

LOGGING AND WATER

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A study of the effects of logging regimes on water catchment hydrology and soil stability on the eastern seaboard of Australia

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Executive summary

The report

This report considers the impacts of logging in forests on the quantity and quality of water available for users. It considers the impacts of:

- the silvicultural regimes, yield control and scheduling systems used;
- the on-site logging technology and the conduct of operations; and
- the infrastructure of roads required to extract the wood from the forests.

It also considers the economic implications of the effect of logging on water yields and water quality and the lessons for policy makers.

This study is concerned with use of the forested catchments of the eastern seaboard of Australia and is not concerned with urban areas, dryland catchments, agricultural areas, the Murray-Darling Basin.

Impacts of logging

The great variability of Australian rainfall and the occasional occurrence of bushfires poses particular problems for the study of hydrological impacts. Occasional, unpredictable peak rainfall events can outweigh or mask the effects of alternative catchment treatments.

Studies reviewed in this report show that the method of harvesting can greatly influence soil disturbance. Landslips on steep slopes with deep soils can be caused by road cuts and road drainage. Such events have occurred in Australia. In Australia up to 25 per cent of a logging coupe can be covered by snig tracks and landings and this indicates a need for scientifically developed standards for the amount of allowable soil compaction. Overseas and local studies show the major impact that poor roading and harvesting practices can have on stream water quality particularly in steep country with unstable or erodible soils. Erosion mitigation measures can minimise, but not prevent, erosion and the supply of sediment to streams. The amount of compaction can be reduced by limiting traffic and increasing soil organic matter especially in sandy soils.

Streamflow is the residue of rainfall after allowing for evaporation from vegetation, changes in soil storage from year to year and deep drainage to aquifers. Forest management operations can interfere with these processes by:

- changing the type of vegetative cover on a catchment. Experimental results show that these changes can affect evapotranspiration and therefore streamflow;
- changing the soil properties. The ability of the soil to both absorb and store moisture infiltration can affect the proportion of rainfall delivered. Forest

operations which compact the soil can reduce both infiltration and storage capacities.

Following clear felling in both ash and mixed species forests, Nandakumar and Mein estimate that for every 10 per cent of a catchment cleared, a 33 mm increase in runoff can be expected. Flows reach a peak 2 to 3 years after clearing and then decline which, in the case of the Melbourne Water experimental catchments, meant a return to pre-treatment levels in some 5 to 8 years. For ash-type catchments subject to clear-felling and regeneration, water yield continued to decline below pre-treatment levels. In one experimental catchment, water yield declined to 50 per cent of its pre-treatment level. This finding is compatible to the yield changes reported by Kuczera after wildfire.

Forest management issues

The potential for forest operations to affect water yield and quality, soil and a wide range of environmental values has been reflected in regulations which, over the last twenty years have become increasingly detailed. Where water production is important, they specify that forests are to be managed by appropriate techniques, such as thinning and long rotations. Water quality is protected by limitations on the proportion of a catchment which can be logged in any one year and the specification of appropriate roading and logging practices. Detailed requirements are elaborated for each forest region.

All the Eastern seaboard States have codes of logging practice or regulations in place aimed at protecting forest values including water yield and quality. The Victorian and Tasmanian codes are particularly comprehensive. Currently the Victorian code is being renewed and revised. A review of the perceptions of the Code of Forest Practice held by workers, contractors and supervisors revealed that most timber workers accept the need for codes of practice but that compliance is in practice not as good as it is perceived. Better training for workers is needed, particularly as the pressure to keep up the supply of timber results in logging during inappropriate weather and soil conditions.

If the comprehensive codes of practice now specified were applied at a high standard in all public and private forests, the impacts on water quality would be greatly reduced. The key matters are:

- better road planning, design and maintenance;
- exclusion of 4WD vehicles from roads unsuited to heavy use;
- better use of buffer and filter strips;
- prohibition of logging when soil moisture content is high;
- better logging site rehabilitation;
- better training of supervisors and operators; and

- better designed logging and roading equipment.

Economic impacts

In the past, the abundance of water on the eastern seaboard has meant that the water used up as a result of forest growth has not been valued. As other uses emerge which can compete with forest use -- including urban consumption, irrigation, fisheries, recreational activities and natural systems -- then the value of water in alternative uses increases. The question now being asked is whether use of water in forest growth is the most efficient way of using the resource or should it be allocated to other uses. The concept of 'efficiency' needs to be interpreted to include long-term sustainability.

The hydrological evidence reviewed in this report indicates that current logging regimes in the native forests of eastern Australia can result in a decline in water yields. Other things being equal, an increase in rotation lengths reduces the volume of logs taken out of a forest over time but increases the run-off due to a decline in evapotranspiration.

The major economic study of forests and water was carried out by Read Sturgess for Melbourne Water. The study evaluated economically a range of management options involving different mixes of wood and water production from the Thomson River catchment. The study deals only with timber values and the value of water for Melbourne consumers. Moreover, the results of the study pertain only to the Thomson catchment and should not be extrapolated to other catchments which may have different forest cover, soils, hydrological characteristics and uses. The results of the Thomson catchment are heavily dependent on the prevalence of ash-type forests in the Thomson catchment and the fact that this catchment is very important to the water supply of a large city.

Apart from the hydrological data on which the study was based, key variables in the study included the pricing of water and of logs, and the discount rate employed. The study concluded that among the options considered, the existing management of the Thomson catchment (based on an 80-year rotation) is the most inefficient. The most economic silvicultural options are either a very long rotation (200 years) or a complete end to logging. The conclusion is that, using the estimated prices for timber and water, the loss of timber as the rotation is lengthened is more than compensated for by the increased water yields. If other values were taken into account, in particular ecological values, it is likely that the results would favour long rotations or no logging options more strongly. However, the Read-Sturgess method of calculating the value of water has been challenged by subsequent authors.

Conclusions

The very substantial differences between catchments in terms of their hydrological characteristics, patterns of land use and array of water users makes it clear that the analysis of forest use and management in relation to water must proceed on a regional scale at which the details can be evaluated properly. The integrated catchment management process now being adopted by most States and the Comprehensive Regional Assessment process being undertaken jointly by the Commonwealth and States, are being carried out at the relevant scale. However, it is far from clear that all

important catchments will be included in the former process within the foreseeable future or that water will be considered at all in the Comprehensive Regional Assessments.

In relation to water quantity, it is clear that in some regions water has to be allocated between tree and other crops, and between primary, secondary and domestic use, but the effect of tree crops on water yield is known for only a few sites.

In relation to water quality, it is clear that the most important issues relate to the standard of forest management practice. The major obstacles in some locations are the continued pressure of governments to reduce field staff, lack of training, the unwillingness of industrial companies holding resource rights to pay adequately for high quality work, and the need to upgrade much of the old roading infrastructure.

The broad conclusion of this report is that existing assessment processes, including those being developed for the Comprehensive Regional Assessments, do not adequately deal with the potential impacts of logging on water yields and water quality. Conflicts over access to water on the eastern seaboard are likely to become a much more pervasive problem in the next decades as water-intensive activities expand on the coastal strip. If the issue is taken up now there is an opportunity to develop the data bases, methods of analysis and institutions that will help to resolve conflicts before they become entrenched.

1. INTRODUCTION

1.1 Concern and context

Water, its quantity, exceptional variability from year to year, and variable quality, is an evolutionary determinant of Australia's ecology and a major determinant of agriculture, settlement, and economic development. In turn, development has substantially modified the catchments for agricultural, industrial and urban use and created many now well-known problems.

Although the total annual runoff per person in Australia is far higher than in many developed countries, more than half the runoff is in northern Australia with a low level of development. Moreover, Australia's rainfall is highly variable with long drought sequences being experienced and occasional heavy rainfall events resulting in flooding. As the population is highly urbanised with a high level of water consumption, large water storages have to be constructed to cope with the variability. Even so, there is significant stress on water resources to supply the largest capital cities.

On the eastern seaboard, the catchments comprise a mix of forest, farmland and urban land uses and they supply water for domestic, industrial and agricultural users. The forested parts are the least modified ones left, but they too are subject to continuing change through deforestation, road construction, weed invasion, logging, mining and bush fires, for example. They are particularly important as the source of water supplies to the majority of the population and this will undoubtedly increase as the population increases. The concern underlying this paper is that the use and management of the forests may become a more important, but not yet fully recognised issue for some of the rapidly growing coastal regions, perhaps even for the whole belt between Sydney and Brisbane and part of the belt between Melbourne and Sydney. This paper examines how the forested catchments are being modified by logging, what implications this has for future water use, the economic consequences for water users and what policies governments should adopt.

The study is being conducted at a time when the Commonwealth and State governments are embarking on a process of regional assessments and agreements which will determine how the forested catchments will be modified in future. Under the 1992 *National Forest Policy Statement*, the Commonwealth and the States are committed to negotiating regional forest agreements based on a process of comprehensive regional assessments. The process is expected to be completed over the next three years. The agreements are intended to provide a representative reserve system for conservation and resource security for large-scale industrial developments - such as continued woodchip exports or new large export pulp mills - based on forests and plantations outside the reserve system. Hence, the decisions that are made over the next three years will shape forest use and management with consequences for water users well into the next century. The process is being driven primarily by

concerns for biodiversity, heritage and wilderness values while a number of other values, such as water, recreation and employment appear to be receiving little attention at present.

1.2 Integrated catchment management

Although issues of riparian rights to divert the natural flow of water have an ancient history, the problems of land degradation and salinity in Australia have led State governments to realise the need to integrate the management of catchments across land-use and property boundaries. They have established organisations to advance an integrated approach over whole catchments, usually in collaboration with local land care groups.

The integrated catchment management approach provides the conceptual model for estimating the physical and economic effects of changes and decisions on water users. For each group of users, the quantity and quality of their water is determined by the interaction between the hydrological characteristics of the catchments, the mix of land uses, the way in which each type of use is managed, and whatever dams and treatment works are installed.

The management of forests and the construction of dams have to be considered over very long time periods; typically 100-200 years for the ecologically sustainable management of native forests, and 30-50 years for the amortisation of investments in infrastructure. With occasional refurbishment, Australian dams seem to last a long time. In Victoria, for example, the Yan Yean dam, built in 1860, and the Silvan and Maroondah dams, built in 1928, are still in use. Considering such long-term futures requires that the needs of future as well as present users be recognised.

There are thus four inter-related areas which public policy has to integrate for the long-term management of catchments:

- the area allocated to each type of land use;
- the way in which each type is managed;
- the investment in infrastructure; and
- the allocation of water and the distribution of costs and benefits between types of user.

1.3 Forest decisions that affect water

The headwaters of catchments are of particular importance and are often covered in forests, or in need of reforestation. Logging, the subject of this paper, needs to be seen in the context of other changes to the forests which affect water. The three greatest are deforestation, reforestation and bush fires. Deforestation is still a significant process on private land and one which requires further monitoring and control (Resource Assessment Commission 1992, v.1, p.129-30). Reforestation may be directed to the rehabilitation of land which should not have been cleared, to commercial wood production, or to some combination of both. Reforestation is being encouraged by several public programmes and plantations are being expanded by both public and private investment. Major bush fires have significant effects on water

quality and quantity, especially in Victoria's forests of fire-sensitive mountain and alpine ash. Public policies on access, fire protection and control can influence, but never eliminate or predict them. Seasonal climatic variations, particularly droughts affect forests but, as they are long-lived systems, to much lesser extent than agricultural land uses. Changes to climatic patterns as a result of global warming are a further source of uncertainty but are not considered in this report. Deficiencies in the scientific knowledge about the effects of logging create further uncertainty.

Forests and plantations have many uses and values and require a wide range of management activities for their protection and regulation: one hundred activities are listed for managing the Otway forests in Victoria, for example (Dargavel and others 1995). Outside the conservation reserve system, logging is a major activity, but several others, such as road construction, utility easements, mining, gravel extraction, recreational and rally driving in cross-country vehicles or motor cycles affect the quality and quantity of water available to users. Camping is particularly important in relation to bacterial contamination because people like stream-side sites, but authorities find it difficult to manage them. Reforestation for commercial wood production obviously leads to logging when the tree crops are ready for harvesting, and there are some connections between logging and bush fire incidence and control.

The conduct and control of logging operations, and the decisions readily available to governments, vary between the privately-owned and public forests. The issues of privatisation or public acquisition, which could affect water users, are considered to be beyond the scope of this report, although it should be noted that most of the public plantations, covering three-quarters of a million hectares, have already been corporatised and may well be privatised. Similarly, the uneven allocation of resource rights between logging firms and processing firms is considered beyond the scope of this report, although it should be noted that the present system does nothing to reward high standards or long-term responsibility.

This report considers four types of decisions which can be made about forests in relation to logging which affect the quantity and quality of water available for users. They are:

- the balance between the area of public forests in the conservation reserve system and the area outside the reserve system open to multiple use management which includes wood production;

and for the forests outside the conservation reserve system:

- the silvicultural regimes, yield control and scheduling systems to be adopted;
- the on-site logging technology and the conduct of operations; and
- the infrastructure of roads required to extract the wood from the forests.

Many other decisions about the use and management of the non-forested parts of catchments, and about the regulation and distribution of water have substantial effects on users but are not analysed in this report. However, they form the context within which the economic analysis of the effects of logging have to be seen.

2. FORESTED CATCHMENTS OF THE EASTERN SEABOARD

2.1 Introduction

This discussion paper is concerned with use of the forested catchments of the eastern seaboard of Australia and is not concerned with urban areas, dryland catchments, agricultural areas, the Murray-Darling Basin or the forested catchments in Western Australia with their particular problems of mining and salinity. Tropical areas are not included, partly because their characteristics are so different from the major areas studied, and partly because there is so little known about their hydrology. The Australian standard definitions and boundaries are used in this paper which focuses primarily on the South-east Coast Drainage Division which lies east of the Great Divide, running from the Queensland border round to the south-east of South Australia. It contains 39 River Basins and includes both Sydney and Melbourne (Map 1). The study also draws on some relevant scientific research from outside the Division.

The term 'forested catchments' is used in this paper to refer to those catchments in which the use and management of native forests and forest plantations is important to the provision of water to other users. Some catchments on the eastern seaboard have been so deforested that only residual patches of forest remain. At the other extreme, are a small number of catchments which are still mostly forested but have very few water users, although they may have more in future. In between these extremes are the great majority of catchments which have some forest, other forms of land cover, and many users.

2.2 Characteristics of South-east Coast Division

Surprisingly in view of the importance of water, no national review of resources and their use has been conducted since 1985 (Department of Primary Industries and Energy 1987). However, the characteristics of the South-east Division relative to Australia as a whole are still relevant (Table 1). The Division has slightly over one-half of Australia's population but uses only 17 per cent of the water. This anomaly occurs because irrigation uses only 40 per cent of water used in the region, compared to 70 per cent in Australia. Domestic (30%), industrial (15%) and commercial (9%) uses account for slightly over half the water used in the Division.

Although urban and industrial uses amount to only 0.8 per cent of the country's runoff, much of the unused resource is in northern Australia. In the South-east Division urban and industrial use amounts to 3.2 per cent of the runoff, or 8.3 per cent of the resource of fresh and marginal quality water that could possibly be diverted by dams and reticulation systems. In this aggregate view of the Division, no absolute shortage of water appears likely for a considerable while. For example, total usage could roughly double before an ecologically critical level of say 30 per cent diversion was reached, and even then urban usage could double again at the expense of irrigation and other land uses including wood production.

Map 1. South-east Coast Division

Source: DPIE 1987

The relationship between water resources and use varies considerably between water regions within the Division (Table 2). The Coffs Harbour region has a high rainfall and several important river basins whose resources are little used. The Snowy-Shoalhaven and East Gippsland regions are in a similar situation. By contrast the Melbourne and Sydney regions are consuming a high proportion of their major divertible resources. The economic consequences of alternative forest use and management strategies for the various sorts of users are quite different in the two situations. There is considerable variation between catchments within regions. Comprehensive Regional Assessment and integrated catchment management processes need to assess the specific water resource, catchment management and water use factors for each river basin.

Table 1 Water resource and use

Characteristic	Units	South-east Coast Division		Australia	SE Coast Div. as proportion of Australia
Area	square km	273,000		7, 680,000	4%
Population	millions				
Urban		7.820	96%	14.1	55%
Rural		<u>0.359</u>	<u>4%</u>	<u>1.28</u>	<u>28%</u>
Total		<u>8.180</u>	<u>100%</u>	<u>15.4</u>	<u>53%</u>
Mean annual water use	000's MI				
Urban and industrial					
Domestic		747	30%	1,790	42%
Industrial		385	15%	790	49%
Commercial		228	9%	481	47%
Sub-total		<u>1,360</u>	<u>54%</u>	<u>3,060</u>	<u>44%</u>
Irrigation					
Pasture		711	28%	5,180	14%
Crops		137	5%	3,550	4%
Horticulture		176	7%	1,510	12%
Sub-total		<u>1,020</u>	<u>40%</u>	<u>10,200</u>	<u>10%</u>
Rural					
Stock		120	5%	1134	11%
Other		24	1%	206	12%
Sub-total		<u>144</u>	<u>6%</u>	<u>1,340</u>	<u>11%</u>
Total		<u>2,530</u>	<u>100%</u>	<u>14,600</u>	<u>17%</u>
Surface water resource	000's MI				
Mean annual runoff		41,900		397,000	11%
Divertible resource					
Fresh		14,700		98,100	15%
Marginal		236		865	27%
Brackish		113		1,040	11%
Saline		<u>16</u>		<u>188</u>	<u>9%</u>
Total		<u>15,100</u>		<u>100,000</u>	<u>15%</u>
Developed resource		4,280		21,500	20%
Groundwater resource	000's MI				
Divertible resource					
Fresh		760		4,860	16%
Marginal		699		6,880	10%
Brackish		353		1,830	19%
Saline		<u>50</u>		<u>836</u>	<u>6%</u>
Total		<u>1,860</u>		<u>14,400</u>	<u>13%</u>
Proportion of resource (surface + groundwater) being used		15%		13%	

Source: DPIE 1987

Table 2 Utilisation of fresh and marginal major divertible resources in the South-east Division

Region	Total resource (000's MI)	Total consumed (000's MI)	Proportion of resource consumed
I Millicent Coast	548	299	55%
C Sydney	1,050	496	47%
F Melbourne	810	348	43%
E Gippsland	2,580	543	21%
H Hamilton	470	84	18%
B Hunter	1,170	202	17%
G Otway	468	68	14%
D Snowy-Shoalhaven	3,510	141	4%
A Coffs Harbour	<u>5,710</u>	<u>97</u>	<u>2%</u>
Total	16,316	2,277	14%

Source: DPIE 1987

2.3 Upper Shoalhaven Valley

The general water supply and land use interaction was illustrated in an intensive study of the upper one-third of the Shoalhaven River Basin which was conducted in light of a proposal to construct a large dam at Welcome Reef to supply domestic and industrial water to Sydney (Costin, Greenaway and Wright 1984). The study drew on detailed land classification and hydrological research conducted by CSIRO since the 1960s and focused on the effects of land use and management on the quantity of water that would be available.

In 1980, one-half of the Upper Shoalhaven Valley was forested (42 per cent eucalypt forest, 9 per cent semi-cleared forest, 4 per cent pine plantation), one-third was covered in improved pasture, one-tenth in native pasture and only a very small area (2 per cent) was cropped. There was considerable scope for both pasture improvement and pine plantations and it was thought that the semi-cleared forest and native pasture could well disappear by the end of the century if then current trends continued. The effect of these trends on decreasing the water yields was the prime concern of the study. However, changes to the eucalypt forest due to logging, a major concern of this report, were not considered.

The study was conducted in considerable detail. The valley's 8 sub-catchments were sub-divided by slope, hydrologic soil types and land use (classified by vegetation). The intentions of land-owners and their possible options were obtained and the effects of alternative uses of the land on future water yields were simulated using water run-

off models for dry, average and wet years. The water yields were found to vary according to rainfall and various soil characteristics, and to a lesser extent to land slope, surface roughness, the extent of vegetation cover and its capacity to intercept and store water. Deep permeable soils were found to be relatively low yielding, but were not very sensitive to changes in how they were used; shallow soils were high yielding and also relatively insensitive; while areas of moderately deep topsoils were fairly high yielding but most sensitive to changes in land use. Evapotranspiration indices were estimated for each type of vegetation on each hydrologic soil type. Although differences in evapotranspiration due to vegetation differed considerably between soil types, each type showed the same ranking from native pasture (least), to improved pasture, to eucalypt forest, to pine plantation (greatest). The application of these and other factors through the water run-off models demonstrated the very considerable differences which could be expected in the different sub-catchments.

While much of the data and models used in the Upper Shoalhaven could now be updated, the study displays a number of features or general principles which can inform the conduct of studies of other forested catchments:

- The hydrology of catchments varies greatly according to topography, geology, soil, vegetation and other factors. Hence, detailed surveys are required before land use and management effects can be estimated reliably.
- The type of land use significantly alters the amount of water which can be harvested. Less water can be harvested from eucalypt forest areas than from grassland, but for each general form of vegetative cover, less water can be harvested the more intense the production.
- These responses vary between wet and dry years.
- Their import for other users depends on whether the water resource is limiting and the extent to which it is stored and distributed.

3. LOGGING REGIMES

3.1 Introduction

In this section, the four concepts -- natural resource regimes, silvicultural systems, logging systems and transport systems -- which make up the very broad scope of the term 'logging regimes' adopted for this paper are defined. The nature of forest landscapes is then described. In the final part of the section, the major logging regimes used in Australian forests are described.

3.2 Natural resource regimes

The concept of 'natural resource regimes' (Young 1981, 1982) provides the basic structure for examining how natural resources are used and regulated. It stresses that each regime has to be seen as a set of three types of relationships:

- *The degree to which resources are devolved by the state into private ownership or are retained and managed by the state.* In Australia, three-quarters of the forest

land has been kept in state ownership and state agencies are responsible for its protection and management.

- *The structure of regulations and administrative practices by which the use of the resource is controlled.* In Australia, a mass of licences and agreements serve to allocate the forest resource to processing companies, while various policies and acts of parliaments specify how the resource should be managed. The interpretation of these policies by long-established forest services has frequently been questioned.
- *The degree to which compliance is enforced.* There has been increased resort to the courts to resolve forest contests. The degree of compliance with regulations by logging contractors and farmers can have a significant effect on water quality, as discussed later in this report.

3.3 Silvicultural systems

A 'silvicultural system' refers to the set of protection, tending, harvesting, regeneration and other operations which determine how the stands (patches of reasonably uniform forest, typically 2-50 hectares) are managed (Troup 1952; Jacobs 1955: 183-249). Separate systems are prescribed for each sort of stand and purpose, and many variations are possible within each system. Those used in the study area include systems for uneven-aged forests such as:

- an individual tree selection system in which only a few large trees in each hectare are removed; and
- a group selection system in which small gaps of 50-100 metres width are created;

and systems for even-aged forests such as:

- a clear-felling system in mature eucalypt forest for woodchip and some sawlog production combined with a thinning system in part of the subsequent regrowth;
- a pine plantation system involving 2 or 3 thinning operations prior to clear-felling and, for the sake of illustration; and
- a small-scale coppicing system in which trees are cut every 5 years or so for eucalyptus oil distillation.

The intensity and frequency with which logging occurs varies both between and within systems. Intensity refers to the proportion of a stand and hence the quantity per hectare removed in an operation. Frequency refers to the time interval between operations and hence the number of operations which occur in a stand each century.

The uneven-aged individual tree or small group selection systems now specified in many state forests on the north coast of New South Wales commonly remove about one-tenth to one-fifth of each stand, returning on a cutting cycle of 30-40 years. Ideally, the quantity cut is related to the growth potential of each stand so that the process can continue indefinitely. Adequate regeneration is often difficult to obtain in these systems. On most private forests logging occurs as unmanaged 'high-grading' in which the largest merchantable trees are cut whenever sufficient have grown to be sold. A few owners take a more managed approach. Most of the readily accessible public and private forests on the east coast have been selectively logged at some time

in the past, even if only lightly for the premium sawlogs. The less accessible forests which have never been logged are the main focus for the well-known environmental controversies.

Even-aged systems of clear-felling are preferred for most eucalypt forests because they enable regeneration to be obtained more successfully and certainly than selection systems do. However, most forests on the east coast, especially those which have been cut selectively for sawlogs in the past, now contain far more pulpwood than sawlogs and can only be clear-felled in regions where there is a domestic or export market for the pulpwood. Some of the very high quality mountain forests are an exception to this general situation. The critical parameter of even-aged systems is the age specified for the final felling or 'rotation'; it can be 5 years for coppice crops of eucalypt leaves, 20 years for eucalypt pulpwood plantations, 30-35 years for pine plantations growing sawlogs and pulpwood, and 80-180 years for eucalypt forests. The pine plantations are well established with some areas now in their second rotation. However, most of the eucalypt forests are in the 'conversion period' during which the first rotation under systematic management is being started.

The case of the state forests in the south-east of New South Wales supplying the Eden woodchip mill illustrates some of the relevant factors (Dargavel 1995). When the Eden mill was proposed in the late 1960s, the native forests there were of little economic value for the production of sawlogs, and the more accessible ones on the coast had been logged over selectively but not in a systematically managed way. Regeneration in the cut-over areas was patchy. It was decided to fell the forests over a 40 year conversion period with the expectation that if woodchip exports continued after that time, part of the forest would be managed on a 30-40 year clear felling system just for pulpwood, and part would be managed on an 80 year or longer system which would produce pulpwood from thinnings and sawlogs and pulpwood from clear felling. Now that slightly over half the conversion period has passed it is apparent that the systems need to be re-thought because the planned frequency of logging would not meet the objective of ecological sustainability; rather than 40 years between clear-felling operations, something of the order of 120-180 years would now be thought necessary. It has also been found that only about one-quarter to one-third of the stands will be able to be thinned due to poor stand conditions, steep slopes or obstructions left on the ground from the original logging.

Planned rotation lengths are likely to be extended for ecological reasons throughout the eucalypt forests of the eastern seaboard and will have an obvious effect on logging frequency. For example, rotation length was found to be one of the important influences to be considered in developing strategies for the preservation of Leadbeater's Possum in Victorian ash forests (Lindenmayer and Possingham 1995), and stand age is a major determinant of habitat quality and species abundance in the Otways as in most forests (Brinkman 1990).

Plantations are managed far more intensively and logged more frequently than native forests. Pine plantations are typically managed with 3 or 4 thinning operations before clear felling at a 35 year rotation age. Improved tree breeding and higher levels of weedicide and fertiliser treatment are likely to reduce this age appreciably. There are few eucalypt plantations in the region, the largest being in Gippsland and near Coffs

Harbour. If more are to be planted, it is likely that they will be managed on 15-20 year rotations for the production of pulpwood only.

3.4 Logging systems

A ‘logging system’ refers to the organisation and technology used in timber production from the forest stands to the transport system. It requires operations of:

- planning and preparing the site,
- felling the trees,
- processing the tree lengths into logs,
- extracting the logs to the transport system, and
- sorting and loading the logs for transport to the mills.

Logging systems vary according to the size of trees, type of forest, type of logs, topography, silvicultural system, and equipment employed. Over the last few years, logging on public land has been subject to increasingly detailed planning and codes of forest practice. Many of the items in the codes relate to measures needed to protection water quality. Operations on public land are supervised to obtain compliance. Some codes and regulations apply to private land..

Planning and preparing the site

This is a critical step in most eucalypt forests involving detailed inspection, locating access roads and sites for log ‘landings’ where the logs are to be prepared and loaded, and in sensitive areas extraction routes through the stand and even sometimes marking the direction each tree is to be felled. Strips along streams and other areas not to be logged are marked out. Map 3 shows how a compartment is divided into coupes (an area to be cut in one operation), the log landings located, and the reserve areas and strips planned. In pine plantations on flat country very little more than identifying the rows or trees to be cut may be required.

Felling

Prescriptions and codes of practice warn against felling trees so that their heads fall into creeks or filter strips of riparian vegetation. The heads and branches are normally cut off at the stump.

Processing to logs and extraction from stump to transport system

In eucalypt forests, the felled trees may be either debarked, cut into log lengths at the stump, and the logs extracted to the landings; or more commonly now the stem is extracted to the landing where it is debarked and cut into logs. The logs or stems are mostly extracted by dragging, or ‘snigging’ them behind a crawler or rubber-tired tractor. This disturbs the soil so that the resulting snig tracks have to be ‘barred’ to prevent erosion. Skyline (overhead wire rope) systems can be used instead of tractors in very steep country, but they are uncommon. The landings are major areas of disturbance, bark accumulation and soil compaction. The bark has to be dispersed or burnt and the landings ripped after logging has finished. Early thinning operations in

pine plantations and some regrowth stands are now often carried out by harvesting machines which fell and process the stems into logs. Some machines which delimb the trees are able to move forward on the branches, thus reducing soil compaction.

3.5 Transport systems

Road haulage is now the only means of transporting logs from the forest landings to the mills. Several categories of roads are used:

- Short ‘spur’ roads lead from the landings to a forest road. These are usually temporary tracks which are opened before logging and left to revegetate naturally, sometimes assisted by ripping afterwards. Creek crossing culverts are installed where necessary, but drainage culverts are rarely installed. They are rarely surfaced although wet patches may be gravelled or stoned. Logging is usually closed in very wet weather to prevent erosion.
- Forest roads lead from each forest block to the public road network. They are drained with culverts and surfaced with gravel or stone. They are closed to trucks, and sometimes all traffic during very wet weather to prevent damage.
- The public road network leading to and through the forest is made up of roads of different standards. Local authorities can close some roads during winter.

The forest roads were extended progressively with a major road-building programmes undertaken during the 1930s and during the 1950s-1960s spurred by the intense post-war demand for timber and the need to improve fire-fighting access to remote forest areas. Some of the primary forest roads were carefully surveyed and designed by engineers, but most of the secondary forest roads were built incrementally, either by local forestry staff or by sawmilling companies; some followed the routes first opened by wooden tramways. Since the 1960s, larger log trucks have come into use, the amount being carted each year over some roads has increased substantially. Many of the existing roads do not meet current standards. The ready availability of bulldozers and the need for better fire-fighting access led to a proliferation of fire trails in the 1950s and 1960s, often on very steep grades without heed for water quality. With the popularity of 4WD travel they now carry far more traffic, but with little maintenance, they often act as sediment sources during rain. Many need to be closed or relocated.

3.6 Major logging regimes

The various silvicultural, logging and transport systems used in the resource regimes described earlier are summarised in Table 3.

Table 3. Major logging regimes

Logging regime	Resource regimes	Silvicultural systems	Logging system	Transport system
<u>State eucalypt forests</u>				
Selective sawmill logging	Small sawmills (short-term licences), Large sawmills (long-term licences)	Individual tree selection and small group selection. State regeneration	Manual felling, tractor snigging. Some operations also produce pulp logs as by-product	Truck haulage on spur, forest and public roads to sawmills.
Integrated	Integrated concession (long-term agreements or licences)	Clear-felling and some thinning. State regeneration	Manual felling, tractor snigging, logs sorted on landings	Truck haulage on spur, forest and public roads to woodchip, pulp or sawmills
<u>Private eucalypt forests</u>				
Selective sawmill logging	Log sales. Natural regeneration	Unmanaged high grading	Manual felling, tractor snigging.	Truck haulage on spur and public roads to sawmills.
Integrated	Log sales. Natural regeneration or reforestation	Clear-felling	Manual felling, tractor snigging, logs sorted on landings	Truck haulage on spur and public roads to woodchip mills or pulp mills, and sawmills
<u>Public and private plantations</u>				
Plantation	Large mills Log sales	Multiple thinnings followed by clear-felling	Various harvesting and extraction machines. Mechanical felling for early thinnings	Truck haulage on plantation and public roads to mills

4. EFFECTS OF LOGGING ON HYDROLOGY AND SOILS

This section examines the potential effects of forest operations in native forests on water catchment values and soil stability. It first outlines what is meant by forest hydrology and examines data collection and analysis procedures. Research results are outlined for the eastern States and the implications of this research drawn out. Gaps in current research and future requirements are outlined. This section draws on a number of recent reviews, describes the main outcomes and updates them with more recent results.

It is important to bear in mind that the great variability of Australian rainfall and the occasional occurrence of bushfires poses particular problems hydrology. Occasional, unpredictable peak rainfall events can far outweigh or mask the effects of alternative catchment treatments. This is particularly so for water quality and soil erosion, and significantly limits the ability to produce statistically significant research results. The problem is compounded by bushfires which drastically alter the vegetative cover. Particular combinations of events, such as flooding rain immediately after a severe bushfire, can lead to far more severe effects than either alone. Such variability makes much of the mean data reported in the literature meaningless for many purposes. Variability is being increasingly recognised and is changing the way in which Australian hydrology is being studied.

The variability of Australian rainfall also results in far larger water storages having to be built to even out the effect of 2-3 years of drought than is the case in more equable climates. The high cost of the large dams required can have a significant economic bearing on how forests in some regions are managed as there are significant advantages if construction can be delayed a few years (see Section 6). However, it should be noted that generally the effects due to changes in land use or management are minor, and are difficult to detect, when compared to the 60-70 per cent inter-year variability in stream flow.

4.1 Forest hydrology

Forest hydrology can be defined as the science which examines the interaction between forest cover and the hydrological processes operating in a catchment. It examines the effects of natural changes to vegetation cover and changes due to human actions. Forest hydrology studies range from the scale of large catchments to detailed process studies. They are normally done by interdisciplinary teams with engineering, hydrology, forest management and plant physiology skills. Forest soils store water and nutrients and changes to the condition of the soil can be detrimental to plant growth. Therefore forest hydrology studies also require a good understanding of soil physics and structure.

McCulloch and Robinson (1993) provide a history of the development of forest hydrology. Catchment experiments in the European Alps at the turn of the century were followed by large scale experiments in the United States. For example, at Coweeta approximately 60 years of data have been collected on the interaction

between catchment condition and streamflow. Although these and other experimental studies had an early emphasis on streamflow, from the 1950s onwards water quality and hydrologic processes were increasingly studied.

Catchment experiments began to be established in Australia from the 1950s (Costin and Slatyer 1967). By the 1970s a range of catchment experiments and other forest studies had been established in all States. Not all of these are still operational but long term experiments are still in progress in Western Australia, Victoria and New South Wales. Doeg and Koehn (1990) identified 36 past, present and proposed Australian studies. They have influenced catchment management policies. For example research in Western Australia on forest clearing and streamflow salinity has been instrumental in the development of restrictions on land clearing; Melbourne Water research into the effects of forest harvesting has influenced aspects of the Victorian Code of Forest Practices for Timber Production and in New South Wales forest hydrology research results are taken up in the environmental assessment of potential harvesting effects.

Data collection and analysis

Collecting hydrologic data is costly because instrumentation has to be bought and maintained, sites have to be monitored, results of accidental damage and vandalism repaired and analysis is labour intensive. Despite manufacturers' claims, instrumentation never operates in a totally trouble free mode, lightning strikes, temperature and humidity place a strain on the equipment, and inquisitive animals chew through cables. For example, the 17 experimental catchments managed by Melbourne Water require 2-3 person years per annum for routine data collection and maintenance and about 2-3 person years for routine data processing. Water quality sample analysis costs at least \$50 per sample. Analysis of the processed data for research reports can take another 1-2 person years or greater if special process studies are undertaken. These labour requirements result in a wages bill alone of about \$200,000 to \$300,000 per annum. These costs need to be considered when the detailed monitoring of all catchments subject to forest harvesting operations are advocated. It would be a better use of resources to monitor some regional scale catchments and to improve code of practice requirements and compliance generally.

Recent developments in instrumentation have facilitated continuous monitoring. For example data loggers allow streamflow data to be stored in a form ready for analysis. Sensors for measuring parameters such as total dissolved solids, pH, and turbidity can be linked to data loggers which interrogate the sensors and record the results. However, routine calibration of the sensors can be required more often than is claimed by the manufacturers. Recent New Zealand and Australian developments have enabled transpiration flows to be monitored on a continuous basis. A further convenience is that researchers now have access to off the shelf commercial equipment. The main areas where measurements can require a high degree of specialist knowledge are those which measure atmospheric characteristics and soil moisture flows as distinct from changes in soil moisture content.

Experimental approaches to determining land use effects

According to McCulloch and Robinson (1993) researchers working at the turn of the century made direct comparisons of catchment streamflow and vegetation and

ascribed catchment differences in streamflow to, for example, vegetative cover. This early approach took no account of differences in catchment characteristics such as geology, aspect etc. Later researchers used a larger number of catchments to determine average catchment behaviour. Single catchment studies offer an improvement on this approach in that a catchment after a period of monitoring is subjected to an experimental treatment.

Whereas this approach removes the problem of differing catchment characteristics it does not remove the problem of climatic variability. This led to the development of the control catchment approach in which characteristics, such as streamflow, are monitored for a pre-treatment period of at least five years in at least two similar catchments. One catchment is then kept as a control and the other given an experimental treatment. The untreated or control catchment predicts within certain statistical error bands the streamflow from the treated catchment as if it were still in a pre-treatment condition. Actual streamflows from the treated catchment are measured and if they differ statistically from the predicted flows treatment may be judged to have had an effect. Provided the pre-treatment calibration periods covers a long enough period the effects of climate, except for extreme events, are largely removed.

More recently pre-treatment catchment streamflows have been calibrated against daily rainfall and temperature in what is known as the climatic index approach. (Langford et al 1978). Due to the expense and time consuming nature of catchment experimentation hydrologists since the 1960s have been attempting to hasten the techniques of predicting the effect of catchment treatment on streamflow and streamflow quality. Continuous attempts were, and are being made to develop mathematical models which use the input of climatic and catchment characteristics to predict the effect of land use change on streamflows and other values. However these models still require calibration using the results of process experimentation, catchment experiments and detailed measurements of catchment characteristics if the results are to be used with confidence.

Some recent Australian research using these models is encouraging. For example the problems inherent in modelling approaches and the encouraging results obtained from a terrain analysis based model (TOPOG) are described by Vertessy and others (1993). Bonell (1993) made a strong call for further field experimentation particularly in hill slope hydrology in order to improve the performance of physical models. Lacey (1993) provides a detailed review of the interaction between forest activities, soil erosion and soil deformation. He points out that soil strength (resistance to deformation) reduces moisture content increases. He also points out that soil disturbance can expose more erodible subsoil to erosion forces. However, careful operational planning and the right choice of machines can reduce these impacts. Compacted soils can be rehabilitated by fertilisation and deep ripping. High standards of road design, construction and maintenance are required to prevent erosion and the degradation of water quality. While Lacey considers that properly implemented Codes of Practice can prevent these, he calls for more research into the effects of compaction on tree growth and into the ultimate fate of erosion products.

4.2 Effects of logging on soils

The impact of forest operations, such as roading, timber harvesting and site preparation, varies according to the percentage of a catchment subject to an operation, the fragility of the soils, the climate, the nature of the operation and equipment used, and the manner in which they are carried out.

Effects on forest soils

Langford and O'Shaughnessy (1977) review studies which showed that the method of harvesting can greatly influence soil disturbance. Severe soil disturbance can vary from 5 per cent of a harvested area after helicopter logging to over 70 per cent from conventional tractor logging. Skyline systems can reduce impacts of conventional logging to about 15 per cent.

Research in the Pacific North West showed that landslips on steep slopes with deep soils can be caused by road cuts and road drainage. Such events have occurred in Victoria and Tasmania. Rab (1992) reviewed a range of Australian studies. Rab concludes that 25 per cent of a logging coupe can be covered by snig tracks and landings. He considered that scientifically developed standards for the amount of allowable soil compaction are required. The amount of compaction can be reduced by limiting traffic and increasing soil organic matter especially in sandy soils. Where compaction occurs it can be at least partially alleviated by deep ripping and cultivation. Using mechanical methods to dispose of logging slash can reduce the loss of organic matter resulting from burning.

The mapping of readily compactable or erodible soils using a geographic information system (GIS) can enable special precautions to be taken. Systems are needed to develop an index which would indicate the times to avoid traffic on wet soils as some soil types are especially prone to compaction when wet. Constantini (pers. com. 1994) found that for coastal sandy clay loam soils that the depth of compaction on tracks used by rubber tyred skidders increased from 10 cm in dry soil to 20 cm in wet soil. Constantini also found that rutting depths may not always be a direct indication of damage. When rutting depths doubled from 15 cm to 35 cm the area of compaction more than doubled increasing from 10 per cent to 46 per cent.

Rab also points out the need to limit soil compaction as compaction effects can last from 25 to 100 years, while removal of topsoil and compaction can severely limit plant growth. The amount of compaction can be reduced by limiting the number of snig tracks as compaction can occur after a relatively few passes. The use of slope limits has the potential to decrease soil impacts as most unwanted effects increase with slope. Bonell (1993) reported that, for some soils, compaction caused by forest use can disrupt sub-surface macro-pores resulting in an increase in overland flow during storm events.

Effects of regeneration and fuel reduction burning on soils and water quality

There have been several useful Australian studies. Ronan (1985) used plot studies to investigate the processes involved in sediment production and runoff. The plots were subjected to varying intensities of fuel reduction burning. Ronan postulated that for

the gradational red loams on the site most soil movement consisted of a creep process with water flow consisting of a transient process from rainfall input to infiltration. Unit area yields of runoff and silt production in the undisturbed state were low at 1 per cent of rainfall and 75 kg/hectare/annum respectively. Higher yields occurred during the warmer and drier summer months. Following burning, runoff and silt production doubled but recovered within four years. Initially low ion concentrations increased by 100 per cent to 300 per cent but returned to normal within three months.

Immediately north of these plots an intense wildfire burnt over 5000 hectares of largely mixed species forest including the headwaters of several large catchments. All the understorey including the wet gully vegetation was burnt. Water quality sampling commenced immediately and the results compared to historic data. Storm-flow peak concentration of most ions increased by two to five times while base-flow levels doubled. Levels of most parameters returned to normal within 12 months. The changes to water quality were not a concern from a water supply viewpoint. The fact that little deterioration occurred can be put down to the generally low levels of rainfall intensity, stable soils and gentle slopes. Ronan recommended that long term damage to soil structure by repeated burning could be minimised by using low intensity fire, long burning cycles and burning when the surface soil is moist. Talsma and Hallam (1982) reported similar results for a low intensity fuel reduction burn in high altitude dry and wet sclerophyll forest. Water quality was not affected by the burn. They attributed this to the predominance of sub-surface flow and the lack of surface flow.

These results are a contrast to those reported from Leitch and others (1983) who reported on the severe erosion caused by a thunderstorm on a duplex soil six days after a severe wildfire. Debris flows of ash and surface soil resulted with soil and ash losses of about 22 tonnes/hectare which can be put down to high soil hydrophobicity, a steep slope and the high rainfall intensities which occurred in this severe event. Similar results were reported by Brown (1972) who found that massive increase in sediment loads resulted from a wildfire in two Snowy Mountain catchments. Rapid decreases in sediment yield resulted from vegetative recovery. In general, the effects of wildfire on water and soil are determined primarily by soil type, the severity of the fire and the post-fire weather.

4.3 Effects of logging on stream water quality

Physical water quality

Overseas and local studies as reported in Langford and O'Shaughnessy (1977) show the major impact that poor roading and harvesting practices can have on stream water quality particularly in steep country with unstable or erodible soils. They also show that the introduction of good practice prescriptions can markedly reduce these impacts.

More recent research undertaken in the Melbourne Water Catchments reported in O'Shaughnessy and Jayasuriya (1991) has demonstrated the potential impact of roads. Good practice roading and harvesting treatments were applied to two 50 hectare catchments located in the Coranderrk Experimental Area. One catchment had two stream crossings located in shallow gullies and the other had four stream crossings located in steeper gullies. The impact on suspended solids readings and bed load

measured in the weirs was greater and more persistent in the catchment with more stream crossings.

This was considered to be caused by the increased stream disturbance at the time of road construction and the greater impact of road drainage into the streams. These results need to be considered in an operational perspective. Ronan and others (1982) applied the results to the 16,000 hectare Maroondah Catchment where it was estimated that some 5,600 hectare were hypothetically suitable for the application of clear felling and regeneration treatments. They reported that, if the impacts of good practice roading as measured at Coranderrk were assumed to be persistent and were applied to the whole catchment over an 80 year rotation, the sediment input would increase by 15 per cent (or 49 kg/hectare/annum). Although this level of increase would be difficult to detect it still has some potential for concern in catchments where the water is chlorinated without prior filtration.

The importance of roads was illustrated by two subsequent Melbourne Water studies. In one study Haydon and others (1991) reported on the varying erosion rates from an earthen road subjected to 12 years of low and high use and maintenance. Total sediment yields varied from 52 to 89 tonnes per hectare per annum of road surface depending on vehicle use and road maintenance. These levels are much higher than the estimated long term accumulation of sediment in the Maroondah Dam of 0.3 tonnes hectare/per annum.

In the other study of roading effects (Grayson and others 1993) a 28 hectare catchment covered in mountain ash (*Eucalyptus regnans*) old growth was given a harvesting and regeneration treatment in the summer of 1984/85. Long term streamflow and water quality records comprising both grab samples and automatic stormflow samples were available from 1981 to 1991 for both the treated catchment and a nearby control catchment. The logging treatment was carried out under a strict code of practice which limited operations to the summer months, imposed stoppages during wet conditions and required a minimum 20 m buffer around streams and swampy areas. None of the temporary logging roads within the catchment crossed the stream. At the end of the operations all roads and tracks were drained. While relatively small increases were detected in base-flow turbidity, iron, and suspended solids, they were small in absolute terms and of similar magnitude to the measurement error. This seminal study shows the importance of roads and the benefits of good management practice.

The series of Melbourne Water papers reviewed dealt with catchment experiments on land systems with very stable soil subject to a high quality roading and harvesting practice. On more erodible soils the results of a combination of roading and harvesting can have much greater impacts on water quality parameters as is shown by studies reported in Doeg and Koehn (1990). Studies reported in Doeg and Koehn also show that if wildfire occurs at the same time as forest harvesting water quality degrade can be accentuated.

Cornish (1993) and Harper and Lacey (in press 1995) have reviewed the extensive literature based on research conducted for over 20 years in the Yambulla catchments near Eden in New South Wales. They reported quite widespread movement of erodible granite soil after a combination of wildfire and/or logging. Although the

movement was extensive, the soil was largely redistributed locally on the site. Concentrations and total loads of suspended sediment increased but recovered after *either* fire *or* logging in three years, or after *both* fire *and* logging in five years. Although operations were generally undertaken according to good practice, one poorly located and inadequately drained road contributed a large proportion of the sediment deposited in drainage lines by large rainfall events. The rapid decay of the impact of logging/fire can be put down to a combination of the application of good harvesting practice and rapid vegetation recovery. Cornish (1992) reported on changes to water quality caused by roading (at relatively low intensity with good practice) and logging in a high altitude, wet sclerophyll forest near Eden in NSW. The area was monitored for two years prior to logging and it was found that there only relatively minor (but statistically significant) changes to the physical water quality in the two years after logging. He concluded that erosion mitigation measures had minimised, but not prevented, erosion and the supply of sediment to streams.

Both overseas and Australian research confirm that for roading and harvesting operations avoidance of direct stream disturbance and the prevention of turbid water inflows will provide a high level of protection. Borg and others (1988) found that in Western Australia reducing river and stream buffers from 200 m to 100 m and 100 m to 50 m had no impact on water course and stream water quality. Barling and Moore (1992) reviewed the functions of buffer strips and the actual processes which occur in buffer strips. They point out that more research is needed to develop the knowledge for sound recommendations.

4.4 Effects on total dissolved solids and bacterial water quality

The review by Doeg and Koehn (1990) showed that the impacts of forest harvesting and regeneration can be variable with some studies reporting increased ionic concentrations and others a decrease. Even where there is a decrease in concentration the total export can increase due to increased flows. Langford and O'Shaughnessy (1980) provided the results of timber harvesting and roading in the Coranderrk Catchment and these results could be considered to be typical of these likely in the higher quality eucalypt forest growing on deep soils. The average concentration of total dissolved solids varied very little with streamflow and ranged from 50 mg/l in Blue Jacket Catchment to 80 mg/l in the Coranderrk Catchment. The relative proportions of cations and anions were the same as the rainfall with the addition of silica and bicarbonate from the bedrock.

Following clear felling of the Picaninny Catchment the increased streamflow caused a flush of dissolved solids with an average increase in total dissolved solids of 10 mg/l. Concentrations fell as streamflows returned to pre-treatment levels. There was no discernible effect on dissolved material concentrations from the selective cut in the Blue Jacket Catchment. There was a temporary increase in nitrate export from the Picaninny Catchment. No change could be detected in stream temperature, dissolved oxygen, biochemical oxygen demand, pH, and phosphate concentrations. Soil disturbance caused an increase in 22 bacterial plate counts for Picaninny Catchment but no changes could be detected in the levels of bacteria which are used as indications of faecal pollution.

4.5 Impacts of changes in water quality

Domestic water supply systems

The impacts of changes in the quality of water provided for domestic use depend on the quality of the water coming out of the catchment and the way it is stored and treated before it is supplied. At present, many country towns do not have filtration and disinfecting facilities. In Victoria, for example, only 66 of 347 country towns had full treatment facilities, and 149 had no disinfection facilities. Some have only 'run-of-stream' water supply systems, where streams are diverted to supply without detention in storage and are therefore particularly susceptible to changes in water quality (Langford and O'Shaughnessy 1977). This is often critical because the average turbidity of many forested streams is naturally about the maximum turbidity level set by the 1987 National Health and Medical Research Council Standards (5 Nephelometric Turbidity Units) for domestic consumption.

By contrast large reservoirs generally have a major capacity to improve turbidity levels in stored water. However occasionally high turbidity readings can occur in the outflow. Given that their purification ability may not always be effective, there are major benefits in keeping inflow turbidities into major storages as low as possible.

Impact on stream biota

Forest roading and harvesting operations have the potential to affect stream habitat values and therefore stream biodiversity in the following manner:

- Removal of stream bank vegetation thus affecting stream temperatures and reducing leaf fall;
- Introduction of increased bed load and suspended material thus affecting macro-invertebrate habitat and numbers, fish, spawning habitat and fish/prey interactions;
- The introduction or removal of debris in the stream thus affecting stream dynamics;
- Pollution of streams through oil spills, inappropriate choice and use of herbicides and pesticides;
- Change in stream access to vertebrates;
- Changes in flow regimes through accidental diversion of streams and in some cases major changes in vegetative cover.

Doeg and Koehn point out that studies to quantify the effects on biota of forest operations are difficult due to the problems of determining what was the natural variation in populations prior to any disturbance. The studies are necessarily long term and can be technically difficult.

Some studies have not monitored the impact of actual forest operations but instead have artificially manipulated the environment. Doeg and Koehn found that no Australian studies had examined and reported on the impact of forest operations on fish populations using methods which lead to absolute confidence in the results. Since their review, Davies and Nelson (1994) have reported on a Tasmanian study which used 45 matched sites. One site of each pair was located upstream of a harvesting

operation and the other downstream. The treatments involved conventional and cable logging operations with stream buffer widths varying from 0 to 50 metres. They found that, below a width of 30 metres, buffer width had a significant impact on stream sediment algal growth, water temperature, and the volume of snags. There were also decreases in macro invertebrates and brown trout abundance. Coupe slope, soil erodibility and time since logging (1-5 years) had no effect. Above a buffer width of 30 metres the impacts of logging were not significant.

Overseas studies have reported detrimental affects on fish populations of decreases on stream vegetative cover. Other overseas studies have shown that fish populations can be reduced by activities which increase water temperature and increase silt loadings. American research has shown that macro-invertebrate density reduced with the increasing age of the riparian cover but increased with increased shading. Sediment inflows can reduce invertebrate numbers. Buffer strips have been found to reduce the effects of logging. Some studies show a recovery after disturbance which can vary from a few years to over 10 years. Australian studies have shown qualitative effects on stream fauna due to forest operations but the study reported in from Davies and Nelson is the most definitive to date.

Another Australian study of interest is that by Doeg and Milledge (1990). It shows that many invertebrate taxa increased their rate of drift when suspended sediment concentrations rose above 133 mg/l from a background of 25 mg/l. Such studies are needed in order to develop effective suspended sediment criteria for the protection of aquatic ecosystems. Doeg and Koehn consider that Australian studies into the effects of logging on water quality parameters and stream habitat need to be wider in scope, have a better statistical basis and a longer period of record. Nutrients, temperature, the role of bed load sediment, vertebrates other than fish, and aquatic microphytes all need more study. If the causes of regional differences in experimental results can be understood the results will be transferable.

4.6 Environmental standards and monitoring

The *National Forest Policy Statement*, finalised in 1992 and finally agreed to by all States and the Commonwealth in April 1995, contains a commitment that consistent nation-wide base line environmental standards will be established for forest use and management. They will be endorsed by Governments and met through Codes of Practice. To this end a draft report for comment has been prepared by the Technical Working Group on Forest Use and Management and issued in late July 1995 by the Joint Australia and New Zealand Environment and Conservation Council / Ministerial Council on Forestry, Fisheries, and Agriculture, National Forest Policy Implementation Sub Committee (JANIS).

The report deals with soils, water, flora and fauna and pests and diseases. A critical review of the document is beyond the scope of this report preliminary comments can be made. The section on soils is soundly based and it is agreed that monitoring should be undertaken on a case study basis rather than for all the forest estate. However, the intensity of sampling required to detect a 10 per cent change in the parameters described would make routine monitoring expensive. The section on water requires a detailed review and comment in regard to the protection of those potable water sources which are given only minimal detention and treatment and the management of

water yield especially where potential declines could be caused by afforestation and/or conversion of old growth forest to a regrowth condition.

The question of monitoring needs careful evaluation. Olive and Rieger (1988) show that sediment sources and transport systems need to be understood in the light of natural variability and the effects of extreme events. The costs of sampling and analysis are such that consideration should be given to sampling representative regional catchments for say a 5 to 10 year period. The results need to be linked to catchment events so that management practices can be improved where necessary. Some of the standards need to be made more practicable. For example, the Australian and New Zealand Conservation Council (ANZECC 1992) developed some water quality guidelines. They set the standard to be less than 10 per cent change in seasonal mean concentrations, but it is doubtful if anything less than 15 per cent could be detected. Their standard of 0 faecal coliforms per 100 ml is unrealistic given that forest streams can have high readings due to wildlife.

4.7 Effects of forest change on streamflow

Recent and not so recent reviews have discussed the interaction between forest change and streamflow characteristics for the Australian context and the outcome of these reviews along with recent research will be discussed. This review will have an empirical thrust rather than one dealing with the fundamentals of the hydrological cycle. At its simplest, on a year to year basis, streamflow is the residue of rainfall after allowing for evaporation from vegetation, changes in soil storage from year to year and deep drainage to aquifers. Logging can interfere with these processes by changing vegetative cover, hence affecting evapotranspiration and therefore streamflow, and can compact the soil which can reduce its ability to absorb and store water and hence the proportion of rainfall delivered as base and storm flows.

Changes in forest cover

The outcomes of reviews such as those by Bosch and Hewlett (1982), Cornish (1989), and Nandakumar and Mein (1993) are provided as useful background. Figures 1 (from Cornish) and 2 (from Nandakumar and Mein) show that streamflows from forested eucalypt catchment only become appreciable above rainfalls of 800 mm per annum and greater. The actual streamflows vary according to the location and aspect of the catchment but on average increase with rainfall, elevation, and shelter from radiation. For example the lower altitude mixed species forests of the Melbourne Catchment area yield about 200 mm per annum while the undisturbed upland old growth ash type forests yield over 1000 mm per annum.

Figure 1 shows the impact of higher forest evapotranspiration on water yield compared to pasture. For example for an average annual rainfall of 1000 mm streamflows from forest are 50 per cent less than those from pasture. For higher rainfalls the difference in percentage terms is less at 33 per cent. These differences show the effect of permanently converting forest to pasture and conversely show the effect of afforestation of pasture. Cornish predicts that streamflows from pasture sites with average annual rainfalls of about 1000 mm can be expected to decline by 200 mm, or over a 50 per cent, after afforestation with radiata pine (*Pinus radiata*). These

potential declines raise planning issues for local regions where pasture streamflows may be regulated for local irrigation use.

Figure 1 Evapotranspiration and rainfall for fully forested catchments. The black circles show radiata pine plantations in South Australia (from Cornish 1989)

Figure 2 Annual catchment loss vs. rainfall for eucalypt catchments (from Nandakumar and Mein 1993).

Effects of wildfire on annual streamflow

Both Langford (1974) and Kuczera (1985) investigated the effects of the 1939 wildfire in the Melbourne Water catchments. This wildfire burnt at an intense level through several large catchments supplying water to Melbourne. The fire resulted in the death and regeneration of over 45,000 hectare of ash type forest and the destruction of the canopy along with limited tree death of large areas of mixed species forests. Analysis showed that the known declines in catchment yield could be explained by assuming that water yield from the mixed species forest stayed constant while that from the ash type declined to about 50 per cent of pre-fire flows, reaching a minimum some 30 years after the fire.

Kuczera used streamflow data from a wide range of operational catchments with ash type forests burnt in the 1939 wildfire. He showed that for every 1 per cent of catchment converted from old growth to regrowth a decline of 6 mm in water yield could be expected some 30 years later. Predicted effects were then modelled (Figure 3). For the mixed species foothill forests, Langford (1974), Kuczera (1985), and Read Sturgess (1992) assumed that any yield changes in mixed are temporary due to the rapid recovery of forest canopy and the persistence of the mature rooting system. Hence, they were able to adopt the concept of there being no long-term yield changes.

Figure 3 Water yield and stand age in ash type forests (from Kuczera 1993)

Effect of forest harvesting and regeneration on streamflow

From a hydrological perspective (but not from an ecological one) the impact of harvesting and regeneration in the ash type forests is comparable to the impact of

wildfire. For the mixed species forests of the eastern seaboard harvesting until recently was selective with only minor modifications to the forest canopy. Since the 1970s clear felling operations, used in the integrated logging regime, have resulted in extensive openings of the canopy, although a much reduced upper canopy of seed or habitat trees generally remains. Felling is followed by large scale natural or artificial regeneration.

Following clear felling in both ash and mixed species forests, Nandakumar and Mein estimate that for every 10 per cent of a catchment cleared, a 33 mm increase in runoff can be expected. Flows reach a peak 2 to 3 years after clearing and then decline which, in the case of the Melbourne Water, meant a return to pre-treatment levels in some 5 to 8 years. For these ash type catchments, water yield continued to decline below pre-treatment levels (as shown in Figure 3). In the case of Piccaninny catchment, which had 80 per cent of its forest cover clear-felled and regenerated, water yield declined to 50 per cent of its pre-treatment level. This finding is compatible to the yield changes reported by Kuczera after wildfire. The temporary increase in yield following experimental clearing and regeneration has been incorporated into the Kuczera model (Figure 3) for recent modelling studies (such as the Read Sturgess 1992 study).

Cornish (1993) reported clear felling and regeneration experiments in moist old growth eucalypt forests in the central coastal ranges of New South Wales. Immediately after logging, water yields increased in a similar manner to those reported by Nandakumar and Mein. Streamflows then decreased at a rate proportional to proportional to the density of the regrowth and reached pre-treatment level in about 4 to 6 years. In a catchment with the highest density of regrowth, water yields five years after treatment had dropped significantly lower than the pre-treatment level by about 200 mm representing an approximate 30 per cent reduction in pre-treatment streamflow. This work is important because it shows effects similar to those in the Victorian ash forests.

Unfortunately there are no recent long term catchment experiment results available for mixed species forests on the eastern seaboard which might indicate effects of clear felling and regeneration on streamflow. Although, a number of experiments have been established the results have not been analysed due to staff and funding shortages. However, Cornish (1993) and Harper and Lacey (1995) have reviewed the extensive literature dealing with the results of fire and timber harvesting on streamflow in five small sub-catchments of the Wallagaraugh River known as the Yambulla Catchments (quality effects are noted elsewhere in this report). These catchments have a granite bedrock with relatively shallow, erodible soils. After fire and logging, separately or in combination, large increases in the annual flows occurred but largely returned to pre-treatment levels within 4 to 8 years. Return to pre-treatment levels was slowest where catchments were both burnt and logged. Peak and storm flows increased by 2 to 10 times, with the increases being larger where the catchments were both burnt and logged. As the vegetation recovered, the flows returned to normal within four years. Harper and Lacey concluded that most of the impacts fell within the natural fluctuations of the Yambulla catchments and that any excessive results were of short duration.

A recent study (O'Shaughnessy and others 1995) shows, for a central Victorian mixed species catchment (The Lerderberg), that logging 16 per cent of its area between 1985 and 1994 had no statistically detectable effect on long term water yield, which has been stable for the entire period 1960 to 1995.

Clearly, research work into the problems of water yield from the drier mixed species forests of the eastern seaboard requires an increase in research resources and active support and direction by government.

Effect of forest thinning on streamflow

O'Shaughnessy and Jayasuriya (1991) described the effects of various forms of thinning in the ash type forests. Reductions of 50 per cent in the basal area of stands about 40 years of age lead, in the case of a uniform thinning, to streamflow increases of about 30 per cent which lasted for about 15 years. In the case of a similar reduction in basal area due to strip thinning a similar streamflow increase occurred but indications are that the increases will be more persistent. Overall it appears that changes in streamflow occur in the spring-summer period when evapotranspiration is highest and rainfall reaches its seasonal maximum. While a 50 per cent reduction in basal area due to thinning leads to a decline in final timber production, Benyon (O'Shaughnessy and others 1993) found that in economic terms this is more than off set at discount rates of 2 per cent or greater by the value of obtaining an intermediate timber return with a further bonus compensation due to the value of the increased streamflows.

4.8 Mechanisms operating to change streamflows

When streamflow changes occur they are mainly due to changes in evapotranspiration caused by changes in canopy leaf area which in the ash type forest are reflected in the area of sapwood. Jayasuriya and others (1993) describe the processes operating in mountain ash in terms of relatively uniform sap-flow velocity independent of age but a variation in the amount sapwood per hectare. This reaches a peak early in the life of a stand and then steadily declines. The combination of sap-flow velocity and sapwood area allows transpiration volumes to be determined. Increased evapotranspiration during the spring/summer period due to the high leaf area of regrowth leads to a greater proportion of winter rainfall being needed to replenish the soil store thus delaying and reducing the amount of spring and summer rain converted to streamflow. Conversely the much lower leaf area/sapwood area of old growth ash type forest leads to reduced transpiration rates and higher streamflows. For any one forest stand, the total water use is a combination of its rainfall inception and transpiration characteristics. Both vary with the type of stand and change with time.

Seasonal distribution

Nandakumar and Mein examined the seasonability of changes in streamflow following forest treatment. They concluded that the greatest proportion of the annual increase appeared in winter and spring while the bulk of yield decreases occurred in

spring and summer. For the Corranderrk Catchment inspection of raw data indicates flow declines are greatest during spring and summer.

O'Shaughnessy and Jayasuriya (1994) found that the higher percentage flow increases following uniform thinning appeared in the January-April period. Haydon (O'Shaughnessy and others 1993) found that both the highest absolute increase in flow and percentage increase occurred in the October/March period. In summary, for temperate climates it appears that changes in streamflow from the ash type forests are greatest during spring and summer. Similarly, Cornish (pers. comm.) considers that, for the central NSW coast, the greatest relative changes in yield occur during August, the driest month.

5. FOREST USE AND MANAGEMENT

The management of forests outside the conservation reserve system involves the recognition, assessment and balancing of all the uses, values and functions which they provide. The full decision-making problem is formidable. Although valiant attempts have been made to place economic values on matters such as species survival, scenery and wilderness, they have not found a place in planning practice. However, water and timber are commodities to which commensurate market values can be attached, as discussed in the next section of this report. This section describes advanced planning operational planning, and operational practice.

5.1 Advanced planning systems

The decision-making problem can be described first in relation to wood production. There are two types of decision which have to be made: the silvicultural system to be applied to each stand in the forest has to be prescribed, and the total yield of the forest, or 'allowable cut', has to be set at a level that is sustainable. The problem is difficult because forests are made up of a great many stands, the decisions have to be made simultaneously, and for a planning period long enough to ensure that sustainability criteria can be met. Computer-based modelling has enabled this to be done since the 1970s. The models provide schedules showing, for the prescribed silvicultural systems, which logging operation should be conducted in which patch of forest in each future period in order to meet the overall supply commitments.

Advanced planning systems were developed from this approach in order to model forests with multiple uses and values. They were first applied in Australia in a pilot project conducted in the Otway Ranges in Victoria (see Brinkman 1990; Dargavel and others 1995; McKenney 1990; McKenney and Common 1989; and the references to the extensive documentation these contain). There was sufficient quantitative information to be able to model wood production, water yield, habitat change, budget requirements and employment. A planning period of 100 years was used, made up of 10 periods each of 10 years.

The Otway model provided interesting results in relation to water. Some but not all of the catchments were important in providing water supplies to Colac and Geelong and

the ash forests there have a marked response of stand age to water yield, hence it was important to ensure that logging in the forest did not unduly diminish the water yield. The model was constrained to ensure that this could not happen and showed that by carefully distributing the logging between the various catchments throughout the planning period, both timber and water yields could be sustained in an even manner. Such models can provide important economic insights (from the marginal values attached to constraints). More importantly, they provide the most thorough means of conducting an economic analysis of the trade-offs over time between water and timber production (especially in the face of the many other values and constraints which apply). The reason for this originates in the great diversity of stand conditions in a forest and the number of silvicultural alternatives available for each. For example, a forest might reasonably be modelled with say 1000 stands for each of which there might be say 20 alternative silvicultural options for varying the frequency and intensity of logging operations. Theoretically, there could be 20,000 different ways of scheduling the operations in the forest as a whole; in practice there are fewer but still several thousand from which to select. The remarkable malleability of the decision-making problem comes from the ability to juggle wood yields, and their consequent effects on water yields in future years, between stands over a long periods of time. This means that economic analyses of the effects of land use or management changes often need to examine values attributable to long-term changes in the system as a whole. Analyses of simple trade-offs between water and timber production may lead to erroneous estimates. The importance of this for determining public policy is not as widely appreciated as it should be.

5.2 Operational planning

The manner in which logging operations are planned has a significant effect on their impact on water quality and other values. Operational planning is guided not only by the long-term plans, but also by the raft of legislation, policies, and regulations that apply to the forest sector including those from State water and soil conservation authorities. Having digested all these, operational plans are made for 1 to 3 year periods. Critical features are:

- specification and siting of any new forest roads,
- the siting of feeder roads, landings and dump sites,
- the identification of the trees or stands suitable for logging and the particular silvicultural regime to be applied,
- the recognition of areas to be excluded from logging, or require special treatment on account of their soils, slopes, habitat, wildlife corridors, amenity and other reasons,
- the distribution of coupes across the landscape, and
- their landscape design.

Having been planned, the design has to be laid out in the forest (Map 3) and the loggers and other relevant authorities advised. This involves substantial documentation and field work. Operational plans are also made for fire protection, recreation, plantation establishment, vermin and noxious weed control for example, all of which have effects on water.

Map 3 Example of layout of logging coupes in an operational plan

5.3 Operational practice

The potential for forest operations to affect water yield and quality, soil and a wide range of environmental values has been reflected in regulations which, over the last twenty years have become increasingly detailed. In Victoria, for example, the results of the Melbourne Water research were amongst information used in the formulation of the Government's *Timber Industry Strategy* (1986) and the Department of Conservation Forests and Lands' *Code of Forest Practices for Timber Production* (1987). These policies require the general protection of water values. Where water production is important, they specify that forests are be managed by appropriate techniques, such as thinning and long rotations. Water quality is protected by limitations on the proportion of a catchment which can be logged in any one year and the specification of appropriate roading and logging practices. Detailed requirements are elaborated for each forest region.

Codes of forest practices

All the Eastern seaboard States have codes of logging practice or regulations in place aimed at protecting forest values including water yield and quality. The Victorian and Tasmanian codes are particularly comprehensive. Currently the Victorian code is being renewed and revised. O'Shaughnessy (1995) conducted a review of the

perceptions of the Code of Forest Practice held by workers, contractors and supervisors. Its major findings were:

- the overwhelming proportion of timber industry workers accept the benefits and need for codes of practices;
- compliance is perceived to be good, which is not always the case;
- better training for workers and instructors is needed;
- the pressure to keep up the supply of timber results in logging during inappropriate weather and soil conditions;
- loggers need to be paid enough to cover the costs of good practice;
- specialised contractors with the right equipment should be used to clean up coupes and maintain roads;
- fair and efficient mechanisms are needed to penalise non-complying operators;
- low maintenance road drainage systems are needed; and
- more research is needed into the prescriptions for buffer strips and their use for multiple benefits Bren (1995).

If the comprehensive codes of practice now specified were applied at a high standard in all public and private forests, the impacts on water yield and quality would be greatly reduced. They need to be applied retrospectively to old works, especially roads, to bring them up to standard. The key matters are:

- Road planning, design, and maintenance aimed at preventing the direct entry of road drainage into streams.
- Many fire trails being used by 4WD vehicles for recreation and with little maintenance need to be closed or relocated.
- The adoption and protection of buffer and filter strips wide enough to prevent overland drainage from logging areas directly entering stream courses.
- The prohibition of logging when soil moisture content is high.
- Adequate logging site rehabilitation including the ripping of landings and the drainage of snig tracks.
- Good management of herbicides, pesticides and fertilisation applications. This requires avoidance of non-target areas, the use of adequate buffers, control of droplet size and keeping a strict watch on excessive wind speeds.

6. ECONOMIC IMPACTS OF CHANGES IN WATER YIELDS

6.1 Water as a multiple-use resource

Competing demands for water in the Australian inland rivers have driven home the fact that water has alternative uses. There is now a substantial body of research into the economic consequences of the allocation of water among various uses. However, with the exceptions of the Hunter and Nepean-Hawkesbury Rivers, for the most part, on the eastern seaboard there has not been great competition for the water that flows down streams and rivers to the sea. There are signs that this will change as demands for limited water supplies intensify.

The principal uses of coastal water resources are to support:

- domestic and industrial consumption;
- irrigation for crops and livestock production;
- fisheries;
- recreational activities;
- hydroelectricity production;
- natural systems; and
- cultural, scientific and educational purposes.

Domestic and industrial consumption

Water use for these purposes is growing at rates of around 2 per cent per annum and would continue to grow at this rate in the absence of water conservation measures, which are expected to become more widespread. However, the switch from rate-based to user charging by metropolitan water authorities does appear to have reduced increases in domestic and industrial water consumption. For example, Sydney Water shifted to a pricing system based on user charges, eliminating cross-subsidisation from industrial to domestic users, but at the same time introduced demand reduction measures. About half of the domestic water consumed is used for gardens. While demand for water for use inside houses is not very responsive to price increases, demand for water for outside purposes (gardens and car washing) is price sensitive, especially in the longer term as households have the opportunity to switch to native gardens.

There are very large investment costs associated with providing water storage for urban water supply, so that decrease in stream flow may mean that greater or earlier investments in dams become necessary. Similarly, increased siltation of streams due to upstream economic activities may require dredging of dams or construction of new ones before they are due. These both impose costs on urban water consumers. Sediment from logging activities can increase the cost of municipal water treatment. Holmes (1988) found that the cost per thousand tonnes of sediment is between \$10.84 and \$27.95.

Irrigation for crops and livestock

On the eastern seaboard agricultural irrigation includes dairy cattle, sugar cane and horticulture. Declines in streamflow may have a significant impact on the volume of water available for irrigation. For example, it has been reported that dairy farmers require 1000 litres of water for every litre of milk produced.

Fisheries

Fisheries are used by both recreational and commercial fishers. In some areas it includes aquaculture. Changes in water quality and quantity affect the ability of rivers to sustain fish populations.

Recreation

The types of water-based recreation in a catchment depend on the type of river. Narrow, fast-flowing upland rivers characterised by rapids and clear, clean water are preferred for rafting, bushwalking and picnicking, while wide, slower-flowing and turbid lowland rivers are preferred for power boating, skiing, house-boating and camping. Both types of rivers are used for swimming, fishing and canoeing.

In many parts of the eastern seaboard, tourism based on nature recreation is emerging as an important industry sustaining regional growth. Hansen and Hallam (1991) found that the cost to recreational users and tourist industries of declines in water quantity and quality could be substantial in some catchments. Loomis (1987) calculated marginal values of in-stream water flows for recreation to be in the range from \$11 to \$22 per megalitre. Brown and Daniel (1991) found that in-stream flow is an important factor in public perceptions of scenic beauty.

Hydroelectricity production

The Snowy River has been diverted as part of the supply for the Snowy Mountains hydroelectric scheme. Beyond this, there is almost no hydroelectricity generation in the eastern seaboard area under study as the river systems on the coast are mostly unsuitable. However, it may be noted that in other regions where hydroelectricity is generated any decrease in streamflow will have a direct bearing on the amount of energy generated. Bearing in mind that hydroelectric energy is especially valuable because it can be generated at times of peak usage, the value of this foregone energy is the opportunity cost of generating electricity at peak times by other means.

Natural systems

Continued healthy functioning of a water course is often measured by its assimilative capacity. Australian river systems are unique in the world for the high levels of variability in flows due to seasonal factors and droughts. Activities that cause inputs such as silt and pesticides to exceed the capacity of rivers to assimilate them or which lead to larger fluctuations in water flows may disturb the ecological quality of water courses. Blue-green algae blooms on the Hawkesbury-Nepean are a case in point. While such disturbances may not have any direct or indirect economic costs, it is likely that they are nevertheless considered by most people to be impacts to be

avoided even if it means some loss to the economy. An analogy might be drawn with the natural values of Coronation Hill in Kakadu National Park which was threatened with disturbance from mining. Australians expressed a strong desire to preserve the hill even though \$500 million of gold and other minerals would be forgone (Imber, Stevenson and Wilks 1991).

6.2 Scarcity and the value of water

Introductory economics textbooks often use the ‘diamond-water paradox’ to illustrate the idea of utility. Adam Smith pointed out in the 1760s that while water, which is essential to life and has many uses, sells at a very low price, diamonds, which have limited usefulness, sell at a very high price. This puzzle - that why something that is enormously useful has a very low value while something that is not very useful has a very high value - was resolved by understanding the relationship between abundance of a resource and its price. When water is in abundant supply, as it has been in most parts of the eastern seaboard, people use as much as they want to. An extra litre of water does not add much to their level of satisfaction, so the price they are willing to pay for it is small. Diamonds, on the other hand, are very scarce and each extra diamond makes a substantial addition to the value of the stock of diamonds. People are thus willing to pay more for them.

There are signs that the demand for water in more catchments on the eastern seaboard from various users is beginning to approach the supply and that therefore water will become more and more scarce. As various users begin to compete for water resources the price of water is likely to rise. According to economic theory, water should be allocated to the users who are willing to pay most for it, and they will be the users who benefit most from its use, although this fails to take account of equity and sustainability conditions. Scarcity will mean that some users will miss out, or will gain access to less water than they might want. Allocation of water to one use means that it has an ‘opportunity cost’, and that is the foregone output of water users who missed out.

In the past, the abundance of water on the eastern seaboard has meant that the water used up as a result of forest operations has not been valued. As other users emerge who can make use of the water used up in forest operations then that water has a value. Thus forest operations use water as an ‘input to production’ and the question is now being asked is this: given that there are alternative users of water that flows out of forests, is the use of water in forest operations the most efficient way of using the water or should it be allocated to other uses? The concept of ‘efficiency’ needs to be interpreted to include long-term sustainability.

On the big inland rivers, where the availability of water and quality of water has been a contentious issue for some time, systems have developed to allocate and regulate it. On the eastern seaboard, water licenses have usually been required, although they have not always been based on volume. Little is known about the effects of changed water conditions due to licensed water extraction on downstream water users.

Logs-water production possibilities

The hydrological evidence reviewed in this report indicates that current logging regimes in the native forests of eastern Australia result in a decline in water yields. Other things being equal, an increase in rotations reduces the volume of logs taken out of a forest over time but increases the run-off due to a decline in evapotranspiration. In catchments used to supply urban centres, this means that there is less water flowing into dams that provide water to cities and towns for drinking, washing, cleaning, watering gardens and industrial uses. We can represent this trade-off between the volume of logs and the water yield from a catchment by a 'logs-water production possibilities frontier' (Greig n.d.). Figure 4 shows a hypothetical production possibilities frontier for a catchment. As the volume of logs increases along the horizontal axis (due to shorter and shorter rotations) the water yield from the catchment declines.

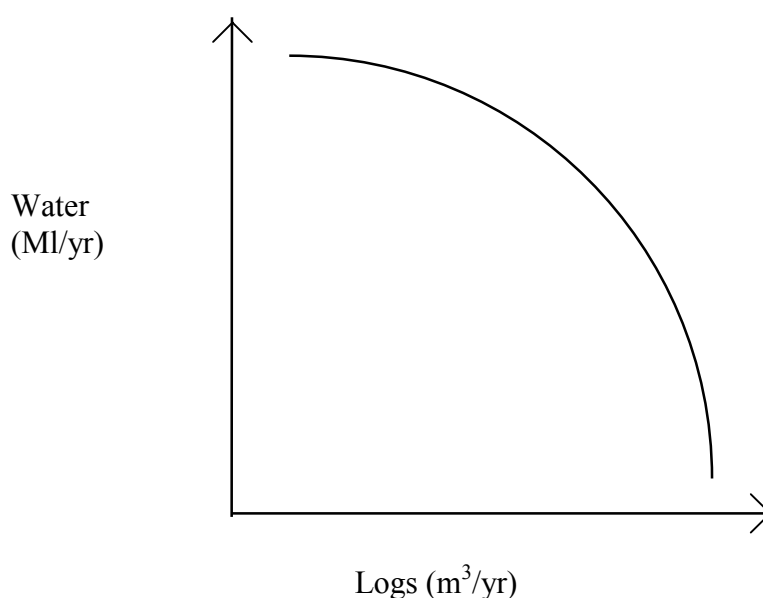


Figure 4 Logs-water production possibilities frontier

In practice, the story is more complex because rotation length is only one of the factors affecting the volume of logs and the yield of water. Others include the prevalence of thinning and various other silvicultural practices. In addition, the log volume-water yield relationship varies according to the type of forest and location of the catchment.

The curve in Figure 4 shows possible combinations of logs and water yields. It is the ability to manage forests according to a great many silvicultural options (section 3.3) produce different combinations of logs and water. The economic optimum combination depends on the relative prices of logs and water. Determining the prices of logs and water thus becomes very important to the efficient allocation of water to tree growing rather than other uses.

6.3 Pricing of water

The actual prices of logs and water are determined in large measure by administrative measures rather than by market pressures. In the case of logs, prices are set as royalties determined partly by the costs of forest management (usually weighted from area to area by production and processing costs), partly by historical precedent and political pressure, and partly by market prices obtained in auctions of non-licence parcels of logs. Water prices have also been determined by costs of collection and distribution and social priorities rather than opportunity costs, although this is changing. While pricing by means other than markets may be appropriate in practice, this raises difficulties in the measurement of the values of logs and water.

On the eastern seaboard water is not bought and sold in markets, putting prices on water in its different uses needs to be done indirectly and may involve technical complexities. In the case of water used for town and city water from the tap does have a price, but this price will be higher than the value of water in the streams of catchments because there are costs associated with getting the water from the catchment to the urban user. In this situation, three methods are available to estimate the value of water for urban consumption so that it can be compared with its alternative use in growing trees.

The constant residual price approach

This method requires first an estimate of the true willingness to pay per kilolitre by urban users (actual prices are administered prices and do not necessarily reflect true economic values). To arrive at a price for water 'in the stream' it is necessary to subtract the costs of water distribution (disinfection, pumping and augmentations to storage) from the final volumetric charges paid by urban consumers.

Variable price approach

The above approach does not take account of the responsiveness of demand for water to changes in price, but estimates the price for the current level of demand. Estimation of the responsiveness of demand to price changes into the future allows a better estimation of the value of water in different uses. However, accurate estimation of demand curves is difficult.

The opportunity cost approach

Growing populations in the cities and towns will require investments in augmentation of water storage capacity -- increasing the capacity of existing dams, building new dams, and river diversions. If stream flows are reduced as a result of logging then it will be necessary for these capital works to be undertaken sooner than they otherwise would. This imposes an economic cost on urban water users. The opportunity cost of using water to support log harvesting is the cost of bringing forward these investments in headworks.

Conversely, additional water obtained by not logging the forests is valued at the extra cost of capital works required to augment the supply of water. This extra cost arises from the need to bring forward capital works as a result of reduced stream flow after logging. Increased stream flows as a result of longer rotations would allow authorities, such as Melbourne Water, to delay building more dams or other

expenditures on augmenting headworks. The approach attempts to find whether the least cost way of augmenting future capacity is by reducing logging intensity or by investing in additional capital outlays. This method deals with total costs and does not need to calculate a unit price for water.

The opportunity cost method can be also used to estimate the value of water to other types of water users. For example, dairy farmers require water to irrigate pastures for their cattle. If logging reduces streamflow to the point where farmers cannot get enough water then the milk productivity of their cattle will decline. Although this is especially likely during droughts, the impacts of forest use on yield are less during droughts than in other years. The value of water can then be estimated by the lost output of the farms. A similar procedure may be used to estimate the value of water to water-based tourism industry and fisheries. However, in these cases it is very difficult to isolate the impact of changes in streamflow and water quality on output.

6.4 Economic studies of the impact of logging on water

There are very few studies in Australia (or elsewhere) of the economic impact of logging on other users. A prescient and interesting precursor was carried by P. J. Greig in 1981 examining water-timber trade-offs in another Victorian catchment. The outstanding study was undertaken by Read Sturgess and Associates for Melbourne Water. It examined options for the use of the Thomson catchment (Read Sturgess 1992). That study was revised by Read Sturgess and Tasman Economic Research in 1994 but its report has not been publicly released. The only other study of direct relevance is by Costin, Greenaway and Wright (1984) although that study is much more notable for its hydrology than for its economics and is not reviewed in this section.

Greig's study

Greig (n.d.) set out to estimate the optimal production of logs and water from the Maroondah catchment that supplies some of Melbourne's water. The catchment had never been logged at the time of the study because of the perceived scarcity of high quality water and its value for nature conservation. Hydrological data suggested that the effect of harvesting and regeneration in a mountain ash forest would be first an increase in average streamflow and then, after 5 to 6 years, to a decrease which would persist for many decades. The average streamflow after logging was expected to fall by around 13%.

Greig valued logs at their royalty rates (\$10.65 per cubic metre), despite acknowledgment that these rates were set by administrative decree and probably underestimated the true economic value of logs. The unit value of water was estimated by the marginal cost of augmenting yield (the estimate was \$79 per megalitre). These costs would include increased costs of storage and distribution.

Greig considered various options involving different rotations and thinning practices. The results of the analysis showed that logging using 60-year rotation generated slightly higher revenues than the no-logging (status quo) option, while logging with a 150-year rotation showed revenues a little higher still. However, the option with highest return was one involving a thinning without regeneration. In this case, 50% of

the forest is cleared and turned over to scrub (i.e. deforested). This option not only generates a once-only log volume but actually increases the water yield (by 6%). Recognising the problems with such a conclusion, Greig abandons the strict economic approach and rules out this last option as 'infeasible'. He develops a further option with a 60-year rotation with thinning at 30 years and concludes that this is the best one. A dubious discussion of other impacts of the various options does not lead to any modification of this conclusion.

Read Sturgess Study 1

Melbourne Water was concerned about the potential loss of water as a result of logging in catchments which became part of the Melbourne system in the early 1980s. It commissioned Read Sturgess to evaluate economically a range of management options involving different mixes of wood and water production from the Thomson River catchment. It should be stressed that each forest management option has impacts on several types of forest value, including ecological values, non-timber forest products, non-urban water uses, and recreational values. The study deals only with timber values and the value of water for Melbourne consumers. Moreover, the results of the study pertain only to the Thomson catchment and should not be extrapolated to other catchments which may have different forest cover, soils, hydrological characteristics and uses. The results for the Thomson catchment depend on (at least) three important factors:

- logging in ash-type forests appears to have a higher impact on water yields than in other forest types;
- the Thomson catchment provides a large proportion of the water supply of a major urban centre; and
- excess storage capacity in the Thomson means that increased water yields will be economically valuable because the water can be captured.

Previous hydrological work by Melbourne Water in similar, older catchments indicated that a reduction in timber harvesting would be very likely to increase the water yields from the Thomson catchment and thus the water supply to Melbourne. The study simulated the physical and economic implications of a range of silvicultural options and compared them with the status quo, that is, the existing harvesting plans for the Thomson catchment. The status quo is defined by an 80-year rotation in ash-type forests, the predominant forest type in the Thomson.

Two harvesting features were varied to give a range options for evaluation:

- the rotation -- varied from 40 years to 200 years and to no logging at all. Other things being equal, a longer rotation will reduce the volume of timber and increase the water yield; and
- the use of thinning, that is, removal of a proportion of the basal area after, say, 20 or 50 years, followed by clear felling. Not all parts of the area are suitable for thinning. Thinning can take the form of strip (or 'corridor') thinning involving the thinning by long thin corridors of perhaps 20 to 35 metres wide.

Table 4 Returns to silvicultural options in the Thomson Catchment
(net present values in \$ millions)

<i>Option</i>	<i>NPV (\$M) relative to Status Quo (Base Case)</i>
No logging	147
40 year rotation	4
120 year rotation	45
200 year rotation	102
80 year rotation with thinning	19
200 year rotation with thinning	113
200 year rotation with strip thinning	169

Source: Read Sturgess (1992), Table 4.3

Estimates were made of wood yields and water yields for the eight silvicultural options thus generated for the 200 year period of the study. These volumes of wood and water were then valued using price estimates. The price of standing timber was estimated by relying on information from auction prices for timber harvesting licences. The base case prices for sawlogs ranged from \$35 to \$60 per cubic metre. The price of water 'in the stream' was estimated using the constant residual price approach described in the last section. The base case price for urban water was estimated at \$530 per megalitre. Using a discount rate of 4%, the study calculated net present values for the silvicultural options and reported the difference between NPVs for the status quo and each other option. The results are reproduced in Table 4.

All of the options considered show improved returns over the status quo. In other words, among the options considered, the existing management of the Thomson catchment is the most inefficient. According to this analysis the best options are either a very long rotation (200 years) or a complete end to logging. The clear conclusion is that, using the estimated prices for timber and water, the loss of timber as the rotation is lengthened is more than compensated for by the increased water yields. If other values were taken into account, in particular ecological values, it is likely that the results would favour long rotations or no logging options even more strongly.

Read Sturgess Study 2

The 1992 Read Sturgess study was revised by Read Sturgess and Tasman Economic Research in 1994. The second study differed from the first by valuing water by the opportunity cost method and considering a wider range of silvicultural options. Although the report itself has not yet been publicly, press reports indicate the study generally confirmed the results found in the first study. However, both studies have been criticised by Ferguson (1995) for their methods of valuing water.

6.5 Some general principles of forest economics

The results of the Greig and the Read Sturgess studies illustrate some of the general principles of forest economics which should be applied to the economic analysis of other catchments.

Relative pricing. Finding the optimum economic mix of commodities which can be produced jointly from forests requires estimates of the economic values of timber and water (and other commodities and attributes where possible). It is their relative marginal values that are important. In some cases, such as the Thomson catchment, the need to augment water storage through expensive capital works at various points in the future can give water a very high value. Such data then must be combined with the silvicultural options (joint production possibilities, Figure 4) to find the best economic solution. However, there are environmental impacts of silvicultural options that are difficult to quantify, so that ultimately decisions require social and political judgements as well as economic analysis.

Silvicultural options The silvicultural options which affect water yield are those of rotation length and thinning (including a do-nothing option). When water is of far greater value than timber, then very long rotations will be preferred to short ones because (under 'normal' management) a far smaller proportion of a catchment will be covered with fast-growing regrowth.

Discount rate The choice of a discount rate is a critical but contentious issue. For long-term public works, a discount rate of 4 or 5 per cent is now generally advocated for evaluation; it is interpreted as a social rate of time preference and is derived from long-term bond or similar rates. However, its application to forest evaluation is more problematic. Higher discount rates favour short rotations and, it can be argued, are contrary to the interests of future generations when account is taken of the option and existence values of forests.

7. CONCLUSIONS: REGIONAL ASSESSMENT, PUBLIC POLICY AND RESEARCH

This report introduced the general concepts of logging and forest management in the forested catchments of the eastern seaboard and reviewed the available scientific literature concerning the effects of logging regimes on hydrology and soils. The preceding section reviewed the economic effects of changes in water yields due to forest management practices. This concluding section draws together these matters, considers how water issues should be considered in the Comprehensive Regional Assessment process and forest policy generally, including research.

7.1 Context and types of forest decisions

The very substantial differences between catchments in terms of their hydrological characteristics, pattern of land use and array of water users makes it clear that the analysis of forest use and management in relation to water must proceed on a regional scale at which the details can be evaluated properly. The integrated catchment management process now being adopted by most States and the Comprehensive

Regional Assessment process being undertaken jointly by the Commonwealth and States are occurring at the relevant scale. However, it is far from clear that all important catchments will be included in the former process within the foreseeable future or that water will be considered at all in the latter process.

The situation is complicated because the decisions and actions discussed in this report are of different types, some being far more amenable to public policy processes than others. Those related to water quantity appear more straightforward than those related to water quality.

In relation to water quantity, it is clear that in some regions - and in more as demand increases - water has to be allocated between tree and other crops, and between primary, secondary and domestic use. Tree and other crops grow on both public and private land and there are few examples as yet in Australia of integrated catchment management systems being able to effect such allocations efficiently or equitably. Moreover, the effect of tree crops on water yield is known for only a few sites.

In relation to water quality, it is clear that the most important issues relate to the standard of forest management practice. This, of course, also applies to agricultural practice. However, as three-quarters of the forests are in the public domain, the task of ensuring good practice is somewhat easier. The major obstacles are the continued pressure of governments to reduce field staff, the unwillingness of industrial companies holding resource rights to pay adequately for high quality work, and the need to upgrade much of the old roading infrastructure. A series of detailed matters relating to standards, training, equipment and so forth are contained in various places in this report.

7.2 Comprehensive Regional Assessments

The Comprehensive Regional Assessments leading to Regional Forest Agreements should involve evaluation of the range of uses of forests including comparison of impacts of various management regimes on users. Assessment of the impacts of management regimes on water users should be an important aspect of this in many forest areas. The assessment process needs to include the following stages.

- For each forest area being assessed it will be necessary, as far as possible, to match data on the forested area (area forested, forest types, silvicultural management, expected growth rates) with data on catchments. It should be noted that some water users are well outside of the catchment itself.
- All major water users from the catchment/forested area in question need to be identified along with the uses to which they put water and any rights or entitlements to water that they may have.
- For each user or class of users the assessment needs to assess the amount of water used, its approximate contribution to their economic and other activities and the likely impact on those activities of changes in its quantity and quality.
- In this context, it will also be necessary to make some projections of future demands for water from the various users. It will not be possible to make these assessments with a great deal of accuracy, but some order of magnitude estimates will be possible using rapid appraisal techniques.

- Finally, it will be necessary to assess the economic impacts of possible changes in water yields and water quality as a result of feasible silvicultural regimes and logging and roading systems. Approximate data on the impact of changes in water yields and quality on output or consumption need to be combined with price data.
- This assessment should also consider alternative sources of water (such as diverting irrigation water) and demand management (especially for urban water).

As a result of these analyses for each forest region, consideration of water impacts may lead to recommended changes in the silvicultural regimes chosen (including rotation lengths and thinning systems) and the logging and roading systems applied. The former are more relevant for issues of water yields while the latter are more relevant to water quality.

7.3 Implications for public policy

The broad conclusion of this paper is that existing assessment processes, including those being developed for the Comprehensive Regional Assessments, do not adequately deal with the potential impacts of logging on water yields and water quality. The National Forest Policy Statement gave inadequate attention to forest water issues. These issues cannot be resolved through information gathering, analysis and negotiation at central levels but must be resolved through detailed regional studies. There are however, a few areas -- such as catchments for major cities -- where the issues need to be developed in coordination with other major planning processes that extend beyond the boundaries of particular catchments.

There do appear to be a few catchments in the study area where conflict over limited water is already a serious issue. However, we expect that conflicts over access to water will become a much more extensive problem in the next century as more and more water-intensive activities develop on the eastern seaboard. Questions about the impact of logging on water supplies and water quality will be asked with increasing frequency and choices will need to be made about the optimal distribution of water resources across competing uses.

This emerging situation provides an opportunity to develop the data bases and methods of analysis that will help to head off conflicts before they become entrenched. It would be foolish to allow this resource-use issue to create yet another battleground over conservation and resource management.

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