An Economic Analysis Of Multiple Use Management Of Mountain Ash Forests In Victoria For Timber And Water Harvesting

D.C.Galapitage*

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1 Introduction

The Melbourne and Metropolitan Board of Works (MMBW) harvests about 90 percent of its water requirements from the catchments in the Central Highlands of Victoria to the north and east of Melbourne (O'Shaughnessy 1986). By 1979 the area covered by these catchments was 121,000 ha including buffer areas. Of this area 119,000 ha are forested and cover approximately 3 per cent of the productive publicly owned forest in Victoria. Approximately 64,000 ha or 53 per cent of this catchment area is covered by ash type forests, mainly mountain ash. This comprises approximately 10 per cent of the State's ash type forests (MMBW 1980). About 20 percent of these stands is over 150 years old while the remainder has regenerated after the 1939 fire (O'Shaughnessy 1986).

These catchment areas are densely forested and the MMBW maintains a policy of managing them solely for water supply purposes. They have first class potential as timber producing areas and are well stocked with mature and re-growth timber of high stumpage value. Over the years several attempts have been made by the timber industry and related interest groups to get access for logging in these catchments (Lawrence et al., 1961). The Board has successfully resisted these attempts and still maintains the policy of managing

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these catchments solely for water supply purposes (Greig 1981).

However, the timber industry in Victoria views this single purpose management of catchment areas as an under utilization of a valuable resource. The availability of good quality hardwood timber in other parts of the State is declining. The stands available in catchment areas have a very high resource value as they are situated close to the main market in Melbourne. The catchments are situated about 50 to 100 kilometers away from the city of Melbourne.

The representations from interest groups seeking access for logging in the water catchments became a significant issue for the government and the MMBW to deal with over the years. Because of the mounting pressure the Board expanded its catchment hydrology research activities to investigate the effects of logging on water quality and streamflow yield in the Maroondah catchment. The technical conclusions released in 1979 indicated that the logging operations can be carried out without significantly affecting the quality of water, if logging is done under strict control (MMBW 1980). However, the streamflow yield will increase immediately after harvesting and then begin to decline a few years after regeneration. The streamflow yield will reach its lowest at about 25 years after harvesting and then will gradually recover.

The economics of multiple use management for water and timber harvesting has been analysed in America for pine species forests (Black 1963, Calish et al., 1978 and Bowes et al., 1984), and in Australia for Mountain Ash forests (Greig 1981). Calish et al., estimate the optimal rotation age for the stands under multiple use while Bowes et al., estimate the optimal rotation age and then derive a management plan for the catchment. These two analyses are based on infinite rotations while the study by Black which describes a few management plans for a catchment is based on a single rotation. The Australian study derives management plans for the Maroondah catchment without considering the optimal rotation age for the Mountain Ash species under multiple use management. It also has the weakness of incorrect treatment of future returns and seems to be based on the infamous forest rent model (Gregory 1972).

Because of the current social consciousness on conservation, multiple use management has become important more than ever and it has become necessary to have correct evaluations of economic issues related to the multiple use management of public forests. This study evaluates the economic aspects of opening the Maroondah catchment for timber harvesting in addition to its current use of water harvesting. The specific objectives of the study are to:

1. Develop a model to derive optimal management plans for Maroondah catchment under multiple use management.

2. Evaluate the economic effects of various policy and social constraints on logging.

3. Analyse the economic effects of long-rotation periods as a conservation strategy.

Section 2 of this paper contains a description of some relevant characteristics of the Maroondah catchment. In section 3 the theoretical background of the study is reviewed. This is followed by the description of the methodology and the model used in the study. The results and analysis are then presented.

2 Some characteristics of the Maroondah catchment

The catchment basically consists of two major forest types. They are Ash type forests and the mixed species forests. The current analysis is concerned with the multiple use management of Mountain Ash stands in the catchment. Table 1 shows the total area of Mountain Ash forest and the areas identified as suitable for harvesting in the Maroondah catchment. They comprise four age strata which include over mature stands, mature stands and relatively young re-growth stands which were regenerated after the forest fires in 1926 and 1939.

Some of the Mountain Ash forest in the catchment is not identified as suitable for timber production due to following reasons.

1. The slope of the land. Land with a slope greater than 25^0 is excluded due to soil erosion effects on water quality.

2. Some areas are excluded for reasons relating to water supply and stream protection, scientific and reference areas, recreation and ridge-line protection.

3. Some areas have been identified as unsuitable for harvesting in order to protect the landscape values and the scenic beauty in the region.

As shown in table 1 about half the Mountain Ash forest area is unavailable for timber production under these constraints.

3 Efficient management and sustained yield

Two of the basic management problems a forest manager encounters are when the growing forest stand should be harvested and how the harvesting of the entire forest be scheduled over time within the rotation period[1]. The solutions to these problems depend on the management objectives, and the constraints. The objective could be maximization of physical output or

[1] Rotation period is the time between planting and cutting a forest stand.

Table 1:

Area of Mountain Ash Forests In The Maroondah Catchment Identified Unsuitable For Logging Due To Various Reasons

Forest Type	Age	Unsuitable Due To Slope	Fixed Zones	Land-scape	Suit-able	Total
		ha	ha	ha	ha	ha
Over Mature	220	74	177	20	243	514
Mature	165	416	910	244	874	2,444
1926 Re-growth	64	4	107	68	51	230
1939 Re-growth	51	1,468	1,597	218	4,193	7,476
Total		1,962	2,791	550	5,361	10,664

Source: Ronan (1980)

economic returns. The optimal rotation age which maximises the objective function value under no restrictions may have to be adjusted to accommodate other constraints such as environmental restrictions or other public policies in the case of public forests and mill capacity limitations or requirements in the case of private forests. In both cases, multiple use management would become a fundamental issue.

In this paper, the forest management problem is analysed to derive optimal harvesting schedules under multiple use management when the objective is to maximize financial returns from a heterogeneous forest with a mix of ages above and below the rotation age. One of the major constraints taken into account is that the existing forest should be converted to a regulated forest and managed under a steady state management policy.

3.1 Single use forest management

The problems involved in the management of a forest are both biological and economic. From the economic point of view the forest is one form of growing capital. The fundamental economic problem is how much capital should be invested for what duration. This is known as the rotation problem in forestry. The timber volume in a stand of forest changes over time. The dynamics of forest growth involves growth of height and diameter of individual trees, and mortality and basal area growth of the whole stand over the years. The rate of growth is not constant over time. Young trees grow at a faster rate than the mature trees.

In an even-aged stand[2] the rate of growth of volume at early ages may be slow because of the high mortality of young trees. Once the stand has stabilized, the rate of growth can be maintained at a high rate. However, as the stand grows older the rate of growth declines. At some age there could be a stagnation in growth, and thereafter, due to old trees decaying, the rate of growth could become negative.

The economic problem in forestry is to determine the optimum rotation period which maximises financial returns. A variety of economic criteria are used in forest management analysis. These include present net worth, financial maturity, the site value, the internal rate of return and the forest rent. In these analyses, which are designed to obtain the optimum rotation period, the output of a timber stand is expressed as a function of age, holding other inputs constant. Other basic assumptions include perfect knowledge, constant relative prices over time and a perfect capital market.

The theoretical solution to the forest rotation problem has been in principle known since Martin Faustmann's work in 1849 (Samuelson 1976). At the optimum rotation age the growth of the value of timber must be equal to the opportunity cost of holding timber in the stand for one more year plus the opportunity cost of investment in land for the extra year. The investment in land is equal to the market value which also reflects its value in its best use. This can be found by obtaining the present value of returns to infinity given that forestry is the best use of the land.

3.2 Multiple use forest management

In the above specification of the solution, attention is given to the timber value of the forest only. In addition to the value of harvested timber a standing forest may provide goods and services such as water, wild-honey, flood control and recreation. The value of these goods and services is often excluded from the economic analysis of the forest management problem.

A theoretical model to solve this problem has been presented by Hartman (1976). Several others seem to have independently derived similar models around the same time Calish et al (1978), Bowes et al., (1984). Some others have extended or modified the model to cover wider applications of the model (Nguyen 1979, Berck 1981 and Strang 1983). Hartman's model assumes a plot of land owned by a firm facing a perfectly competitive market, and on which all trees must be clearfelled simultaneously.

The growth of the stumpage value is a function of time and has the general characteristics of growth described above. In the usual analysis, the only part of the growth range which is of economic interest is the positive part. Hartman argues that this is no longer necessarily

[2] An even-aged stand is an area of forest where all trees are of the same age.

true if the standing forest provides a flow of values. The value of the recreational and other services is assumed to be initially growing at an increasing rate which is followed by a declining but still a positive rate of growth. Hartman's theoretical analysis shows that the presence of values other than the stumpage value has an effect on increasing the rotation period and in the extreme it may not be profitable ever to harvest.

3.3 Sustained yield and regulated forest

As explained above the Faustmann-Hartman model derives the optimal rotation period for an even aged forest stand. If the age of the currently standing forest is greater than the optimal age, the forest stands should be clearfelled immediately to maximize the returns under the Faustmann-Hartman model.

The stands regenerated after harvesting the existing stand and any future stands that will be regenerated will have to be harvested at the end of their optimum rotation periods in order to maximize the site value for the entire forest. Such a management plan does not consider the need to maintain a sustained yield. It will lead to a situation where in one year of the rotation period the entire forest is clearfelled. In the rest of the years there will be no timber harvesting at all. The problems that this plan might create can be grouped under several categories.

1. Fluctuating level of economic activities; for example there will be gluts in some years in the timber market, depressing prices, and in other years there will be shortages, raising prices.

2. Over-investment in capital equipment; in the logging industry there will be a need for having a large capacity in equipment to handle heavy harvesting years. They will have to be left idle during the non-harvesting years.

3. Fluctuating employment prospects; the availability of jobs in the logging industry will be irregular. This will hinder the maintenance of an efficient labour force in the industry. Loggers will consider the jobs as part time and may not attempt to improve productivity. Mobilisation of experienced labour in sufficient numbers to handle a large-scale harvesting and regeneration may encounter great difficulties. This will lead to an increase in costs. Accompanying the reduction in price due to a glut in the markets, this will result in a decrease in net returns.

4. Another problem especially important in multiple use management is that this plan will result in fluctuations in flow of other values within the rotation cycle, for the entire forest. This may ultimately affect the value of these other services and reduce the benefits

of multiple use management.

The alternative policies are to harvest the forest over a period of several years in coupe sizes determined on some basis. The extreme of this is to harvest equal size coupes every year which will result in sustained flow of yield from future forests. Davis (1966) describes this as converting a natural forest into a regulated forests. The benefits of such a forest include a regular flow of timber output, regular financial flow to the firm, safety from fire and other dangers, maximum opportunity for multiple use and continuity of employment and other activities (Davis 1966). The regulating of forests has been criticized recently as an undesirable objective in terms of regular timber flow. The argument behind this criticism is that it does not consider the market conditions at the harvesting time. However, in multiple use it is desirable specially in terms of regular flow of water and diversity of forest for recreation purposes.

3.4 Optimum harvesting schedules for a forest

Techniques such as dynamic programming, Markov process and optimal control theory which are proposed to determine optimal management schedules have not been used in applications due to unrealistic simplifications or the cost of setting up and solving the model. The application of programming techniques in forest management has been reviewed by Weintraub et al., (1986). In addition to discussing these methods and their weaknesses, they reveal that the most widely used mathematical programming technique in forestry management is linear programming (LP). The availability of computerised algorithm and the adequacy they provide in representing many planning situations are reasons for its popularity. In LP the timber management problem is roughly defined by three parameters; rotation age, spatial and temporal cutting regime and the time path of aggregate harvesting level. These are determined by several factors including species, site index, economic and climatic conditions.

The LP formulation of the problem can be used to analyse a wide range of factors such as a large number of silvicultural prescriptions, various multiple use objectives, and many policy aspects. However, as the number of factors and their variations increase the model formulation becomes very complex and highly demanding in terms of data and becomes difficult for forest managers to understand. The cost of modelling for management applications becomes very high (Weintraub et al., 1986). Hence, very often the output values are generated for discrete intervals of periods, instead for every year.

Nautiyal et al., (1967) developed an LP model to solve the problem of scheduling the harvest of an uneven aged forest, to maximize the site value.[3] They conceded that the

[3]The site value, also known as soil expectation value,is the present value of the timber harvested period-

computational facilities did not exist to solve a practical problem using their model. While their model deals with the problem of single use management other developments in LP applications in forestry incorporated multiple use values of forests, when deriving optimal harvesting schedules. Over the years the US Forest Service developed mathematical programming models which incorporate many policy constraints including multiple use and non-declining timber harvesting. McKenney (1990) describes the current model used by the US Forest Service as a very complex one which can be comprehended only by experts in forestry and programming. He adapted this model to derive optimal harvesting plans for a small catchment in the Otways region of Victoria.

The harvest scheduling problem can be formulated in the LP framework with less sophistication and complexity, and be solved easily using the transportation algorithm. In this paper such a simple model is proposed to analyse the issue of scheduling the harvest of a heterogeneous forest. The model is similar to that of Nautiyal et al., (1967). The growth of forest is simulated separately and the objective function coefficients, the c_{ij} values, are generated using the simulated data. Constraints on rotation age, spatial and temporal cutting regimes can be incorporated into this model. Constraints on the time path of aggregate harvesting level, or any other constraint in terms of volume of timber harvested cannot be directly incorporated into the model if it is desired to be solved using the transport algorithm. All the constraints must be in terms of area of land harvested. Given the prior knowledge of the output per hectare at each age, an indirect volume constraint may be introduced through constraints on harvested area.

The proposed model is very simple and is not capable of handling complex problems that the latest LP formulations can solve. However, the advantages of this model are that it is easy to understand, it directly uses output from forest growth simulation models which are well known to forest managers and it is less expensive to formulate and operate. The data requirements are also minimal.

4 Methodology and Model

If the entire forest is homogeneous then the problem of maximizing returns during the process of conversion is easily solved. The sequence of harvesting in terms of the sections of the forest harvested each year is irrelevant to the maximization problem. However, if the forest consists of heterogeneous stands, the harvesting in terms of sequencing various types of stands affects the optimal solution.

A forest may be heterogeneous in many aspects. The age structure of the forest could

ically, to infinity.

consist of many age stratas of the same species. The topography of the land may bring in heterogeneity to the stands of the same age in terms of various levels of harvesting difficulties. The distance within the forest simply would convert a physically homogeneous stand into an economically heterogeneous stand because of the transport factor.

The methodology used here involves several steps to obtain a solution. The main purpose is to determine the rotation period for the entire forest which maximises the returns from the entire forest. There are two fundamental decisions to be made here. One is to decide the optimum rotation age for the future stands that will maximize the site value of the entire forest. The second is to decide the number of hectares in each group in the standing heterogeneous forest to be cut in each year. In the case of heterogeneity based on the age structure it may be beneficial to cut older stands first, but this will depend on the opportunity cost of taking that action. Hence, it is necessary to use an optimisation technique to determine a cutting plan.

4.1 The Methodology

The methodology proposed here determines the period of one harvesting cycle on the basis of optimum Faustmann - Hartman rotation age for an even age hectare of forest land. The harvesting cycle is defined here as the period in which the entire forest will be once completely harvested, section by section each year.

In the first step of the solution procedure, the present value of returns from a hectare of currently standing forest is estimated. This hectare could be harvested in any year of the rotation cycle. Hence, the present values for it are estimated for every year as if the stand was harvested in each year of the cycle. Then in the second step, assuming that the land was immediately regenerated, the site value of the land is estimated. This estimation will yield the site value of the land in the year in which the initial forest was cut. Hence this value will be discounted and added to the already calculated present value of the standing forest to determine the site value of the land in the current period including the value of the standing forest. These values are the coefficients of the objective function. They will depend on the current age of the stand, the time period between now and when it is cut and the rotation age for the future stands.

This procedure was followed for each and every category of standing forests. These calculations will provide a list of site values for each year in the harvesting cycle for a hectare of standing forest in each category under a management plan with the optimum rotation length for the future stands.

The next step of the solution procedure is to formulate the problem in an LP framework. The optimum harvesting plan for the currently standing forest is derived using a transportation algorithm. The forest categories based on age strata are the supply sources while the individual years in the harvesting cycle are the destinations. The solution will give the optimal harvesting schedule for each type of forest stand for each year. The solution to these formulations will yield the maximum site value and the optimal cutting plan under the optimum rotation length. This will give the optimal site value for the entire standing forest, and the corresponding cutting plan will be the optimal cutting plan for the entire forest. The standing forest will be clearfelled over a number of years equal to the optimal rotation age, in pre-determined size groupes.

4.2 The Model

The problem of maximizing the site value of the entire forest can be formulated as:

$$\underset{X_{it}}{Max}\ V = \sum_{t=1}^{T^*}\sum_{i=1}^{m} P_{it} X_{it} \qquad (1)$$

Subject to:

$$\sum_{t=1}^{T^*} X_{it} = X_i \qquad for\ all\ i \qquad (2)$$

$$\sum_{i=1}^{m} X_{it} = X_t \qquad for\ all\ t \qquad (3)$$

and

$$X_{it} \geq 0 \qquad (4)$$

Where:

$$P_{it} = PV_{it} + SE_t e^{-rt} \qquad (5)$$

$$SE = [\textstyle\sum_{j=1}^{n} Pl_j V_j(T) + (\sum_{k=1}^{T} Pw Y H(k) e^{r(T-k)})$$

$$- C_1 e^{rT} - \sum_{k=1}^{T} C_{2k} e^{r(T-k)}]/[e^{rT} - 1] \qquad (6)$$

V = Present value of returns to infinity from timber and water in the total catchment area harvested

T^{*} = Optimum rotation period for the regenerated stands after clearfelling the current stand t years from now. This is the period over which the current standing forest is clearfelled in equal coupes to generate a regulated forest.

t = Number of years after which the current forest stand will be clearfelled.

T = The age of the forest for which the returns are estimated

P_{it} = Site value including the present value of the currently standing forest, at t = 0, of a hectare of forest in category i whose currently standing forest is cut in t years hence.

X_{it} = Number of hectares of the standing forest of category i, clearfelled in t years hence.

X_i = Total number of hectares of standing forest in category i at t = 0.

X_t = Total number of hectares of standing forest clearfelled each year.

PV_{it} = Present value of a hectare of standing forest in category i, clearfelled t years hence.

SE_t = Site value at t of a forest regenerated in t years hence.

r = Rate of discount

k = Age of the stand

m = Number of forest categories in the heterogeneous forest

C_1 = Cost of establishment of the stand

C_{2k} = Annual cost of maintaining the stand at age k

Pl_j = Price of timber per cubic meter of category j

$V_j(T)$ = Volume of timber of category j at rotation age T[4]

n = Number of categories of timber

Pw = Price of water

YH(k) = Stream flow yield at age k of the regenerated stand [5]

[4]The growth of the Mountain Ash stand was simulated using the equation and format given in the STANDSIM model of the Department of Conservation Forest and Lands (Incoll 1983)

[5]The stream flow yield after clear felling and regeneration is estimated using the model developed by Kuczera (1985).

The major assumptions of this model are that the relative prices are constant and do not vary with the maturity of timber or with time. The royalty system used in Victoria does not directly differentiate logs according to maturity in determining the prices. It also assumes a perfect capital market. The model as presented above assumes the costs and prices are the same for all the stands in the forest. As will be shown later this is not essential. The costs and prices applicable to each stand could vary depending on the distance within the forest and the topography of the land. Such changes in costs and prices will affect the optimum rotation period of the relevant stands. Under such circumstances, the same species in the same forest will have to be managed under different rotation ages. This will maximize the total returns from the total forest but may lead to some of the difficulties described above in relation to a management policy which does not accommodate the need for a steady state management. Hence it would be beneficial to manage the entire forest under one rotation plan. Under such a plan the optimal rotation age could not be the same as the Faustmann-Hartman rotation age. The relevant optimum rotation age could be found by maximizing the maximum of the above given objective function over a range of rotation periods. A model of this type is applied in subsection 5.5 of this paper, and the extended model is presented and explained there.

The other alternative is to consider two areas as two forests and derive independent harvesting schedules using the model described above.

4.3 The value of timber and water

The prices of various categories of timber used in this study were obtained from the royalty rates charged by the Department of Conservation and Energy of Victoria, for timber harvested in State forests.

The price of water is not as readily available as the price of timber. Dixon (1989) estimated the delivery cost of water in Melbourne as 27 cents per kiloliter and the price paid by most families in Melbourne as 15 cents. This analysis based on short run marginal costs indicates a loss of \$120 per megalitre. Under an efficient pricing system, where marginal supply cost equals the willingness to pay, the net value of the marginal unit of water would be zero, and of inframarginal units would be positive depending on the slope of the demand schedule. There are several methods of estimating the value of water in such circumstances (Gibbons 1986). They need extensive analysis which is outside the scope of this paper. For demonstration purposes a price of \$15.00 per megalitre is used in this analysis.

5 Results and Analysis

As explained in the methodology section the objective function coefficients are determined by combining the present value of the standing forest and the site value of the forest land. The present value of the standing forest depends on when the forest is clearfelled. The optimum site value of a hectare of land is derived using equation 6. In the current analysis, this value is taken as the site value of the land at the time of first regeneration after clearfelling the currently standing forest. This value will be discounted to the present and added to the present value of the standing forest. The resulting figure will show the value of land in growing Mountain Ash trees and harvesting water to infinity, including the value of both timber and water in the currently standing forest. The analysis in this and the following sections maximises this value for forest area under various management plans to obtain an optimal harvesting schedule for the existing forest.

5.1 Present value of the standing forest

The estimated optimum rotation age for a Mountain Ash stand under multiple use management for timber and water harvesting is 36 years at 4 percent rate of discount. This age was derived under the current relative prices for a stand regenerated with 1,400 trees. If the future forests are to be managed under an optimum plan and the supply of timber to be maintained at regular levels, the currently standing forest has to be clearfelled and regenerated completely within 36 years. To derive the optimum cutting plan over the next 36 years for the standing forest it is necessary to estimate the present value of net returns per hectare clearfelled in each of these 36 years. Since there are four age strata in the current forest, 36 estimates have to be derived for each strata making a total of 144 values.

These values were derived using the same stand growth simulation model used in deriving the optimal rotation age. However, instead of starting the growth cycle with a barren land and an initially specified stocking density, the growth cycle here starts with the input values on the existing forest stands. These input values include the current age of the stand and the diameter distribution of the standing trees. The diameter distribution for a typical one hectare stand in each category of Mountain Ash stands in the Maroondah catchment, which were used in the current analysis, are shown in the appendix.

The present value of the standing forest plus the site value of the forest land is shown in table 2, for all four forest categories, at six yearly intervals for 36 years. The value in year 36 shows the present value of a hectare of standing forest in 1990 if it is clearfelled in 36 years from now in 2026 plus the value of timber and water harvested from the same

Table 2:

Present Value of Standing Forest
Plus The Site Value
Under Different Age Strata

Year Clearfelled	Over Mature (220Yrs)	Mature 165Yrs	1926 Regrowth 64Yrs	1939 Regrowth 51Yrs
1	2670.67	10399.70	9324.40	8602.30
6	2728.11	9362.49	8490.76	7845.83
11	2783.52	8379.21	7759.18	7128.07
16	2835.41	7585.92	7103.57	6481.06
21	2882.54	6648.84	6503.11	5856.83
26	2924.59	6119.64	5951.96	5352.09
31	2961.66	5644.07	5462.07	4862.46
36	2994.12	5253.61	5034.30	4460.76

site to infinity with a 36 year rotation. The over mature stands currently standing in the Maroondah catchment have passed their growing stage and are in decaying stage. The timber in these stands have been categorized as suitable only for pulpwood. Recognizing these factors, the growth model was modified to estimate the value for the next 36 years under decaying conditions. For the currently standing mature stands this modification is incorporated after they reached the age of 200 years when required

5.2 Unrestricted optimisation

Optimum returns derived under various constraints are given in table 3. Unrestricted optimisation, in this section, refers to the management policy which assumes that the entire Mountain Ash forest area in the catchment is available for logging operations without the restrictions shown in table 1. The analysis in this section assumes that the lifting of these restrictions is cost free. However, in later sections, a maximum limit to the cost will be estimated within which the lifting the restriction is beneficial.

The entire Mountain Ash forest should be clearfelled over a period of 36 years. A total of 10,664 hectares under four main forest types of Mountain Ash will be harvested at the rate of 297 hectares per year in the first eight years and at the rate of 296 hectares per year

Table 3:

Optimal Returns Under Management Plans Which Accommodate Various Constraints On Logging In The Maroondah Catchment

	Management Option	Returns Dollars '000	Difference Compared To Option 1 Dollars '000
1.	Entire Forest	70,421	------
2.	Excluding Slopes	62,055	8,363
3.	Slopes at Higher cost	68,512	1,909
4.	Excluding Landscape	67,999	2,432
7.	Excluding Fixed Zones	58,567	11,854
8.	Suitable Only	47,779	22,642

in the remaining 28 years of the rotation cycle.

The management plan indicates that it is advantageous to clearfell 165 year old mature stands first. This is not consistent with what a forester would intuitively expect to happen. It is logical to expect for over mature stands to be clearfelled first as delaying the clearfelling of these stands reduces their timber value. However, the optimal management plan does not agree with the intuition. This is because the value of timber and water in mature stands is higher than that of in any other age group and is declining as the stands age, compared to stands of younger age. Next in the harvesting order are 64 year old 1926 re-growth stands and after that the 51 year old 1939 re-growth stands. The 1926 re-growth stands have a higher timber value than the 1939 re-growth stands. Also the timber value in 1929 stands is declining at a faster rate than that of 1939 stands. Hence it is beneficial to clearfell 1929 stands before 1939 stands.

The last group to be clearfelled is the 220 year old over mature stands. These stands are in decaying stage, hence does not produce any saw log quality timber. They are suitable only for pulpwood. The merchantable timber value of these stands is very low and rapidly declining. However, the annual stream flow yield in these stands is higher than in other stands and increasing as the stands age. Hence, the total value of the current stand increases in terms of the present values. Even after the returns from the future rotations are added this increasing trend continues. Hence it is advantageous to clearfell the other stands before harvesting the over mature stands in order to maximize net returns from the entire forest. The total site value, including the present value of the standing forest, is $ 70.4 million.

5.3 Restricted Optimisation

The analysis in the above section assumes that the entire Mountain Ash forest area in the catchment will be available for intensive logging. As such, the analysis does not take values of the forest other than the values of the timber and water into account. Another important aspect that is neglected in that analysis is the effects of logging on water quality and soil stability in the catchment. The analyses presented in the following sections take these and other similar issues into consideration when deriving optimal harvesting plans.[6]

[6] Unless otherwise stated the information relating to these constraints in the Maroondah catchment, which are used and given in this paper is obtained from Ronan (1980). They are used extensively in the following analysis and hence not mentioned individually.

5.4 Steep Slopes

Duncan et al., (1980, p258) state that the available literature on timber harvesting and water quality indicates that the effect of timber harvesting on water quality is largely influenced, among other things, by the conditions of the forest including the site slope and soil conditions. Ronan (1981, p41), further states that the literature on the same field shows that logging on steep slopes would be a poor management policy under most conditions. The hydrology research team of the MMBW has investigated this issue in some of its catchment experiments and has concluded that the logging operations should not be carried out in areas with a slope higher than 25 degrees (Langford et al., 1980, p106).

The present value of total returns is $57.5 million for the area clearfelled, excluding the area unsuitable due to slope. This is $12.9 million less than the revenue from unrestricted management. However, these values do not represent the accurate value of the opportunity cost of protecting the quality of water by not harvesting the stands in steep slopes. They are over estimated to the extent of the value of water derived from the stands not clearfelled due to slope, as they are not calculated within the process of deriving the optimal management plans. They were calculated separately and the method is explained below.

The stands in steep slopes are assumed to have a natural life span of 300 years, unless they are destroyed by a forest fire before that. Since the stochastic nature of forest growth is not considered in this paper, it is assumed that the current stands will be regenerated once the stands in each age strata reach a mean age of 300 years. Regeneration of the new stands will be spread over a 36 year period starting from the age of 283 years. The new stands will be replaced every 300 years to infinity. The present value of water harvested from these stands under such a management plan is estimated and added to the optimal returns given by the management plan for the rest of the stands.

The present value of total optimal return is $62 million under a management plan which excludes stands on steep slopes from clearfelling. The opportunity costs of excluding steep slopes from harvesting is $ 8.3 million. This value indicates that if the deteriorating effects on water quality can be adjusted with a total expenditure of less than $8.3 million it is beneficial to log in areas with a slope higher than 25^0. This gives an annualized perpetual value of about $0.33 million for the total area of steep slopes or $169.00 per hectare per year. This indicates that if the annual cost of rectifying the damage caused by logging in steep slope is greater than $169.00 per hectare, then the slopes should not be harvested. One of the precautionary actions that can be implemented to reduce the effects on water quality due to logging in steep slopes and its effects on costs are discussed in the next subsection.

5.5 Constrained Logging

The soil erosion in steep slopes can be reduced by implementing improved methods of harvesting and regeneration. In a single purpose management the cost of these new methods may be prohibitive. Bowes et al., (1984) discuss a similar problem in relation to prohibitive roading costs under timber harvesting only, but multiple use allows profitable timber harvesting. In multiple use management especially one that considers the values of water quality, landscape, and other non-wood products, the total cost of using advanced methods may be justified. Opie et al., (1978) have estimated the costs of logging operations under restricted conditions for Australian eucalypt forests. The highest cost they have estimated in relation to the slopes is for the slopes exceeding 20 degrees. Four strategies under each slope class have been identified according to the logging method and machinery used. The fourth strategy aims to conserve, as fully as possible, the other forest values. In calculating the results shown above, it is assumed that the logging in the flat areas of the catchment will be done using flat land strategy 4. The additional cost of logging in steep slopes is estimated from the difference in costs between his strategy 4 in steep slope and flat land classes. The differences in current dollars are $1.00 on roading and $0.23 on logging and hauling per cubic meter and $445.20 on regeneration per hectare. Higher roading and logging costs reduce the net royalty of timber and the higher regeneration cost increases the input cost on the same activity. These changes are included in the calculations and returns are estimated for areas falling under deep slopes in the Maroondah catchment. Under these new costs and returns the optimal rotation period increases to 41 from 36 years. As before the returns from the currently standing forest stands in each age strata are estimated and added to the discounted site value to determine the c_{ij} coefficients in the transportation matrix.

The new transportation matrix consists of 8 sources, four more than earlier matrices. The new four represent the forest areas in steep slopes under each age strata. The number of destinations rises as the rotation period increased from 36 to 41. To obtain an optimal solution for the problem the optimal solutions under each rotation period from age 36 to 41 were derived and then the global optimum was selected. Accordingly the model for this analysis is changed as shown below.

The objective function which maximises the site value for the entire forest stand is:

$$\underset{T}{Max} \left[\underset{X_{it}}{Max} \; V = \sum_{t=1}^{T} \sum_{i=1}^{m} P_{it} X_{it} \right]$$

Subject to all the constraints shown before plus:

$$T_L > T \cdot T_H$$

where T_L and T_H are the lower and upper limits respectively of the range of rotation periods for which the solutions will be derived to determine the optimal rotation period for the entire forest.

This model was applied and solutions were derived for six rotation periods ranging from 36 to 41 years. The main emphasis in this analysis is to maintain a steady supply of timber and water throughout the rotation period after the currently standing forest is clearfelled and new stands are regenerated. The results indicated that total benefits can be maximized while maintaining a steady state by having a 36 year optimal rotation. The bulk of the forest (82 percent) comes under low cost management which gives a 36 year optimum rotation. The weight of this large proportion has carried the small proportion in determining the optimal rotation period for the entire forest, although the small proportion of the forest independently has an optimum rotation period of 41 years. Also the difference in returns between 36 and 41 years is very small in present value terms. Delaying the cutting age to 41 years involve postponing some returns which are currently received within 36 years. This involves additional discounting for the stands that are delayed. The difference between the returns of 36 and 41 years from the stands in deep slopes is not large enough to justify an optimal rotation period higher than 36 years for the entire forest, because of the additional discounting involved. A change can be expected only if the total of the negative effect of postponing the stands with a 36 year optimal rotation is more than offset by the positive effect of the stands with a 41 year optimal rotation age in present value terms. This could be possible if the difference in net present value of returns in these stands is very large or the proportion of the long-period rotation stands is substantially higher.

The other alternative is to consider two areas as two forests and derive independent harvesting schedules using the model described above.

The optimal returns under new conditions is \$68.5 million. The total returns under constrained logging conditions for slopes are lower than the returns under no constraints, but much higher than the returns obtained with no logging in slopes at all. The difference is \$1.9 million. This difference indicates the cost of implementing one of the possible solutions to reduce the effects on quality of water of logging in steep slopes. This leaves an extra return of \$6.5 million which can be used to take any other possible measures to further reduce the deteriorating effects on the quality of water and still be better off with logging in slopes. These calculations assume that the entire area under slopes can be logged with the methods used in constrained logging. However, Opie et al., state that the methods used in their calculations are not suitable for logging in convex slopes. The information on the areas of each age strata in each slope types in the Maroondah catchment is unavailable at present. If and when this information is available, the methodology used in the current study can be used to derive different optimal management plans with convex slopes as a set of extra sources and to estimate the optimal returns from the loggable areas.

5.6 Landscape values

The optimal harvesting plan under this restriction reserves 550 hectares of Mountain Ash forest to protect the landscape values of the region. The optimal harvesting plan derived after allowing for landscape values generates a return of $68 million.

The opportunity cost of reserving these areas for the protection of the scenic beauty in the region can be estimated by the difference in total returns with and without the protection. This is $2.4 million. This is about $96,000 per year in perpetual values. Per hectare value per year is $175.00. Any plan to clearfell these stands for timber production must compare these values with the values the society attributes to the scenic beauty in the region and the contribution to it by the forests in the catchment.

5.7 Fixed Zones

The area under fixed zone includes areas identified due to factors ranging from scientific experiments to recreation. The total area allocated for these purposes results in an opportunity cost of $11.8 million. The annual perpetual value is $472,000 giving a cost of $169.00 per hectare per year. A major part of this area is reserved on both sides of streams to protect the quality of water. This practice of leaving a protective zone is carried out in logging operations of the forests under the department of Conservation and Environment (DCE) as a policy. If the areas reserved solely for this purpose within the catchment were obtained the cost of such a policy can be estimated. Recreation in the catchment is the reason for another important part of the area reserved under fixed zone. The opportunity costs given above includes the timber value of these zones as well.

5.8 Area suitable for timber harvesting activities

After allocating land for the protection of water quality and other values the remaining land is considered suitable for logging operations. The area suitable for logging is shown under age class strata in table 1. The return from multiple use management of this area is $47.8 million. This is $22.6 million less than the returns under the optimal management plans that include the entire Mountain Ash forests of the catchment in the harvesting schedule. The annual perpetual value is $904,000 giving a value of $170.00 per year per hectare. This value represents the opportunity cost of allocating the relevant areas for the uses other than timber production.

6 Cost of Conversion

As the current stands have passed their economic rotation age, the site value of the forest can be maximized by immediately clearfelling the entire forest under the current relative prices. It was argued earlier that it would be desirable to spread the harvest of the current stands over a period of time rather than immediately clearfelling. The reasons include the effects on prices, costs and level of economic activities. In this section the practical aspects of immediate harvesting is examined in relation to its effects on other activities.

If the total area is immediately harvested it will result in a site value of $93.2 million under the current relative prices. This is $22.8 million higher than the returns under regulated management. In such a situation it is economically beneficial never to convert the forest to a regulated one. This is identified as the cost of conversion of a natural forest to a regulated forest. The level of this cost is affected by the effects of extra output on prices and logging costs. The effects on price is determined by the elasticity of demand and the relative change in output. Loane et al., (1986) on the basis of other studies have estimated the elasticity of demand for sawlogs and pulpwood to be 1. If this is taken to be reasonably accurate elasticity of demand then a 10 percent increase in total output will result in a 10 percent reduction in price. The total production of hardwood and softwood sawlogs and pulpwood in 1988/89 in Victoria was 2.4 million m^3 (DCE 1989). With an average output of 600 m^3 per hectare the immediate harvest of the Mountain Ash area of 10,664 ha in the catchment will produce 6.4 million m^3 of timber. This is a 267 percent increase in the output of the public forests. This will definitely result in a collapse in the stumpage market. Hence, the immediate harvesting of the entire catchment is not a practical proposition. Under such circumstances, the cost of conversion could not be as high as $22.8 million. The conversion into a regulated forest, compared to immediate harvesting, may not result in any costs at all. This will be particularly so when the cost of carrying out an immediate harvesting programme is taken into account.

7 Conservation values

The management of native hardwood forests for timber production in Victoria is heavily constrained to protect conservation values. One of these restrictions is on the minimum age of harvesting, which for Mountain Ash is 80 years (DCFL 1986). This policy would have

Table 4:

Optimal Returns Under Various Management Plans With A Minimum Rotation Period Of Eighty Years

Management Options	Returns Dollars '000
Eighty Year Steady State Management	
1. Entire Forest Equal Instalments	48,060
2. Entire Forest UnEqual Instalments	46,398
3. Net Suitable Area Equal Instalments	36,490
4. Net Suitable Area UnEqual Instalments	34,650
Immediate Clearfelling	
5. Entire Forest	58,904
6. Net Suitable Area	40,802
Thirty Six Year Steady State Management	
7. Entire Forest	70,421
8. Net Suitable Area	47,779

many implications for management decisions in hardwood forests. In this section, the effects of managing the entire Mountain Ash forest in the Maroondah catchment under an 80 year rotation is examined.

As already noted above some of the Mountain Ash stands in the catchment are more than 80 years old. They are identified as over-mature and mature stands. They are currently 220 and 165 years old, respectively. These stands can be clearfelled immediately. The next age strata of forest is 64 year old 1926 re-growth stands. They will not be available for harvesting on an 80 year rotation policy for another 16 years. The last group of forest in the catchment is the 51 year old 1939 re-growth stands. They will not be available for clearfelling under the same policy for another 29 years. The management of these stands under an 80 year rotation policy can be analysed under several options. The two options discussed below are evaluated in the current analysis. All these evaluations are based on a steady state management policy.

1. Management of entire Mountain Ash forest with an equal annual harvest. This requires some of the 1939 re-growth stands to be clearfelled before they reach the age of 80 years. However, the entire area under over-mature, mature and 1926 re-growth stands must be clearfelled before any of the 1939 re-growth stands are clearfelled.

2. Under the second option the policy is to maintain every forest stand till the age of 80 years. The 1939 re-growth stands are not harvested till they reach the age of 80 years. During the first 29 years the other stands are harvested in equal number of hectares each year including 1926 re-growth stands between the years 17 and 29 inclusive. From 30 to 80 years, the 1939 re-growth stands are harvested in equal number of hectares each year. This was imposed on the solution because the total area of over-mature, mature and 1926 re-growth stands are not sufficient to cover the period before 1939 re-growth stands became 80 years old, when harvesting is done in equal instalments annually. Also, the total hectares under the first three strata are less than the number of hectares under the 1939 re-growth stands. If the latter were less than the former, the annual harvest could be made equal and the model could be allowed to optimally select the harvesting schedule, including 1939 re-growth stands, after they reach the age of 80 years. If this has been the case, the model would definitely generate harvesting schedules that recommend cutting the 1939 re-growth stands, before harvesting at least some of the over mature stands.

The analysis under these two options was carried out for the entire forest as well as for the area identified as suitable for harvesting operations. These four analyses are based on the assumption that the harvesting operations are conducted every year. In addition to these options, the returns are estimated under a management policy which harvests the older stands immediately and the rest as soon as they become 80 years old. The results are given in table 4, along with the returns under a 36 year optimal rotation.

The results in table 4 are shown under two extremes of management constraints. One is for the entire forest where no constraints on logging were taken into consideration in calculating the results. The other category, net suitable area, shows the returns calculated after land allocations are made to satisfy all the constraints evaluated in section 5 of this paper into account. They are presented under 80 year steady state management, immediate clearfelling and optimal steady state management. The 80 year rotation category is further divided into sub categories of equal instalments and unequal instalments. The former gives returns under a policy where an equal number of hectares are clearfelled every year, which includes harvesting 1939 re-growth stands before they reach the age of 80 years. The latter gives results under a plan where all stands are harvested only after they reached the age of

80 years. Under both cases all the regenerated future forest stands will be managed under a complete 80 year rotation cycle.

The returns obtained under a 30 year management plan are shown in table 4 for comparison. The difference of $24 million in returns for the entire forest under optimal management and the 80 year unequal instalment management system indicates the cost of keeping the entire 1926 and 1939 re-growth stands and all future regenerated forest stands till they are 80 years old. This is part of the cost of conservation, society has to bear in order to enjoy the non-timber benefits from the catchment. When the cost of preserving areas identified as unsuitable for logging in the catchment is included this cost increases to $35.8 million.

8 Conclusion

The main objective of this paper is to develop a model to derive an optimal management plan for harvesting a currently standing heterogeneous forest and apply the model to the Maroondah catchment. Giving emphasis to steady state management, a model formulated on the basis of the transportation model is used to derive optimal management plans.

The information about the physical characteristics of the Maroondah catchment were obtained from various MMBW publications and used in the economic analysis in this paper. The effects of various physical and social constraints on logging were evaluated and the costs were estimated in terms of the lost opportunity.

In terms of policy, the analysis in this paper gives an indication of the opportunity cost of various social restrictions imposed on logging operations in Victorian forests. These are estimated under the current royalty rates for timber.

Overall the analysis in this paper indicates that there are benefits society can gain by harvesting the currently standing forests in the Maroondah catchment. The net benefits are positive even at higher costs of logging and regeneration required to satisfy some of the constraints. The benefits can be obtained even after preserving some areas required to meet the physical constraints and to reasonably satisfy the requirements to obtain the other values of forest such as recreation, scenic beauty, scientific and conservation values. Net positive benefits can be obtained even after meeting the requirement of an 80 year rotation period to safeguard the habitats for native flora and fauna, though there is an opportunity cost that should reflect the minimum value of preservation.

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10 Appendix

Table 5:

The Diameter Distributions Of The Mountain Ash Forests Currently Standing In The Maroondah Catchment

Diameter Class cm	Number of Stems Per ha. Over Mature	Mature	Diameter Class cm	Number of Stems Per ha. 1926 Re-growth	1939 Re-growth
25	0	1.4	LT.10	0	0
45	5.0	1.5	15-19	4	24
55	5.0	2.4	20-24	6	43
65	3.0	1.5	25-29	19	45
75	4.0	3.1	30-34	16	41
85	2.0	4.4	35-39	20	33
95	2.0	6.8	40-44	18	30
105	1.0	5.1	45-49	22	35
115	1.0	5.1	50-54	20	22
125	2.0	4.7	55-59	19	17
135	0.0	5.6	60-64	15	15
145	0.0	4.0	65-69	16	9
155	1.0	3.9	70-74	12	4
165	1.0	2.5	75-79	8	3
175	0.0	0.6	80-84	6	3
185	0.0	1.3	85-89	4	1
195	0.0	0.8	90-94	1	0
205	0.0	0.4	95-99	1	0
215	0.0	0.4	100-104	2	0
225	1.0	0.3	105-109	1	0
235	0.0	0.0	110-114	1	0
245	5.0	0.7	115-119	1	0
Total	57.9	37.0		218	328