perpetuity.

It is also evident from Figure I.1 that the maximum reduction in present value to infinity from following any rotation other than 10 years is only 20 per cent. Present values are very similar for all rotation lengths above 40 years.

What if the initial situation is not one of bare land, but of standing forest? Dynamic programming (DP) results for this problem, for the base data in Table I.2, indicate that once trees are aged 140 and over, it is optimal never to log the trees. For trees less than 140 years old, it is optimal to fell, and from then on follow a minimum rotation period.

It is to be expected that this policy result will be different for sufficiently low prices of water. When the price of water is zero, the optimal rotation period is 40 years. It is optimal to fell any trees above 40 years of age, and follow a 40-year rotation. This is also the optimal policy for water prices up to \$50/ML.

From a wider perspective a 40-year rotation may not be viewed as optimal. Frequent cuttings may cause excessive soil erosion, reservoir sedimentation, and loss of mature forest for wildlife habitat and recreation. The Victorian Timber Industry Strategy (State Government of Victoria, 1986, p. 33) states that "sustainable volumes of sawlogs from mature forests will be calculated for minimum rotations of 80 to 150 years depending on forest type". DP results for Ash-type forest show that if a minimum rotation of 80 years is stipulated it is optimal never to fell, whatever the current age of the trees. If the minimum rotation age is reduced to 40 years, it is optimal to follow a 40-year rotation if trees are currently less than 40 years old. Trees older than 40 should not be felled.

Reducing the annual rate of discount from 4 to 2 per cent results in a lowering of the age beyond which trees should not be felled from 140 years to 70 years. At 1 per cent the age is further reduced to 40 years.

For the base case except that regeneration costs are \$300 instead of \$607 per hectare, the only change in policy is that the age beyond which trees should not be felled is increased marginally from 140 to 150 years.

TABLE I.1 TIMBER AND WATER YIELDS FROM ONE HECTARE OF ASH-TYPE FOREST

Age	Merchantable volumes by log type			Stumpage Value	Streamflow Value[a]	Present Value
t (years)	A&B (M^3)	C (M^3)	Pulp (M^3)	s{t} ($)	w{t} ($)	V{t} ($)
10	0	0	0	0	45492	138347
20	0	0	120	1218	30822	121894
30	0	0	216	2192	26268	113306
40	54	72	188	8460	26990	110873
50	69	91	240	10762	30054	109150
60	82	108	285	12781	33873	108580
70	116	153	269	16728	37639	108675
80	127	168	294	18332	40989	108768
90	136	181	317	19704	43798	108924
100	143	189	332	20644	46067	109073
110	148	196	343	21377	47851	109198
120	151	200	350	21813	49226	109295
130	152	202	354	22005	50272	109366
140	154	204	358	22258	51056	109419
150	157	209	366	22749	51640	109457
160	160	212	371	23118	52070	109484
170	161	213	374	23254	52386	109502
180	161	213	374	23254	52615	109514
190	160	212	372	23128	52782	109522
200	162	214	376	23380	52902	109528
210	163	215	378	23507	52988	109532
220	163	216	378	23553	53050	109534
230	162	215	377	23437	53094	109536
240	161	213	374	23254	53126	109537
250	163	217	380	23619	53148	109538
260	161	213	374	23254	53164	109539
270	163	215	378	23507	53175	109539
280	164	217	381	23689	53183	109539
290	160	212	371	23118	53188	109539
300	160	212	372	23128	53192	109540
310	160	212	372	23128	53195	109540
320	160	212	371	23118	53197	109540
330	159	211	370	23002	53198	109540
340	164	217	381	23689	53199	109540
350	163	215	378	23507	53200	109540

[a] Streamflow value is here the value of water flow over the ten years to when trees are age t, discounting values to the start of the ten-year period.

TABLE I.2 BASE DATA FOR OPTIMAL ROTATION PROBLEM

Annual rate of interest	4%	
Price of water	$530/ML	
	Ash	Mixed species
Price of sawlogs A & B	$60/m^3	$36/m^3
Price of sawlogs C	$46/m^3	$35/m^3
Price of pulpwood	$10/m^3	$10/m^3
Regeneration cost	$607/ha	$400/ha
Minimum rotation age	0 years	0 years
Stochastic model		
Probability of no fire	0.98	
Timber salvage value proportion after fire	0.67	

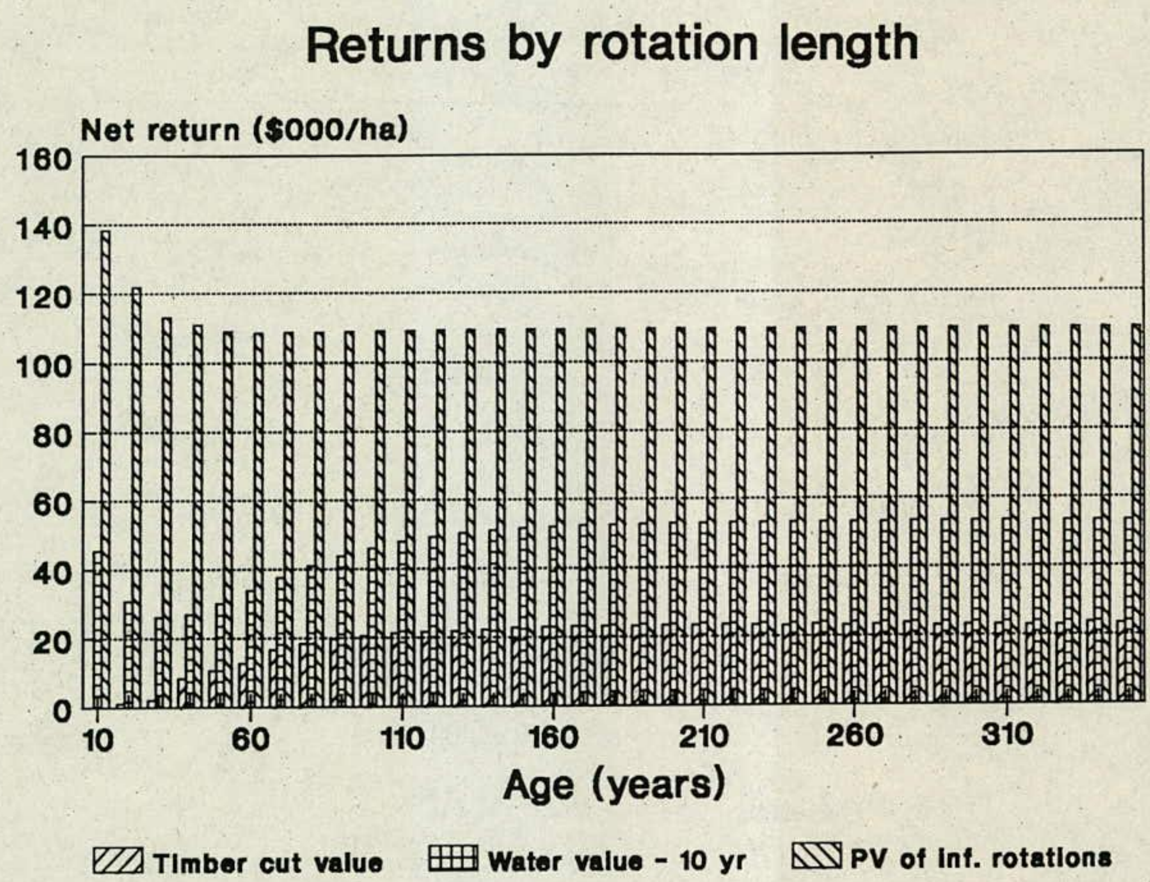

FIGURE I.1: TIMBER AND WATER RETURNS BY AGE, AND PRESENT VALUE OF INFINITE ROTATIONS BY ROTATION LENGTH

I.2 DETERMINING THE SHADOW PRICE OF WATER

Suppose w units of water are lost in year t as a result of implementing one timber option compared to another. How should the loss of the water be valued? The answer depends on how the water is replaced. If the water loss is made up by a reduction in consumption of w units, then the value of consumers' willingness to pay for that water is its opportunity cost. This may be about $60 per megalitre if the consumers are irrigators and about $500 per megalitre if the consumers are domestic users. Alternatively, the loss of w units of water may be made up by supplying an additional w units from a new augmentation scheme. The opportunity cost is then the cost of new supply.

It is quite possible that the lost w units are made up partly from foregone consumption and the remainder from additional supply. The opportunity cost is then the weighted sum of the consumption willingness to pay and the supply cost, the weights being the proportional consumption and supply quantities.

The way in which the w units are made up could be determined by fiat. That is, Melbourne Water could decide, for example, that the supply to Melbourne users will be reduced by w units. Another possibility is for Melbourne Water to let the price system determine the optimal replacement combination of reduced consumption and increased supply. The loss in w units will lead to some increase in the price of water. The price increase will be sufficient for the resulting drop in demand and increased supply to equal w units of water.

The possibilities are shown diagrammatically in Figures I.2 and I.3, which show demand (D) and supply (S) schedules for water. This area under a demand schedule between any two consumption levels shows the consumers' willingness to pay for an increase in consumption from the lower to the higher level. The area under a supply schedule (equivalent to a marginal cost schedule) shows the cost of increasing supply from the lower to the higher level. In both figures the initial supply situation is given by schedule S_0. Schedule S_1 depicts the supply situation after a reduction in water supplied at all levels of marginal cost due to a changed timber rotation policy.

Figure I.2 shows the situation where water is subsidised. Quantity Q_0 is supplied, and charged to consumers at price P_0^D, whereas the marginal cost of supply is P_0^S. After the loss of water (shown as the horizontal shift to the left of the supply schedule), water supply to consumers could be maintained, but at an additional supply cost given by the shaded area. Alternatively, supply to consumers could be reduced to Q', and the price to consumers raised to P_1^D, resulting in a loss in the value of water consumption of the area under the demand schedule from Q_0 to Q'. Of the two options, the latter results in lower social cost. If selected, this area would represent the opportunity cost of the loss of water.

Figure I.3 shows the situation where water is priced efficiently. The price and quantity levels are P_0 and Q_0 before the loss of water, and P_1 and Q_1 after the loss of water. The rise in the price of water leads to a reduction in demand of $Q_0 - Q_1^D$, and a corresponding loss in value to consumers given by the left shaded area. The rise in the price of water also makes it economic to bring forth new supply of $Q_1^S - Q_0$ at a cost given by the right shaded area. In this case the opportunity cost of the loss of water is represented by the sum of the shaded areas.

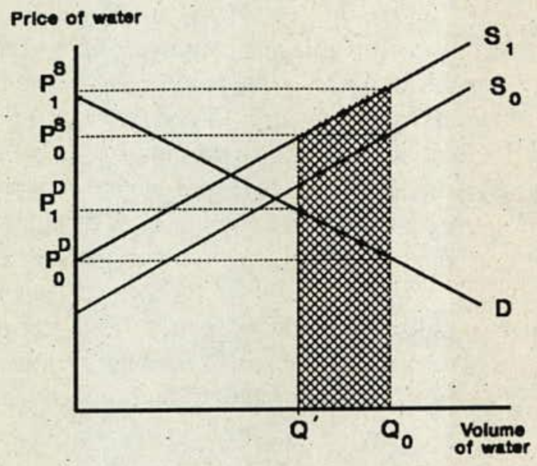

FIGURE I.2: DEMAND AND SUPPLY OF WATER UNDER PRICE SUBSIDISATION

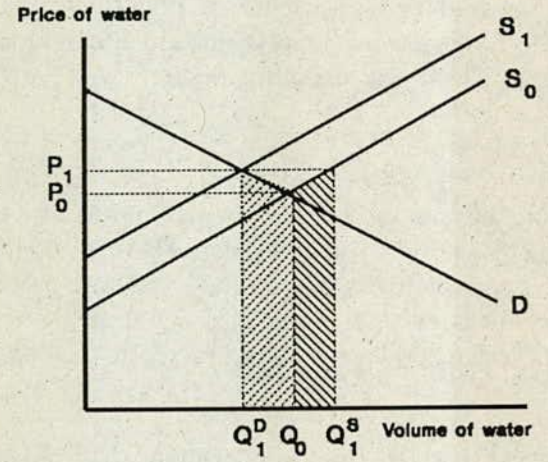

FIGURE I.3: DEMAND AND SUPPLY OF WATER UNDER EFFICIENT PRICING

The social opportunity costs of increments or reductions in water availability in future years due to alternative timber policies can be determined assuming a particular time schedule of water charges to consumers and introducing new supply, or assuming an efficient charging and new supply policy is adopted in future years. Both approaches have problems. The first approach is especially problematic when the planning horizon is long, say longer than 10 years. Current statements on future pricing and supply plans may not be moulded by the economic realities of the future demand and supply situation.

On the other hand, it is virtually certain that, for various reasons, a fully efficient pricing and supply will not be adopted in future. Nonetheless, the second approach may be the more realistic because the future demand and supply situations which will have to be faced and reacted to are recognised. In similar vein, economists find it useful to model firms as making decisions to maximise profits, even although they know firms are influenced by other considerations as well as profit. In the long run firms have to aim to make profits to survive. In the following chapter the results of evaluating alternative timber management options under the second approach are presented.

I.3 EVALUATING TIMBER OPTIONS UNDER OPTIMAL SCHEDULING OF WATER AUGMENTATION SCHEMES

In this section an optimising model is described for determining the net present value of returns from timber and water output from the Thomson catchment over the next 200 years for each of the eight timber management options. It is assumed that charging for water and augmentation of supplies are carried out efficiently over the planning horizon, in the sense that decisions are made so as to maximise the present value of net social returns to the end of the time horizon.

Three model components are dealt with in sequence: first, the modelling of the demand for water; second, the modelling of the supply of water; and third, the dynamic optimisation procedure.

Modelling demand for water

It is assumed that demand for water (see Appendix F) in the base year (represented by Q_1) is a linear function of the price of water (P_1) as follows:

$$Q_1 = a_1 + b_1P_1 \tag{1}$$

where a_1 and b_1 are parameters with $b_1<0$. To obtain estimates of a_1 and b_1 it is assumed that the function holds for currently observed price and quantity ($\bar{P}_1$ and $\bar{Q}_1$) with the elasticity of demand for water (ε) applying to the $\bar{P}_1,\bar{Q}_1$ combination. Given that elasticity is:

$$\varepsilon = (dQ/dP)(P/Q) \tag{2}$$

it follows that

$$a_1 = \bar{Q}_1(1 - \varepsilon) \tag{3}$$

$$b_1 = \varepsilon\bar{Q}_1/\bar{P}_1 \tag{4}$$

The marginal willingness to pay for an additional unit of water when consumption is Q' is the price at which Q' would be demanded, equal to

$$P\{Q'\} = (Q' - a_1)/b_1 \tag{5}$$

The total willingness to pay for consumption Q' is given by the area under the inverse demand schedule (5) from $Q=0$ to Q', equal to

$$\begin{aligned} WTP\{Q'\} &= (1/b)\int_0^{Q'}(Q-a_1)\,dQ \\ &= (Q'/b_1)(Q'/2 - a_1) \end{aligned} \tag{6}$$

Through time the demand for Melbourne's water is likely to grow in step with Melbourne's population and other factors such as incomes and the purchase of water-consuming appliances. If the growth rate of the demand for water is g per year, then for any price of water holding in both base year 1 and year t,

$$Q_t = Q_1e^{gt} \tag{7}$$

The demand equation for year t is then

$$Q_t = (a_1 + b_1P_t)e^{gt} \tag{8}$$

or

$$Q_t = a_t + b_tP_t \tag{9}$$

where $a_t = a_1e^{gt}$ and $b_t = b_1e^{gt}$. (10)

The effect of growth on the demand schedule is shown diagrammatically in Figure I.4. If demand increases from year 1 to year t, the demand schedule swings out about the vertical price intercept, $-a/b$. At any price P, the elasticity of demand in year t is the same as that in year 1.

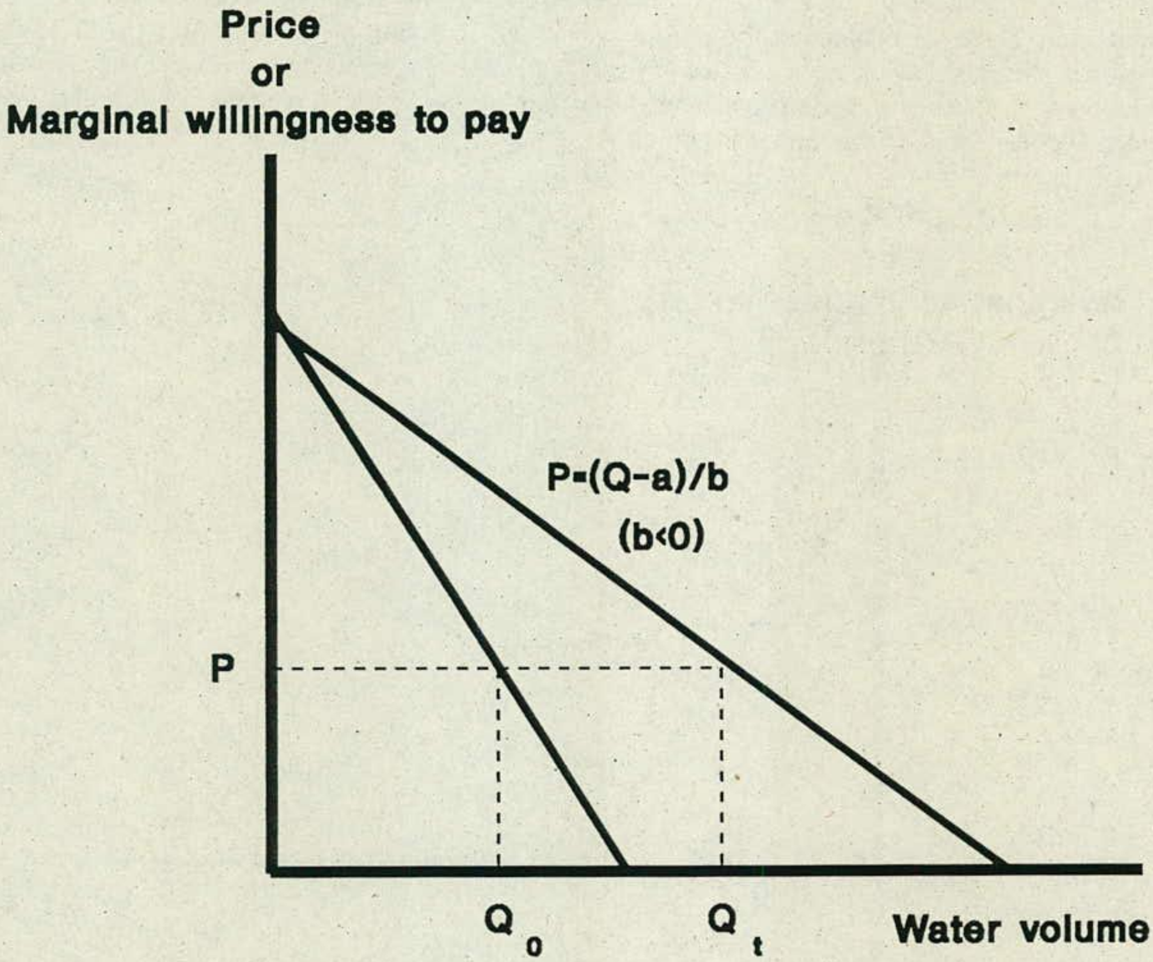

FIGURE I.4: LINEAR DEMAND FOR WATER SCHEDULE THROUGH TIME

Linear demand schedules have the advantage that they are mathematically tractable whilst serving as a first approximation to perhaps more realistic but complex schedules. They have the limitation that the absolute value of the elasticity of demand decreases as quantity demanded increases, contrary to intuition. They also imply that even if price falls to zero there is some finite demand for water.

If there is excess supply of water, the price is not driven to zero. The water has value for non-urban purposes, for irrigation, power generation and environmental services. This is allowed for in the model by using a segmented demand schedule. Let the per unit value of water in non-urban uses be P_L. The first segment consists of the demand schedule already described. However, price is not allowed to fall below P_L, no matter how high the supply quantity. The second schedule shows unlimited demand for water at a price of P_L. This is not entirely realistic, but is more realistic than a single linear demand schedule. The segmented schedule is illustrated in Figure I.5.

Modelling supply of water

It is assumed that in each year the total water available for consumption equals the water output from the Thomson catchment, plus water from other sources and any augmentation schemes, less the fixed amount from Thomson committed for environmental and irrigation purposes. The cost of water provision is calculated as the present value of the maintenance and capital costs of water supply. An operation and maintenance charge is made for each unit of water consumed. Capital costs are incurred for each augmentation scheme brought on.

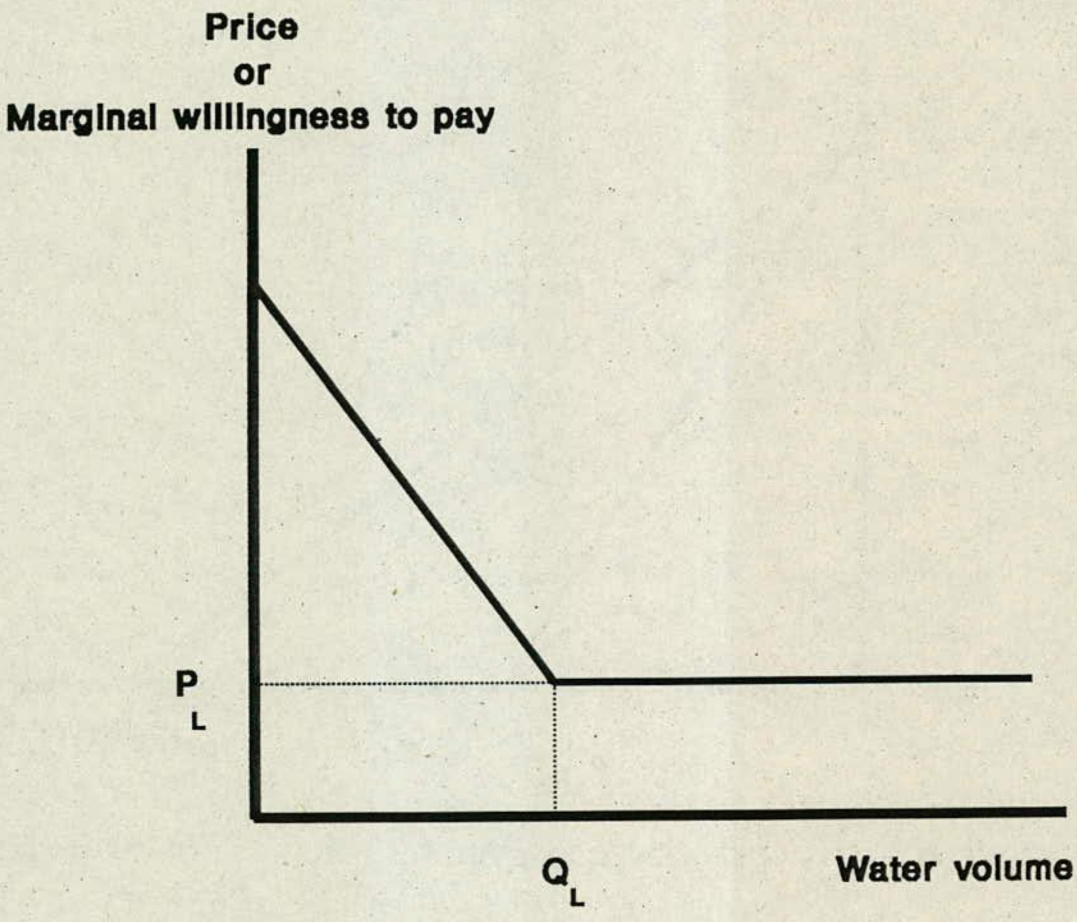

FIGURE I.5: SEGMENTED DEMAND FOR WATER SCHEDULE, WITH $P=P_L$ FOR $Q>Q_L$

In some runs of the model, allowance is made for water consumption to be less than or greater than that collected by storing water if storage capacity is not fully utilized, or releasing water from storage if available. Building up or drawing down water in storage provides the water supply system with buffering. It helps to even out the price swings which are otherwise expected to occur around the time of bringing on a new augmentation scheme. Before commissioning a new scheme, water is likely to be relatively scarce and the price of water high, and the reverse immediately after commissioning. Economic gains can be made by releasing water when the price is high, and storing water when the price falls. The very process of this arbitrage reduces the price differential through time.

Dynamic optimization

The i-th timber policy generates a stream flow $w_t\{i\}$ for all years t=1 to n. The objective is to find the combination of timber policy i, water augmentation sequence m_t, and storage sequence s_t which results in maximum present value of net social returns (Z). Net social return in year t consists of the value of water consumed, measured by consumers' willingness to pay, less the operation and maintenance costs of water supply, and less the capital cost of any new augmentation scheme introduced in year t. The quantity of water consumed in year t (q_t) consists of streamflow $w_t\{i\}$, plus water from all augmentation schemes brought on to year t, less the fixed water commitment from the catchment, and less (plus) any water withdrawal to (release from) storage.

The optimizing model can be specified as follows:

$$Z = \max \sum_{t=1}^{n} \left(WTP_t\{q_t\} - g\{q_t, m_t\} - \left(\left(\sum_{j=m_{t-1}}^{m_t} k\{j\} \right) - k\{m_{t-1}\} \right) \right) (1+r)^{1-t} \qquad (11)$$

with respect to m_t, Δs_t, i

subject to $\qquad q_t = w_t\{i\} + \sum_{j=m_0}^{m_t} c_t\{j\} - f - \Delta s_t$

$$a \geq m_t \geq m_{t-1} \qquad (\forall t)$$

$$0 \leq \Delta s_t + s_t \leq b$$

$$m_0 = 1$$

$$s_1 = \bar{s}$$

where

$WTP_t\{q_t\}$ = willingness to pay for water consumption q_t in year t

$g\{q_t, m_t\}$ = operation and maintenance costs of supplying water volume q_t given m_t

$k\{j\}$ = capital cost of j-th augmentation scheme

m_t = index of most recently introduced augmentation scheme in year t

n = number of years in the planning horizon

r = discount rate per annum

Δs_t = increase in storage in year t

$w_t\{i\}$ = streamflow from catchment for i-th timber policy

$c_t\{j\}$ = supply capacity of j-th augmentation scheme

f = fixed commitment from the catchment for environmental and irrigation purposes

s_t = water in storage at the beginning of year t

a = number of augmentation schemes

b = capacity of storage system.

The problem was solved as a numerical dynamic programming problem, using general purpose routines described in Kennedy (1986) and Kennedy (1989). The state variable spanned all combinations of augmentation scheme index and water storage. For each value of the state variable, the decision variable spanned all feasible combinations of augmentation scheme to be introduced and change in storage.

The number of years in the planning horizon was set at 200, the same horizon as for evaluating the present value of returns from timber for the eight timber options. For computational convenience the interval between decision stages was 10 years instead of one year as in the formulation of the problem above. It was assumed that each stage decision was implemented annually over ten years, with the effects of discounting and growth in water demand calculated annually.

An evaluation of the timber management options

Base case net present values for the eight management options were obtained for the base case parameters shown in Table I.4. The ex-dam price of water is based on a charge of \$600/ML to consumers after allowing for a loss factor of 14 per cent. The minimum price of water which represents demand by irrigators has been set at the ball-park estimate of \$50/ML. This corresponds to P_L in Figure I.5. Operation and maintenance costs have been set at \$25.25/ML for all sources of water supply except for water from augmentation scheme no. 1, which has been set at \$60.00/ML.

The price elasticity of demand for water has been set at -0.10. A study estimated a price elasticity of -0.11 for Perth in 1985 has been reported (MMBW, undated). However, it is clear from other estimates for Australia and other countries that -0.10 is at the bottom of the range.

The rate of growth of demand for water has been set at 1 per cent per annum. It must be emphasized that this is the growth rate for demand for water if the real price of water remains unchanged. In other words, the rate of growth corresponds to g in equation (8). Figure I.6 illustrates consumption over the next 100 years for annual growth rates of 1 and 2 per cent, starting with consumption of 524 GL in 1992. Melbourne Water (Duncan, 1991, Table 9) projections over the next 30 years, under "no demand management" and "current campaign scenarios" are also shown. The Melbourne Water projections appear to imply a growth rate closer to 2 per cent than 1 per cent. It should be noted that before the 1982-83 drought, Melbourne's water use was growing at nearly 3 per cent per year (Connelly et al., 1991, p. 17).

The supply of water to Melbourne from sources other than the Thomson catchment is taken to be 425 GL/year. The fixed commitment for hydroelectricity generation, environmental and irrigation purposes is taken to be 72 GL/year.

Melbourne Water's planned sequence for the introduction of future augmentation schemes is shown in Table I.5, together with capacities and capital costs. In running the model the year of introduction is a decision variable. The solution years of introduction may be compared with those planned by Melbourne Water. The model takes the order of introduction as given, and assumes that the capacity of each scheme is available for consumption in all future years.

Maximum net present values from water provision for each of the timber management options are shown in Tables I.6 to I.13 for base-case parameters and no storage. A legend for interpreting the tables may be found after Table I.14. For all eight options it is optimal to introduce augmentation scheme no. 1 immediately. The scheme is attractive because 100 GL/year is provided at zero capital cost, though the direct costs of water provision are \$60/ML. The price of water, or marginal willingness to pay, is driven down to \$50/ML in each of the middle years of the first few decades.

TABLE I.4: WATER DATA - BASE CASE

Annual rate of interest (%)	4
Current water consumption	524 GL/Year
Current price of water	\$530.00/ML
Irrigation price of water	\$50.00/ML
Cost of water supply (from all sources except scheme 1)	\$25.25/ML
Cost of water supply (from scheme 1)	\$60.00/ML
Elasticity of demand for water	-0.1
Annual growth rate in water demand	1.0
Other supply	425 GL/Year
Fixed amount diverted from Thomson	72 GL/Year

TABLE I.5: WATER AUGMENTATION SCHEMES

Scheme No.	Capacity (GL)	Capital cost ($m)	Year of planned introduction[a]
1	100	0	1992
2	80	110	2010
3	68	160	2019
4	28	140	2028
5	52	260	2032
6	97	600	2039
7	80	500	2057
8	170	1100	2075

[a] Melbourne Water

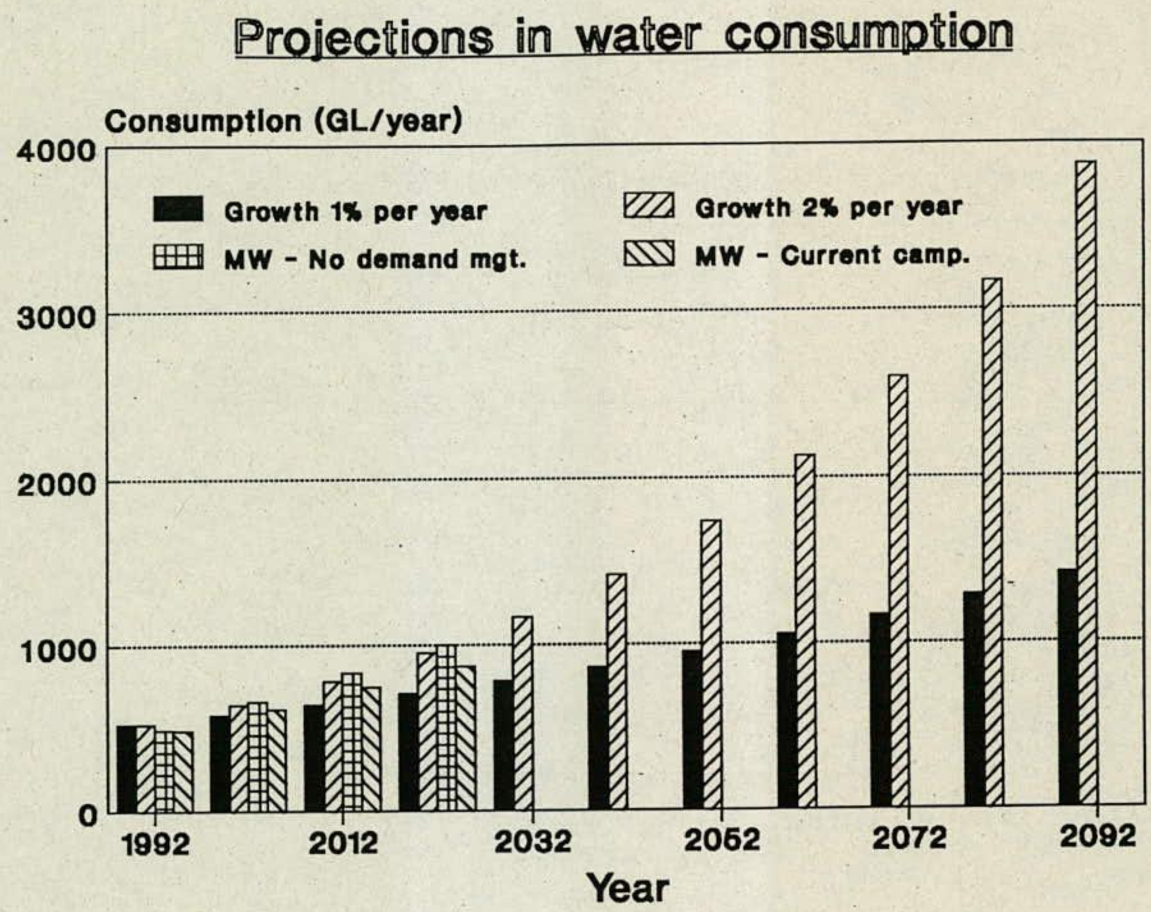

FIGURE I.6: PROJECTIONS IN WATER CONSUMPTION

All augmentation schemes are installed within 80 years for all eight options. Thereafter, the mid-decade price rises rapidly as water becomes relatively scarce with no further augmentation opportunities. In fact there are many further augmentation schemes which would be feasible (see, e.g., Chapman et al., 1991, Ch. 10). For a 200-year planning horizon, other schemes beyond those listed in Table I.5 should be considered. However, the error in ignoring further schemes is probably not great because the impact of net returns after 80 years is relatively slight after discounting at a rate of interest of 4 per cent per annum.

Table I.14 shows the solution for the extended problem for timber option 3 (80-year rotation, status quo), allowing for storage or release of water at each decision stage. In this run the maximum storage capacity is 1000 GL. This approximates the 951 GL of live storage estimated for the Thomson catchment, but does allow for some buffering. Release and storage levels are at 25 GL/year intervals. The model could be run for a finer grid of release and storage levels, but only with a substantial increase in computing time.

Comparing Tables I.14 and I.8 for the 80-year rotation option, if storage capacity of 1000 GL is available, additions to storage (negative releases) occur until storage capacity is reached in the year 2031. Over the next two decades releases occur. The time profile of water price is considerably smoothed with storage. Some augmentation schemes are introduced 10 years earlier. However, the net present value with storage is little higher than without storage - \$57,393 versus \$57,370. This difference would be even less if there were costs for storing and releasing water. Because the difference is small, it was decided to compare net present values for the eight timber options without storage.

The net present value contributions from timber and water for the eight options for base-case parameters are presented in Table I.15, and summarized as a bar chart in Figure I.7. The 80-year rotation option (no. 3) gives the highest timber net present value and one of the lowest water net present values. Overall, it ranks second to the big strip option. Tables I.17 and I.18, and Figures I.9 and I.10 show that for an increase in absolute elasticity of demand for water from -0.1 to -0.2, and (separately) a reduction in the initial price of water from \$530/ML to \$260/ML, returns relative to the 80-year rotation option in general worsen. However, there is a dramatic turnaround if the rate of growth in demand for water is changed from 1 to 1.5 per cent per annum. As shown in Table I.18 and Figure I.7, all options except the 40-year rotation dominate the 80-year rotation. No logging comes out best.

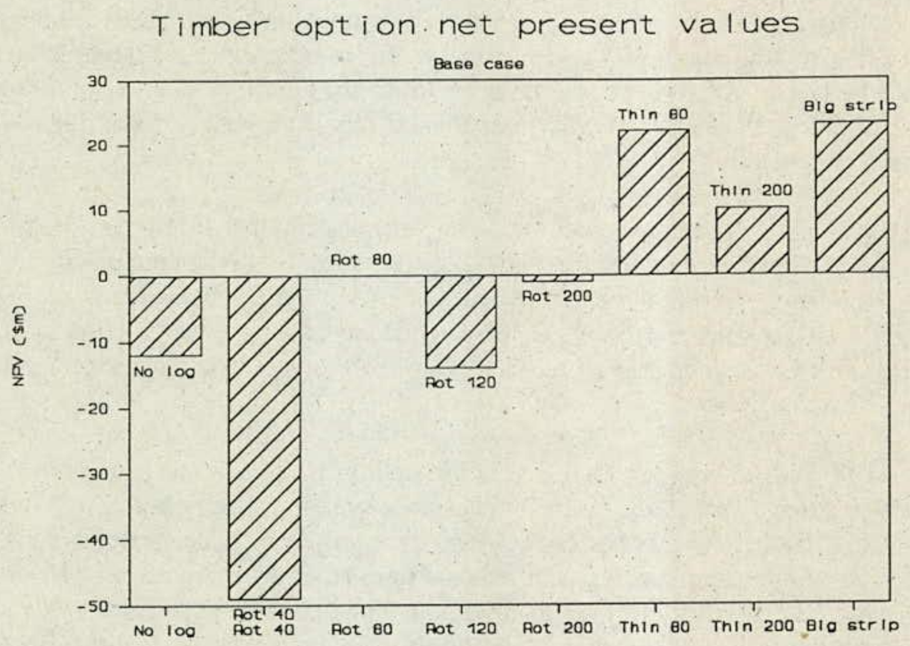

FIGURE I.7: BASE CASE

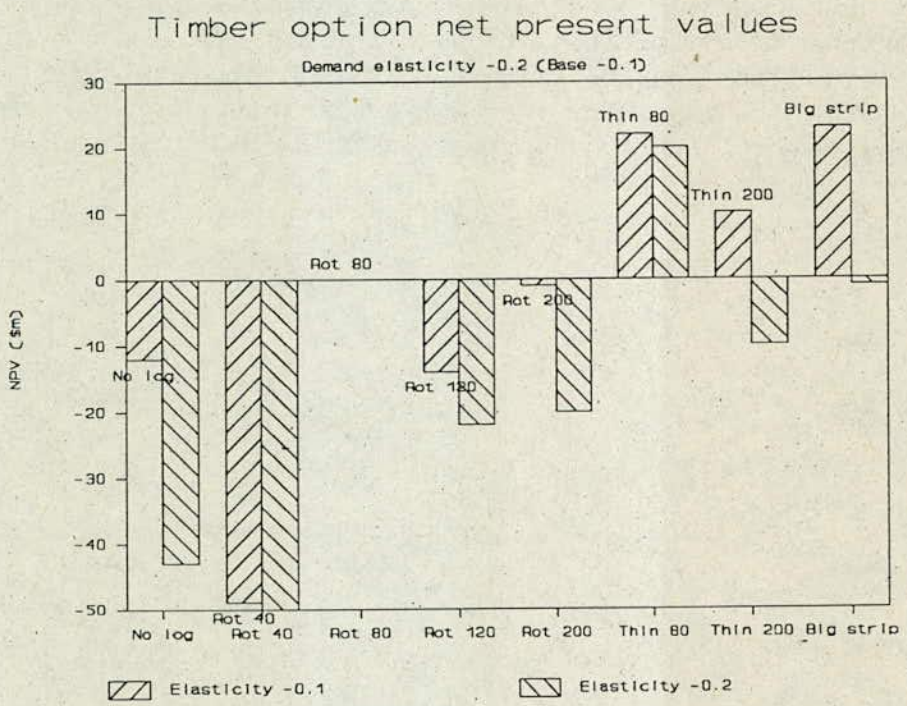

FIGURE I.8: ELASTICITY OF DEMAND FOR WATER -0.2

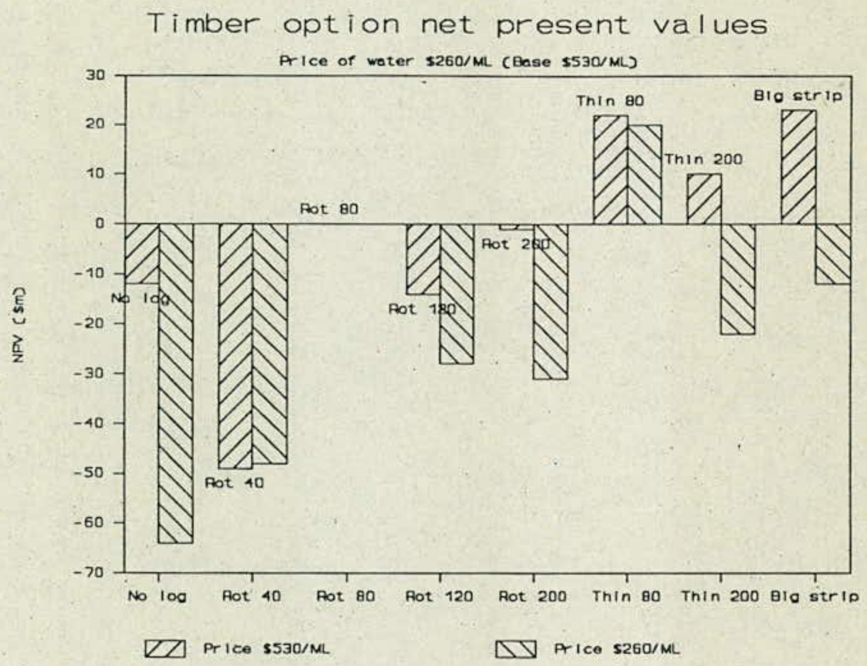

FIGURE I.9: PRICE OF WATER $260/ML

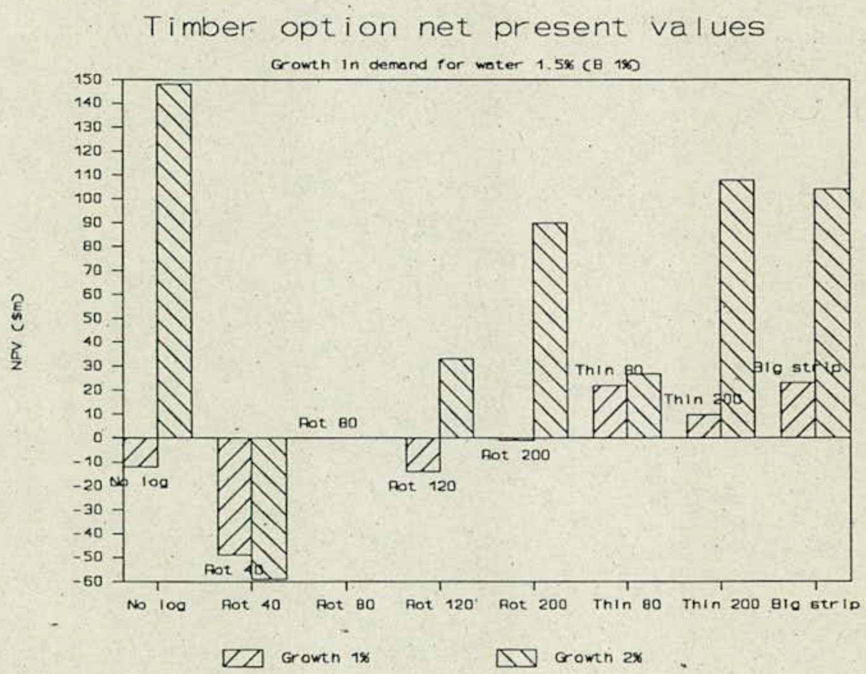

FIGURE I.10: GROWTH IN DEMAND FOR WATER 1.5% PER ANNUM

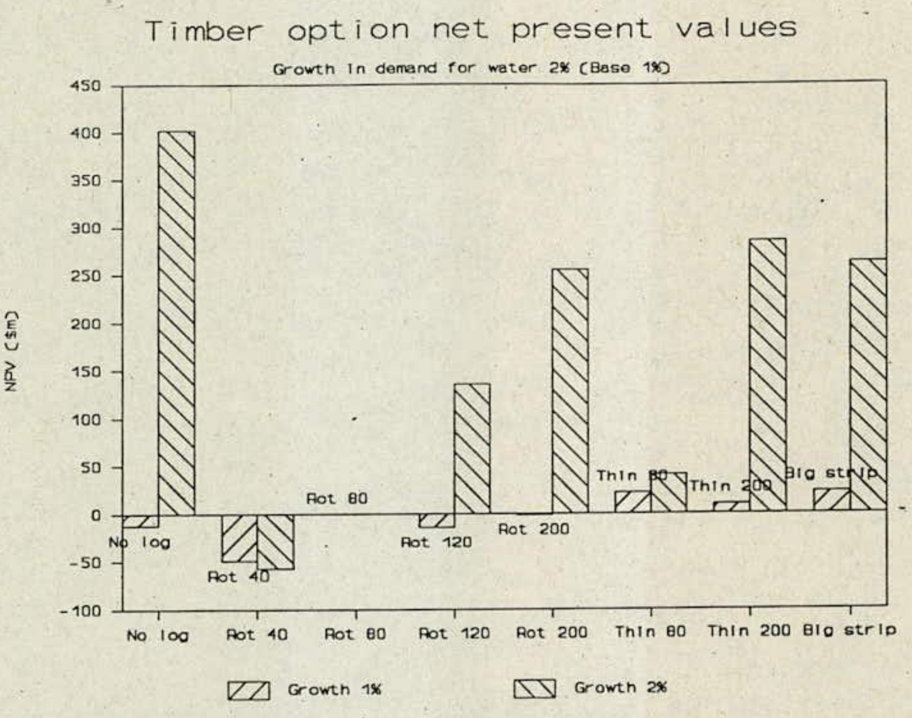

FIGURE I.11: GROWTH IN DEMAND FOR WATER 2% PER ANNUM

TABLE I.6: OPTIMAL AUGMENTATION SEQUENCING FOR TIMBER POLICY: CEASE LOGGING NOW

Base case

YEAR	INITIAL CAP/STOR	OPTIMAL INV/REL	SUPPLY OTHER GL/10Y	SUPPLY CATCH. GL/10Y	SUPPLY REL. GL/10Y	SUPPLY TOTAL GL/10Y	WATER PRICE $/ML	INV. COST $M	DISC. RETURN $M
1992	C0/S_0	I1/R+_0	4528	2381	0	6909	50	0	14823
2002	C1/S_0	I0/R+_0	4528	2470	0	6998	50	0	11049
2012	C1/S_0	I1/R+_0	5328	2558	0	7886	50	110	8202
2022	C2/S_0	I0/R+_0	5328	2639	0	7967	94	0	6147
2032	C2/S_0	I1/R+_0	6008	2708	0	8716	152	160	4554
2042	C3/S_0	I2/R+_0	6808	2765	0	9573	187	400	3367
2052	C5/S_0	I1/R+_0	7778	2810	0	10588	183	600	2499
2062	C6/S_0	I1/R+_0	8578	2845	0	11423	317	500	1872
2072	C7/S_0	I1/R+_0	10278	2872	0	13150	88	1100	1378
2082	C8/S_0	I0/R+_0	10278	2892	0	13170	626	0	1052
2092	C8/S_0	I0/R+_0	10278	2907	0	13185	1116	0	766
2102	C8/S_0	I0/R+_0	10278	2919	0	13197	1561	0	551
2112	C8/S_0	I0/R+_0	10278	2927	0	13205	1965	0	393
2122	C8/S_0	I0/R+_0	10278	2933	0	13211	2331	0	278
2132	C8/S_0	I0/R+_0	10278	2937	0	13215	2663	0	195
2142	C8/S_0	I0/R+_0	10278	2940	0	13218	2964	0	137
2152	C8/S_0	I0/R+_0	10278	2942	0	13220	3236	0	95
2162	C8/S_0	I0/R+_0	10278	2944	0	13222	3483	0	66
2172	C8/S_0	I0/R+_0	10278	2945	0	13223	3706	0	46
2182	C8/S_0	I0/R+_0	10278	2946	0	13224	3908	0	32
					TOTAL NET PRESENT VALUE				57500

TABLE I.7: OPTIMAL AUGMENTATION SEQUENCING FOR TIMBER POLICY: 40 YEAR ROTATION (ALL PULPWOOD)

Base case

YEAR	INITIAL CAP/STOR	OPTIMAL INV/REL	SUPPLY OTHER GL/10Y	SUPPLY CATCH. GL/10Y	SUPPLY REL. GL/10Y	SUPPLY TOTAL GL/10Y	WATER PRICE $/ML	INV. COST $M	DISC. RETURN $M
1992	C0/S_0	I1/R+_0	4528	2464	0	6992	50	0	14826
2002	C1/S_0	I0/R+_0	4528	2465	0	6993	50	0	11048
2012	C1/S_0	I1/R+_0	5328	2401	0	7729	50	110	8199
2022	C2/S_0	I1/R+_0	6008	2304	0	8312	50	160	6106
2032	C3/S_0	I1/R+_0	6288	2303	0	8591	234	140	4553
2042	C4/S_0	I1/R+_0	6808	2311	0	9119	455	260	3369
2052	C5/S_0	I2/R+_0	8578	2324	0	10902	50	1100	2455
2062	C7/S_0	I0/R+_0	8578	2337	0	10915	562	0	1892
2072	C7/S_0	I1/R+_0	10278	2350	0	12628	316	1100	1374
2082	C8/S_0	I0/R+_0	10278	2361	0	12639	836	0	1043
2092	C8/S_0	I0/R+_0	10278	2369	0	12647	1309	0	755
2102	C8/S_0	I0/R+_0	10278	2376	0	12654	1737	0	541
2112	C8/S_0	I0/R+_0	10278	2380	0	12658	2125	0	384
2122	C8/S_0	I0/R+_0	10278	2377	0	12655	2478	0	271
2132	C8/S_0	I0/R+_0	10278	2371	0	12649	2799	0	190
2142	C8/S_0	I0/R+_0	10278	2364	0	12642	3089	0	133
2152	C8/S_0	I0/R+_0	10278	2357	0	12635	3351	0	92
2162	C8/S_0	I0/R+_0	10278	2351	0	12629	3588	0	64
2172	C8/S_0	I0/R+_0	10278	2346	0	12624	3802	0	44
2182	C8/S_0	I0/R+_0	10278	2342	0	12620	3996	0	30
				TOTAL NET PRESENT VALUE					57369

TABLE I.8: OPTIMAL AUGMENTATION SEQUENCING FOR TIMBER POLICY: 80 YEAR ROTATION

Base case

YEAR	INITIAL CAP/STOR	OPTIMAL INV/REL	SUPPLY OTHER GL/10Y	SUPPLY CATCH. GL/10Y	SUPPLY REL. GL/10Y	SUPPLY TOTAL GL/10Y	WATER PRICE $/ML	INV. COST $M	DISC. RETURN $M
1992	C0/S_0	I1/R+_0	4528	2422	0	6950	50	0	14824
2002	C1/S_0	I0/R+_0	4528	2438	0	6966	50	0	11048
2012	C1/S_0	I1/R+_0	5328	2398	0	7726	50	110	8199
2022	C2/S_0	I1/R+_0	6008	2340	0	8348	50	160	6107
2032	C3/S_0	I1/R+_0	6288	2292	0	8580	241	140	4553
2042	C4/S_0	I1/R+_0	6808	2285	0	9093	470	260	3367
2052	C5/S_0	I2/R+_0	8578	2310	0	10888	50	1100	2455
2062	C7/S_0	I0/R+_0	8578	2353	0	10931	555	0	1893
2072	C7/S_0	I1/R+_0	10278	2381	0	12659	302	1100	1375
2082	C8/S_0	I0/R+_0	10278	2398	0	12676	822	0	1043
2092	C8/S_0	I0/R+_0	10278	2410	0	12688	1294	0	755
2102	C8/S_0	I0/R+_0	10278	2415	0	12693	1724	0	541
2112	C8/S_0	I0/R+_0	10278	2415	0	12693	2115	0	385
2122	C8/S_0	I0/R+_0	10278	2413	0	12691	2469	0	271
2132	C8/S_0	I0/R+_0	10278	2405	0	12683	2791	0	190
2142	C8/S_0	I0/R+_0	10278	2397	0	12675	3082	0	133
2152	C8/S_0	I0/R+_0	10278	2388	0	12666	3345	0	92
2162	C8/S_0	I0/R+_0	10278	2378	0	12656	3583	0	64
2172	C8/S_0	I0/R+_0	10278	2370	0	12648	3798	0	44
2182	C8/S_0	I0/R+_0	10278	2363	0	12641	3993	0	30
				TOTAL NET PRESENT VALUE					57370

TABLE I.9: OPTIMAL AUGMENTATION SEQUENCING FOR TIMBER POLICY: 120 YEAR ROTATION

Base case

YEAR	INITIAL CAP/STOR	OPTIMAL INV/REL	SUPPLY OTHER GL/10Y	SUPPLY CATCH. GL/10Y	SUPPLY REL. GL/10Y	SUPPLY TOTAL GL/10Y	WATER PRICE $/ML	INV. COST $M	DISC. RETURN $M
1992	C0/S_0	I1/R+_0	4528	2399	0	6927	50	0	14823
2002	C1/S_0	I0/R+_0	4528	2456	0	6984	50	0	11048
2012	C1/S_0	I1/R+_0	5328	2490	0	7818	50	110	8200
2022	C2/S_0	I1/R+_0	6008	2511	0	8519	50	160	6109
2032	C3/S_0	I1/R+_0	6288	2522	0	8810	91	140	4560
2042	C4/S_0	I1/R+_0	6808	2527	0	9335	328	260	3379
2052	C5/S_0	I1/R+_0	7778	2526	0	10304	335	600	2493
2062	C6/S_0	I1/R+_0	8578	2520	0	11098	474	500	1865
2072	C7/S_0	I1/R+_0	10278	2513	0	12791	245	1100	1376
2082	C8/S_0	I0/R+_0	10278	2504	0	12782	780	0	1045
2092	C8/S_0	I0/R+_0	10278	2497	0	12775	1263	0	757
2102	C8/S_0	I0/R+_0	10278	2490	0	12768	1700	0	543
2112	C8/S_0	I0/R+_0	10278	2490	0	12768	2093	0	386
2122	C8/S_0	I0/R+_0	10278	2490	0	12768	2448	0	272
2132	C8/S_0	I0/R+_0	10278	2490	0	12768	2770	0	191
2142	C8/S_0	I0/R+_0	10278	2489	0	12767	3062	0	133
2152	C8/S_0	I0/R+_0	10278	2489	0	12767	3325	0	93
2162	C8/S_0	I0/R+_0	10278	2489	0	12767	3563	0	64
2172	C8/S_0	I0/R+_0	10278	2489	0	12767	3779	0	44
2182	C8/S_0	I0/R+_0	10278	2489	0	12767	3974	0	31
				TOTAL NET PRESENT VALUE					57415

TABLE I.10: OPTIMAL AUGMENTATION SEQUENCING FOR TIMBER POLICY: 200 YEAR ROTATION

Base case

YEAR	INITIAL CAP/STOR	OPTIMAL INV/REL	SUPPLY OTHER GL/10Y	SUPPLY CATCH. GL/10Y	SUPPLY REL. GL/10Y	SUPPLY TOTAL GL/10Y	WATER PRICE $/ML	INV. COST $M	DISC. RETURN $M
1992	C0/S_0	I1/R+_0	4528	2392	0	6920	50	0	14823
2002	C1/S_0	I0/R+_0	4528	2461	0	6989	50	0	11048
2012	C1/S_0	I1/R+_0	5328	2517	0	7845	50	110	8201
2022	C2/S_0	I0/R+_0	5328	2562	0	7890	150	0	6144
2032	C2/S_0	I1/R+_0	6008	2597	0	8605	225	160	4549
2042	C3/S_0	I2/R+_0	6808	2622	0	9430	272	400	3363
2052	C5/S_0	I1/R+_0	7778	2641	0	10419	273	600	2496
2062	C6/S_0	I1/R+_0	8578	2652	0	11230	411	500	1868
2072	C7/S_0	I1/R+_0	10278	2658	0	12936	182	1100	1377
2082	C8/S_0	I0/R+_0	10278	2661	0	12939	718	0	1048
2092	C8/S_0	I0/R+_0	10278	2662	0	12940	1204	0	761
2102	C8/S_0	I0/R+_0	10278	2663	0	12941	1644	0	546
2112	C8/S_0	I0/R+_0	10278	2663	0	12941	2042	0	389
2122	C8/S_0	I0/R+_0	10278	2662	0	12940	2403	0	274
2132	C8/S_0	I0/R+_0	10278	2662	0	12940	2729	0	193
2142	C8/S_0	I0/R+_0	10278	2661	0	12939	3024	0	135
2152	C8/S_0	I0/R+_0	10278	2661	0	12939	3291	0	94
2162	C8/S_0	I0/R+_0	10278	2660	0	12938	3533	0	65
2172	C8/S_0	I0/R+_0	10278	2660	0	12938	3752	0	45
2182	C8/S_0	I0/R+_0	10278	2660	0	12938	3950	0	31
						TOTAL NET PRESENT VALUE			57450

TABLE I.11: OPTIMAL AUGMENTATION SEQUENCING FOR TIMBER POLICY: 80 YEAR COMBINATION THINNING ROTATION

Base case

YEAR	INITIAL CAP/STOR	OPTIMAL INV/REL	SUPPLY OTHER GL/10Y	SUPPLY CATCH. GL/10Y	SUPPLY REL. GL/10Y	SUPPLY TOTAL GL/10Y	WATER PRICE $/ML	INV. COST $M	DISC. RETURN $M
1992	C0/S_0	I1/R+_0	4528	2502	0	7030	50	0	14828
2002	C1/S_0	I0/R+_0	4528	2438	0	6966	50	0	11048
2012	C1/S_0	I1/R+_0	5328	2422	0	7750	50	110	8199
2022	C2/S_0	I1/R+_0	6008	2343	0	8351	50	160	6107
2032	C3/S_0	I1/R+_0	6288	2292	0	8580	241	140	4553
2042	C4/S_0	I1/R+_0	6808	2333	0	9141	442	260	3370
2052	C5/S_0	I2/R+_0	8578	2342	0	10920	50	1100	2455
2062	C7/S_0	I0/R+_0	8578	2377	0	10955	543	0	1893
2072	C7/S_0	I1/R+_0	10278	2381	0	12659	302	1100	1375
2082	C8/S_0	I0/R+_0	10278	2398	0	12676	822	0	1043
2092	C8/S_0	I0/R+_0	10278	2434	0	12712	1286	0	756
2102	C8/S_0	I0/R+_0	10278	2418	0	12696	1723	0	541
2112	C8/S_0	I0/R+_0	10278	2415	0	12693	2115	0	385
2122	C8/S_0	I0/R+_0	10278	2460	0	12738	2456	0	272
2132	C8/S_0	I0/R+_0	10278	2436	0	12714	2783	0	191
2142	C8/S_0	I0/R+_0	10278	2422	0	12700	3076	0	133
2152	C8/S_0	I0/R+_0	10278	2388	0	12666	3345	0	92
2162	C8/S_0	I0/R+_0	10278	2378	0	12656	3583	0	64
2172	C8/S_0	I0/R+_0	10278	2393	0	12671	3795	0	44
2182	C8/S_0	I0/R+_0	10278	2366	0	12644	3992	0	30
					TOTAL NET PRESENT VALUE				57379

TABLE I.12: OPTIMAL AUGMENTATION SEQUENCING FOR TIMBER POLICY: 200 YEAR COMBINATION THINNING ROTATION

Base case

YEAR	INITIAL CAP/STOR	OPTIMAL INV/REL	SUPPLY OTHER GL/10Y	SUPPLY CATCH. GL/10Y	SUPPLY REL. GL/10Y	SUPPLY TOTAL GL/10Y	WATER PRICE $/ML	INV. COST $M	DISC. RETURN $M
1992	C0/S_0	I1/R+_0	4528	2474	0	7002	50	0	14827
2002	C1/S_0	I0/R+_0	4528	2461	0	6989	50	0	11048
2012	C1/S_0	I1/R+_0	5328	2524	0	7852	50	110	8201
2022	C2/S_0	I0/R+_0	5328	2570	0	7898	144	0	6144
2032	C2/S_0	I1/R+_0	6008	2605	0	8613	219	160	4550
2042	C3/S_0	I2/R+_0	6808	2640	0	9448	261	400	3363
2052	C5/S_0	I1/R+_0	7778	2666	0	10444	260	600	2496
2062	C6/S_0	I1/R+_0	8578	2684	0	11262	395	500	1869
2072	C7/S_0	I1/R+_0	10278	2684	0	12962	170	1100	1377
2082	C8/S_0	I0/R+_0	10278	2681	0	12959	710	0	1049
2092	C8/S_0	I0/R+_0	10278	2678	0	12956	1198	0	761
2102	C8/S_0	I0/R+_0	10278	2675	0	12953	1640	0	546
2112	C8/S_0	I0/R+_0	10278	2671	0	12949	2040	0	389
2122	C8/S_0	I0/R+_0	10278	2669	0	12947	2401	0	275
2132	C8/S_0	I0/R+_0	10278	2666	0	12944	2728	0	193
2142	C8/S_0	I0/R+_0	10278	2665	0	12943	3024	0	135
2152	C8/S_0	I0/R+_0	10278	2663	0	12941	3291	0	94
2162	C8/S_0	I0/R+_0	10278	2662	0	12940	3533	0	65
2172	C8/S_0	I0/R+_0	10278	2661	0	12939	3752	0	45
2182	C8/S_0	I0/R+_0	10278	2661	0	12939	3949	0	31
				TOTAL NET PRESENT VALUE					57457

TABLE I.13: OPTIMAL AUGMENTATION SEQUENCING FOR TIMBER POLICY: 200 YEAR CORRIDOR THINNING ROTATION

Base case

YEAR	INITIAL CAP/STOR	OPTIMAL INV/REL	SUPPLY OTHER GL/10Y	SUPPLY CATCH. GL/10Y	SUPPLY REL. GL/10Y	SUPPLY TOTAL GL/10Y	WATER PRICE $/ML	INV. COST $M	DISC. RETURN $M
1992	C0/S_0	I1/R+_0	4528	2451	0	6979	50	0	14826
2002	C1/S_0	I0/R+_0	4528	2531	0	7059	50	0	11050
2012	C1/S_0	I1/R+_0	5328	2574	0	7902	50	110	8202
2022	C2/S_0	I0/R+_0	5328	2565	0	7893	147	0	6144
2032	C2/S_0	I1/R+_0	6008	2580	0	8588	236	160	4549
2042	C3/S_0	I2/R+_0	6808	2598	0	9406	286	400	3362
2052	C5/S_0	I1/R+_0	7778	2616	0	10394	287	600	2495
2062	C6/S_0	I1/R+_0	8578	2629	0	11207	422	500	1868
2072	C7/S_0	I1/R+_0	10278	2638	0	12916	190	1100	1377
2082	C8/S_0	I0/R+_0	10278	2645	0	12923	724	0	1048
2092	C8/S_0	I0/R+_0	10278	2650	0	12928	1208	0	761
2102	C8/S_0	I0/R+_0	10278	2653	0	12931	1647	0	546
2112	C8/S_0	I0/R+_0	10278	2658	0	12936	2044	0	388
2122	C8/S_0	I0/R+_0	10278	2661	0	12939	2403	0	274
2132	C8/S_0	I0/R+_0	10278	2663	0	12941	2729	0	193
2142	C8/S_0	I0/R+_0	10278	2664	0	12942	3024	0	135
2152	C8/S_0	I0/R+_0	10278	2665	0	12943	3291	0	94
2162	C8/S_0	I0/R+_0	10278	2665	0	12943	3532	0	65
2172	C8/S_0	I0/R+_0	10278	2665	0	12943	3751	0	45
2182	C8/S_0	I0/R+_0	10278	2665	0	12943	3949	0	31
						TOTAL NET PRESENT VALUE			57452

TABLE I.14: OPTIMAL AUGMENTATION SEQUENCING FOR TIMBER POLICY: 80 YEAR ROTATION

Up to 1000 GL storage possible - Base case

YEAR	INITIAL CAP/STOR	OPTIMAL INV/REL	SUPPLY OTHER GL/10Y	SUPPLY CATCH. GL/10Y	SUPPLY REL. GL/10Y	SUPPLY TOTAL GL/10Y	WATER PRICE $/ML	INV. COST $M	DISC. RETURN $M
1992	C0/S_0	I1/R+_0	4528	2422	0	6950	50	0	14824
2002	C1/S_0	I1/R-_50	5328	2438	-500	7266	50	110	10982
2012	C2/S_50	I0/R-_25	5328	2398	-250	7476	50	0	8244
2022	C2/S_75	I1/R-_25	6008	2340	-250	8098	50	160	6102
2032	C3/S100	I0/R+_50	6008	2292	500	8800	98	0	4589
2042	C3/S_50	I2/R+_50	6808	2285	500	9593	176	400	3367
2052	C5/S_0	I2/R+_0	8578	2310	0	10888	50	1100	2455
2062	C7/S_0	I1/R-100	10278	2353	-1000	11631	217	1100	1837
2072	C8/S100	I0/R+_0	10278	2381	0	12659	302	0	1422
2082	C8/S100	I0/R+_25	10278	2398	250	12926	723	0	1048
2092	C8/S_75	I0/R+_50	10278	2410	500	13188	1115	0	766
2102	C8/S_25	I0/R+_25	10278	2415	250	12943	1643	0	546
2112	C8/S_0	I0/R+_0	10278	2415	0	12693	2115	0	385
2122	C8/S_0	I0/R+_0	10278	2413	0	12691	2469	0	271
2132	C8/S_0	I0/R+_0	10278	2405	0	12683	2791	0	190
2142	C8/S_0	I0/R+_0	10278	2397	0	12675	3082	0	133
2152	C8/S_0	I0/R+_0	10278	2388	0	12666	3345	0	92
2162	C8/S_0	I0/R+_0	10278	2378	0	12656	3583	0	64
2172	C8/S_0	I0/R+_0	10278	2370	0	12648	3798	0	44
2182	C8/S_0	I0/R+_0	10278	2363	0	12641	3993	0	30
					TOTAL NET PRESENT VALUE				57393

LEGEND FOR TABLES I.6 TO I.14

CAP/STOR	- capacity/storage levels (state variable label)
Cn/S_x	- augmentation scheme no. n/water storage level x (10^{-1} GL)
INV/REL	- investment in capacity/release levels (decision variable label)
In/R_d	- augmentation level n/release from storage level d (10^{-1} GL)
REL.	- release from storage
WATER PRICE	- the price of water in the fifth year of the decade starting in the year shown
INV. COST	- cost of investment in capacity
DISC. RETURN	- discounted net return

TABLE I.15: TIMBER OPTION NET PRESENT VALUES

Base case

	PV timber $m	PV water $m	NPV $m	NPV-ROT80 $m
No log	-60	57500	57440	-12
Rot 40	34	57369	57403	-49
Rot 80	82	57370	57452	0
Rot 120	23	57415	57438	-14
Rot 200	1	57450	57451	-1
Thin 80	95	57379	57474	22
Thin 200	5	57457	57462	10
Big strip	16	57452	57468	16

TABLE I.16: TIMBER OPTION NET PRESENT VALUES

Elasticity -0.2

	PV timber $m	PV water $m	NPV $m	NPV-ROT80 $m
No log	-60	33885	33825	-43
Rot 40	34	33784	33818	-50
Rot 80	82	33786	33868	0
Rot 120	23	33823	33846	-22
Rot 200	1	33847	33848	-20
Thin 80	95	33793	33888	20
Thin 200	5	33853	33858	-10
Big strip	16	33851	33867	-1

TABLE I.17: TIMBER OPTION NET PRESENT VALUES

Price of water $260/ML

	PV timber $m	PV water $m	NPV $m	NPV-ROT80 $m
No log	-60	28104	28044	-64
Rot 40	34	28026	28060	-48
Rot 80	82	28026	28108	0
Rot 120	23	28057	28080	-28
Rot 200	1	28076	28077	-31
Thin 80	95	28033	28128	20
Thin 200	5	28081	28086	-22
Big strip	16	28080	28096	-12

TABLE I.18: TIMBER OPTION NET PRESENT VALUES

Growth 1.5%

	PV timber $m	PV water $m	NPV $m	NPV-ROT80 $m
No log	-60	65663	65603	148
Rot 40	34	65362	65396	-59
Rot 80	82	65373	65455	0
Rot 120	23	65465	65488	33
Rot 200	1	65544	65545	90
Thin 80	95	65387	65482	27
Thin 200	5	65558	65563	108
Big strip	16	65543	65559	104

TABLE I.19: TIMBER OPTION NET PRESENT VALUES

Growth 2%

	PV timber $m	PV water $m	NPV $m	NPV-ROT80 $m
No log	-60	73618	73558	402
Rot 40	34	73065	73099	-57
Rot 80	82	73074	73156	0
Rot 120	23	73269	73292	136
Rot 200	1	73410	73411	255
Thin 80	95	73102	73197	41
Thin 200	5	73435	73440	284
Big strip	16	73402	73418	262

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