FOREST FOCUS

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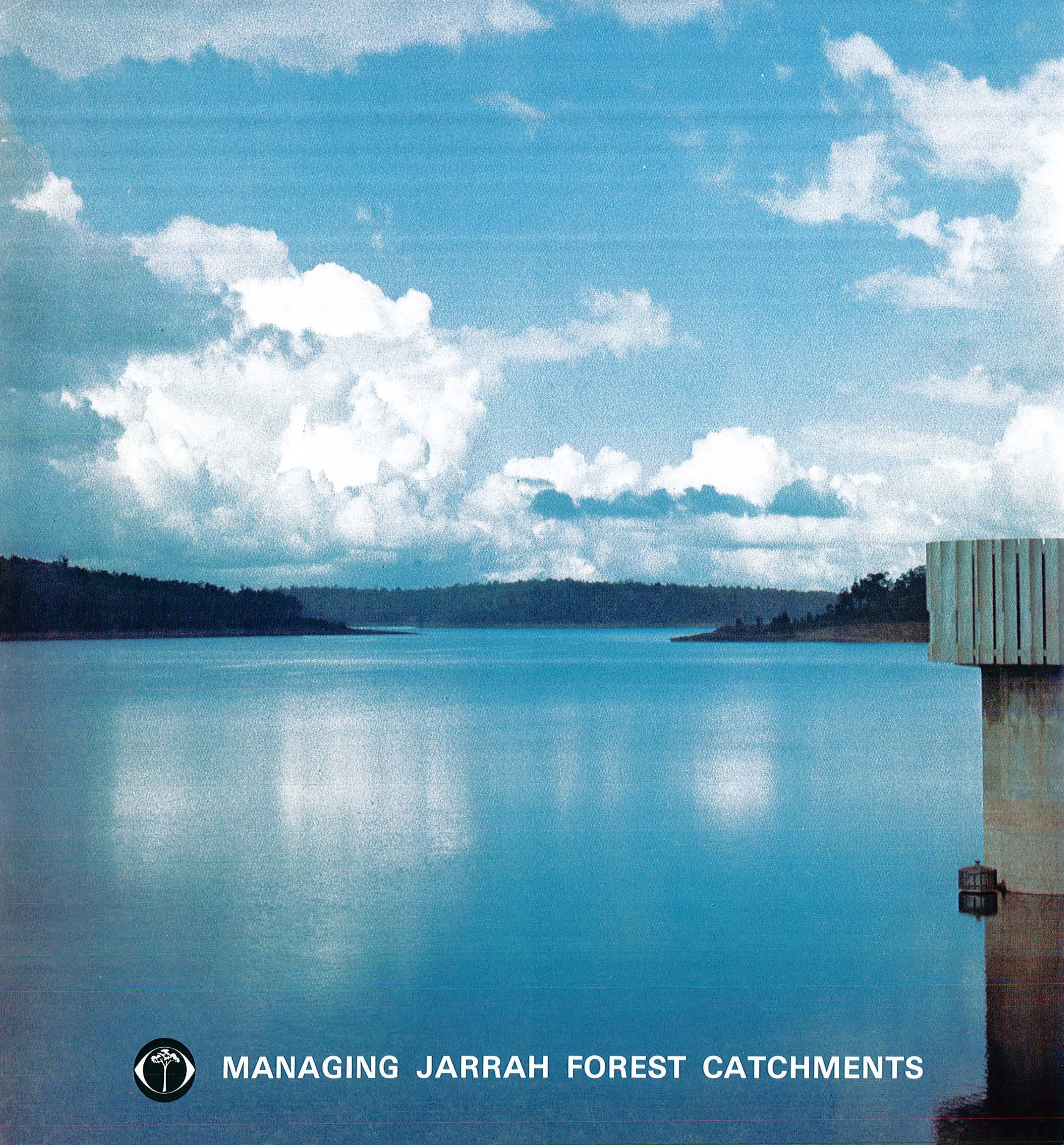

MANAGING JARRAH FOREST CATCHMENTS

▲ *High quality jarrah pole stand.*

Bullich. ▲

JARRAH FOREST VEGETATION TYPES

Although jarrah is the dominant overstorey component in the catchments there is also a variety of trees which occupy specific sites.

▲ *Wandoo.*

Treeless swamp. ▲

▼ *Flooded gum.*

Melaleuca preissiana *swamp.* ▼

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PRODUCTION RECREATION CONSERVATION PROTECTION

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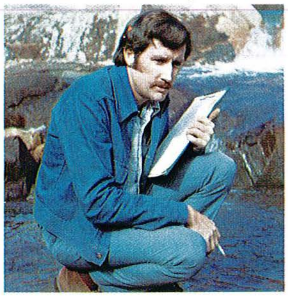


Eugene Herbert

Managing Jarrah Forest Catchments

By Dr. SYD SHEA and EUGENE HERBERT

Forests have a multiplicity of uses but in Western Australia their most important product is fresh water. For over 80 years jarrah forest catchments have been the major source of fresh water for the South-West and Goldfields regions of Western Australia. Currently, over 80 per cent of the water supplied to the metropolitan water supply system originates from jarrah forest catchments.

Despite its importance, fresh water has, until recent times, been considered an abundant, cheap and automatic by-product of forests. A system of forest management which has primarily been concerned with timber production and protection of forests from wildfire has also ensured catchment protection.

Two important changes have occurred which have made this "passive" catchment management policy inadequate:

- The demand for water is rapidly approaching the maximum capacity of catchments and coastal plain groundwater aquifers to supply the south-west of Western Australia. Public Works Department engineers have estimated that within approximately 30 years (at current rates of demand) the South-West and Goldfields regions of Western Australia will consume over 50 per cent of the water which can be produced from suitable catchments in the South-West and coastal plain groundwater aquifers.
- The assumption that the existing catchments will continue automatically to supply fresh water is no longer valid. Disturbance of the forest cover on these catchments resulting from changes in land use practice or because of disease, has the potential to cause increases in salinity.

In this issue the role of forests in the hydrological cycle is explained and progress towards the development of an "active" jarrah forest catchment management strategy which is aimed at increasing fresh water production and preventing salination, is described.

THE JARRAH FOREST HYDROLOGICAL CYCLE

Like many processes in natural ecosystems the movement of water is cyclic. A proportion of the rain falling on a forest is intercepted by the leaves and almost immediately evaporated. Interception also takes place in the shrub and litter layers of the forest. In forested catchments, flow over the surface of the soil (overland flow) is rare. As water percolates through the soil a proportion is absorbed by the roots and conducted to the leaves where it is evaporated (transpiration). That water which is not either intercepted or transpired percolates through the soil to the groundwater table and eventually, via streams and rivers, to the ocean. It is possible by measuring rainfall and streamflow to draw up a budget for a catchment consisting of water income, water consumption and water lost through streamflow. The Public Works Department water resources section has monitored a number of jarrah forest catchments for a number of years. These measurements show that *fully forested* catchments yield between 1 and 15 per cent of the total annual rainfall.

Front cover

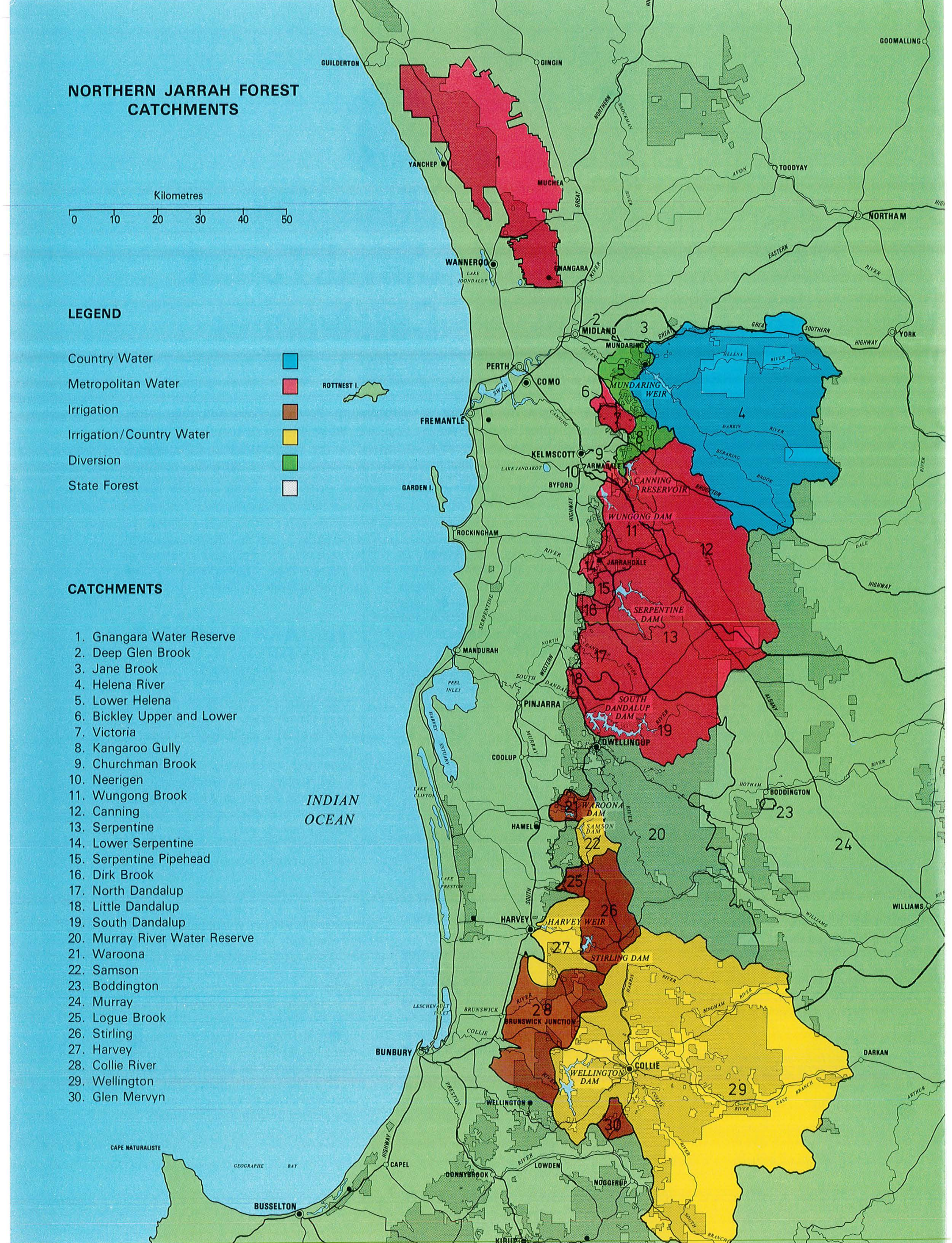
South Dandalup Catchment. The catchment is 319 km² in area and is contained entirely in State Forest.

Inside back cover

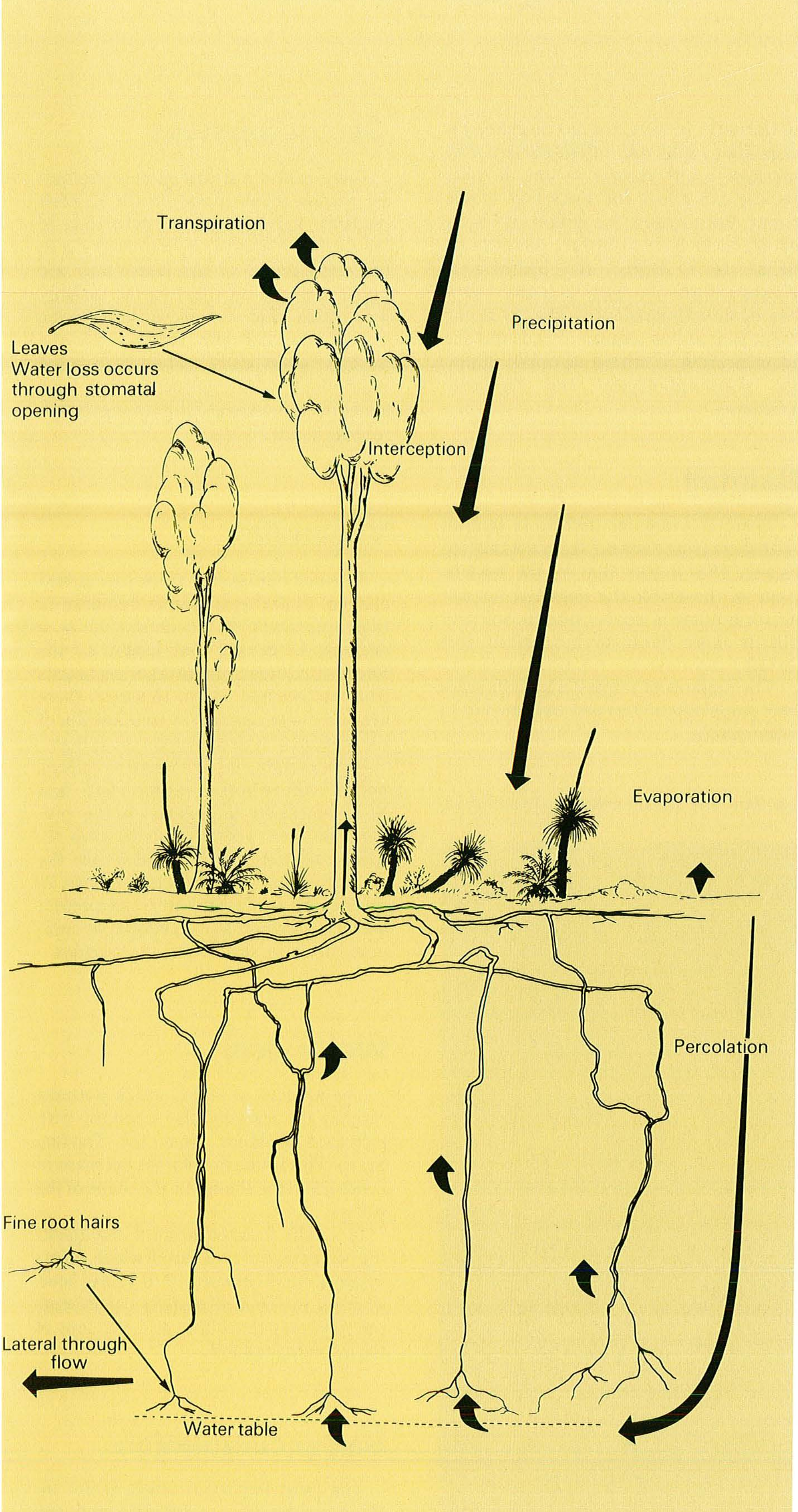
Although fresh water is the most important product of the jarrah forest catchment, management must be integrated with timber production, conservation and recreation. (Peter Kimber, Eugene Herbert, Les Harman and Dale Watkins.)

Back cover

Salt pan formed following clearing of forest for agriculture. The water flowing from streams where this has occured is too saline for human consumption. (Les Harman.)



NORTHERN JARRAH FOREST CATCHMENTS
Kilometres
0 10 20 30 40 50
LEGEND
Country Water
Metropolitan Water
Irrigation
Irrigation/Country Water
Diversion
State Forest
CATCHMENTS
1. Gnangara Water Reserve
2. Deep Glen Brook
3. Jane Brook
4. Helena River
5. Lower Helena
6. Bickley Upper and Lower
7. Victoria
8. Kangaroo Gully
9. Churchman Brook
10. Neerigen
11. Wungong Brook
12. Canning
13. Serpentine
14. Lower Serpentine
15. Serpentine Pipehead
16. Dirk Brook
17. North Dandalup
18. Little Dandalup
19. South Dandalup
20. Murray River Water Reserve
21. Waroona
22. Samson
23. Boddington
24. Murray
25. Logue Brook
26. Stirling
27. Harvey
28. Collie River
29. Wellington
30. Glen Mervyn
INDIAN OCEAN
GUILDERTON
GINGIN
GOOMALLING
YANCHEP
MUCHEA
TOODYAY
NORTHAM
WANNEROO
LAKE JOONDALUP
GNANGARA
MIDLAND
MUNDARING
YORK
PERTH
COMO
ROTTNEST I.
FREMANTLE
MUNDARING WEIR
KELMSCOTT
ARMADALE
LAKE JANDAKOT
GARDEN I.
BYFORD
CANNING RESERVOIR
WUNGONG DAM
ROCKINGHAM
JARRAHDALE
SERPENTINE DAM
MANDURAH
PEEL INLET
PINJARRA
SOUTH DANDALUP DAM
DWELLINGUP
COOLUP
BODDINGTON
WAROONA DAM
SAMSON DAM
HAMEL
HARVEY
HARVEY WEIR
STIRLING DAM
WILLIAMS
BRUNSWICK JUNCTION
BUNBURY
DARKAN
COLLIE
WELLINGTON DAM
WELLINGTON
CAPE NATURALISTE
CAPEL
GEOGRAPHE BAY
DONNYBROOK
LOWDEN
NOGGERUP
BUSSELTON
KIRUP



Diagrammatic representation of the hydrological cycle.

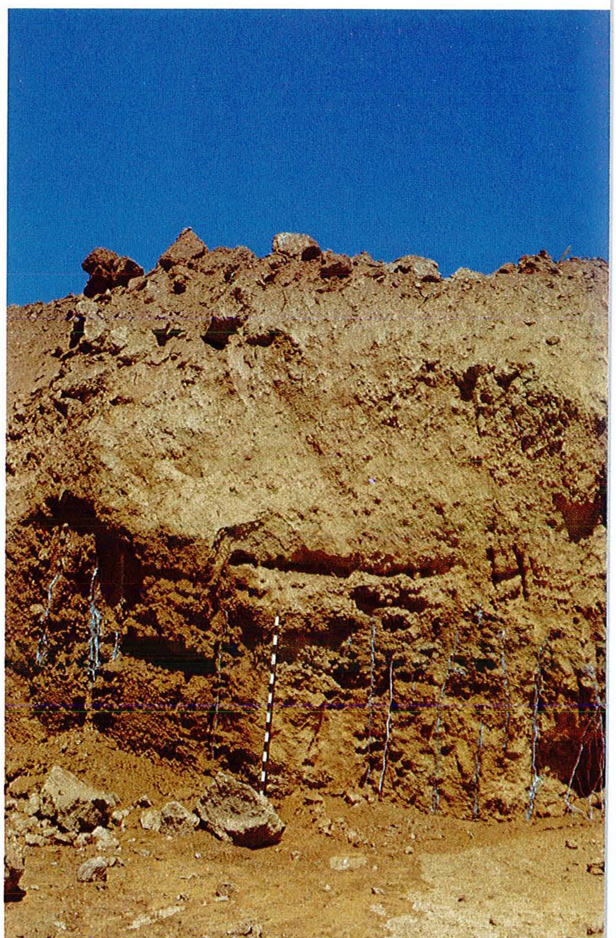
Water supply catchments in relation to State Forest. Over 80 per cent of the water supplied to the south-west of Western Australia and the goldfields comes from these catchments.

An additional important factor in the jarrah forest hydrological cycle is the presence of large accumulations of salt deep in the soils of some forested areas. The processes involved in salt accumulation are not completely understood but three factors—relatively large inputs of salt in rainfall, deep soils with a high capacity for water storage, and a native vegetation which is adapted to consume water—are thought to be responsible.

As the winds which bring rain to the south-west of Western Australia sweep across the Indian Ocean they absorb salt, so that on average between 60 and 260 kg of salt are deposited each year on each hectare of forest.

Where the soil is either porous or shallow, permitting rapid movement of water through the profile, or where rainfall is high, most of this salt is flushed from the soil and accumulation does not occur. However, in lower rainfall areas or where the soils are such that only slow movement of water occurs, the deep rooted native vegetation consumes nearly all of the rainfall. The roots absorb the water but not the salt. Therefore, over thousands of years large quantities of salt have accumulated in the soil.

Jarrah roots penetrating lateritic soil. The deep rooting characteristics of the native vegetation allow it to consume a large proportion of the annual rainfall.



While the cause of salt accumulation is still not completely understood the effect of removal of vegetation on salt discharge is well known. While the vegetation remains undisturbed the system remains in equilibrium and stream salinity is low—even when there are large quantities of salt in the soil. But disturbance of the vegetation results in less water consumption, greater throughflow of water and movement of salt into streams. C.S.I.R.O. scientists have estimated that it would take hundreds of years to flush the salt that has accumulated in these soils.

The jarrah forest can therefore be viewed as having both positive and negative effects on water quality and yield. The forest cushions the impact of rainfall and prevents erosion, and in areas where salt is stored in the soil profile it prevents the discharge of salt into streams. However, in salt-free areas a dense forest consumes large amounts of water and significantly decreases the yield of potentially useable water.

One of the most deceptive characteristics of the jarrah forest is its apparent uniformity. In fact, the geomorphology, vegetation, soils and micro-climate vary markedly. Any change in one of these factors can affect the hydrology of the forest. Fortunately, the major variations which occur have a distinct pattern and hence, to a degree, the hydrological characteristics of a particular forest area can be broadly predicted. The key to the unlocking of this pattern or code was the identification of strong west-east climatic, geomorphological and vegetative gradients.

Rainfall

There is a regular decline in rainfall with increasing distance from the Darling Scarp. This means that in the western zone of the forest the potential for salt to accumulate is less because the soil profile is more likely to be flushed free of salt.

The amount of rainfall also influences the sensitivity of forested catchments to disturbance.

▼ *Stream gauging station. By measuring rainfall, streamflow and stream salinity, a hydrological budget can be constructed for a catchment.*

Geomorphology

There is also a strong geomorphological pattern which parallels the rainfall gradient. Valleys in the western zone of the forest are sharply incised whereas in the eastern zone of the forest they are broad. This has an effect on the rapidity with which water can move through the soil profile and into streams. In the western valleys water movement is more rapid than in the eastern valleys and hence the time available for the vegetation to absorb water is less.

Vegetation

As would be expected there are marked changes in the vegetation in response to these gradients. Most noticeable is a decrease in density and height of the forest with increasing distance eastwards from the Darling Scarp. However, there are also major changes in composition of the vegetation which occupies the valleys.

For example, in the western valleys, bullich (*Eucalyptus megacarpa*) and W.A. blackbutt (*E. patens*) is the predominant tree whereas flooded gum (*E. rudis*) and wandoo (*E. wandoo*) are the tree species in the more eastern valleys. In some eastern valleys no trees are present and the predominant vegetation is composed of dense, shrubby tea-tree species.

Water yield

The amount of water which actually reaches the streams also changes with increased distance from the Darling Scarp. This is due to both the decrease in rainfall and the change in the shape of the valleys.

In a fully forested western catchment the percentage of the rainfall which enters streams varies between 10 to 15 per cent, whereas in forested eastern catchments the yield may be as little as 1 per cent of the incoming rainfall.

Salt accumulation

The most important single factor influencing the effect of different land uses and forest management practices on water quality in the jarrah forest is the presence or absence of salt in the soil profile. In broad terms, land use practices which result in the disturbance of the vegetation in salt accumulation areas will have a deleterious effect on water quality, whereas in salt-free areas reduction of forest cover will increase the yield of water without increasing stream salinity.

Two methods have been used to detect salt. Firstly, by direct analysis of soil and the watertable. Sampling is carried out with a conventional drilling rig. This provides conclusive evidence on the presence or absence of salt in the areas sampled but wide variation is often found from bore to bore. However, the total cost of drilling and chemical analysis of the samples is in excess of $1 500 per hole.

A second, cheaper but less reliable method, is stream sampling. This method involves sampling streams in the period before cessation of flow (the base flow period) when the groundwater proportion of total streamflow is large and its salinity approximates the salinity of the groundwater table. This method of determining if salt is present, however, usually underestimates the total quantity of salt stored in the soil. In fact, in some forest areas large quantities of salt have been detected in the soil by direct sampling even when stream salinity throughout the year was relatively low.

These two techniques have been used over a large proportion of northern jarrah forest catchments and it is possible to broadly identify areas where salt has accumulated.

Generally, the western zone of the forest is salt-free whereas in the easternmost forest zone there are large accumulations of salt. The general salt gradient parallels the rainfall and geomorphological gradient, but the pattern is by no means uniform. For example, in the intermediate forest zone the pattern is more complex and areas of relatively low and relatively high salt accumulation areas form a mosaic.

A typical pattern of salt accumulation in this intermediate zone is illustrated by salt distribution in the Yarragil catchment.

THE EFFECT OF DISTURBANCE

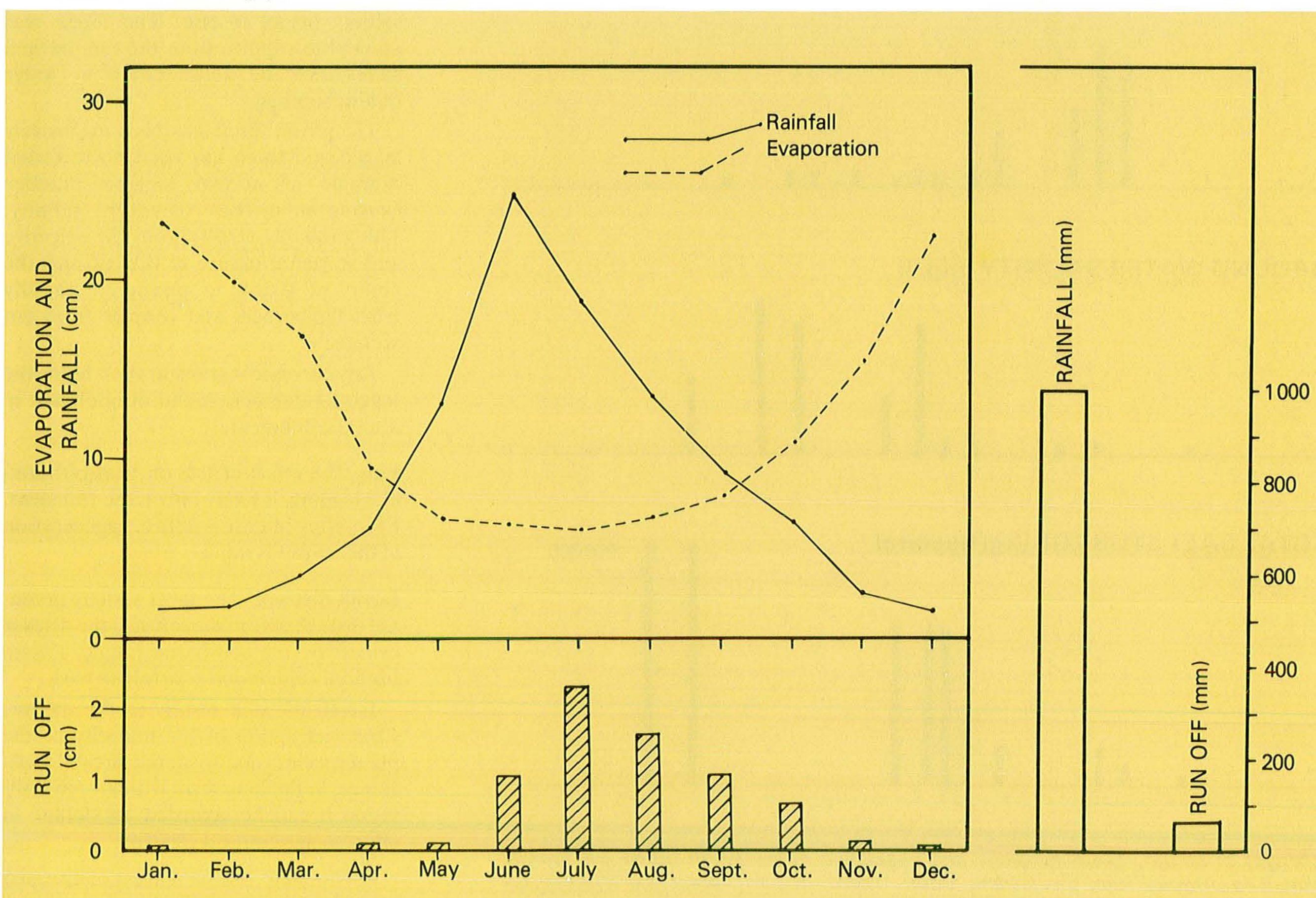
Almost any practice which results in the reduction of forest canopy will cause a reduction in transpiration and an increase in the amount of water flowing into the streams. The impact of the disturbance on water quality and yield of a total catchment will depend on the size of the area disturbed, rainfall, amount of salt in the soil profile and the ability of the native or replanted forest to regain predisturbance water consumption levels.

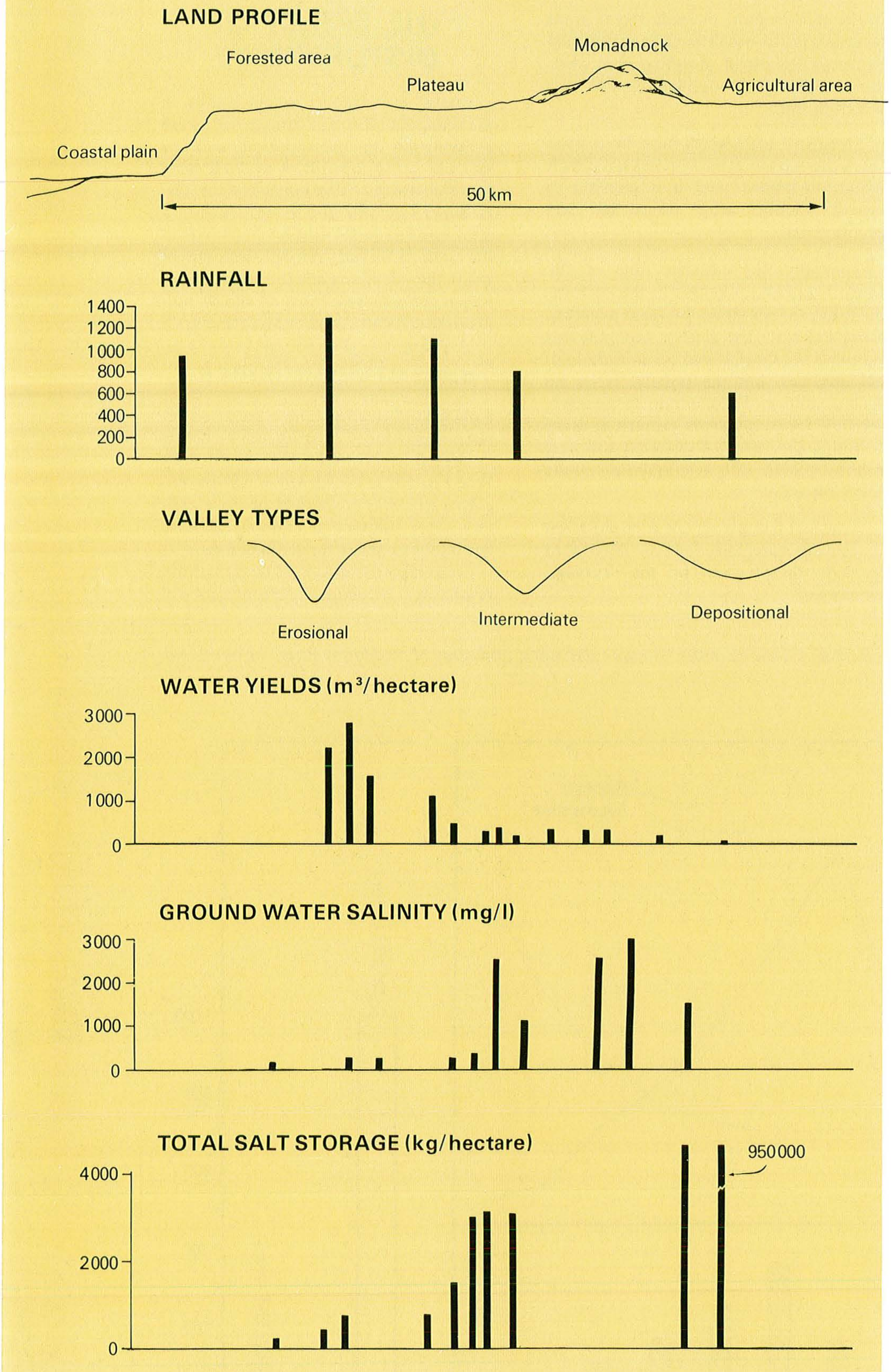
Types of Disturbance

Agricultural clearing. The association between agricultural clearing and increases in stream salinity was first recorded by Wood in 1923. Wood was a railway engineer who was concerned because railway water supplies in many areas were becoming too saline for use in boilers.

Conversion of forest land to agriculture results in a reduction in the quantity of

Hydrological budget for a typical jarrah forest catchment. Data from the Yarragil catchment, a tributary of the Murray River, located 12 km south-east of Dwellingup.





Changes in rainfall, geomorphology and vegetation in the jarrah forest are broadly related to distance from the Darling Scarp. These, in turn, affect the hydrological characteristics of the forest.

water consumed. This is because agricultural species are shallow rooted and are unable to grow during late spring, summer and early autumn when the demand for water is greatest.

Throughout the agricultural area on the eastern boundary of the jarrah forest there are numerous examples of the effect of clearing native forest on water quality. The visible impact of clearing—the formation of salt pans in the valleys—although serious is not as important as the impact on streams and eventually reservoir salinity.

Stream salinity can increase to unacceptable levels without any obvious salt pan formation.

Agricultural clearing, of course, does not always result in salination. There are some catchments on the western edge of the forest where extensive clearing for agriculture has not caused increases in stream salinity.

Logging. In 1903, in an attempt to increase water yield in the Mundaring catchment, extensive areas of forest were ring-barked (also mentioned in *Forest Focus* No. 2). Following the clearing streams became brackish and reservoir salinity began to rise. The forest was allowed to coppice from the ring-barked stems and the deterioration in water quality stopped.

The jarrah forest has been extensively logged and there has been no recorded example of normal logging practice causing an increase in stream salinity. This probably results from the selective and scattered nature of the cut and the ability of jarrah to regenerate rapidly from lignotubers and coppice from cut stumps.

Any decrease in transpiration following logging is temporary and insignificant in a total catchment.

Fire. The effect of fire on transpiration, like logging, is likely only to be transient. Even after intense wildfire, regeneration of the crowns is rapid.

Jarrah dieback. The most serious potential disturbance to the forest is the disease caused by the soil-borne fungus *Phytophthora cinnamomi*—jarrah dieback.

Jarrah dieback results in the irreversible destruction of the majority of the plant species making up the jarrah forest. Hence, in the long term without rehabilitation it can be regarded as similar in effect to agricultural clearing.

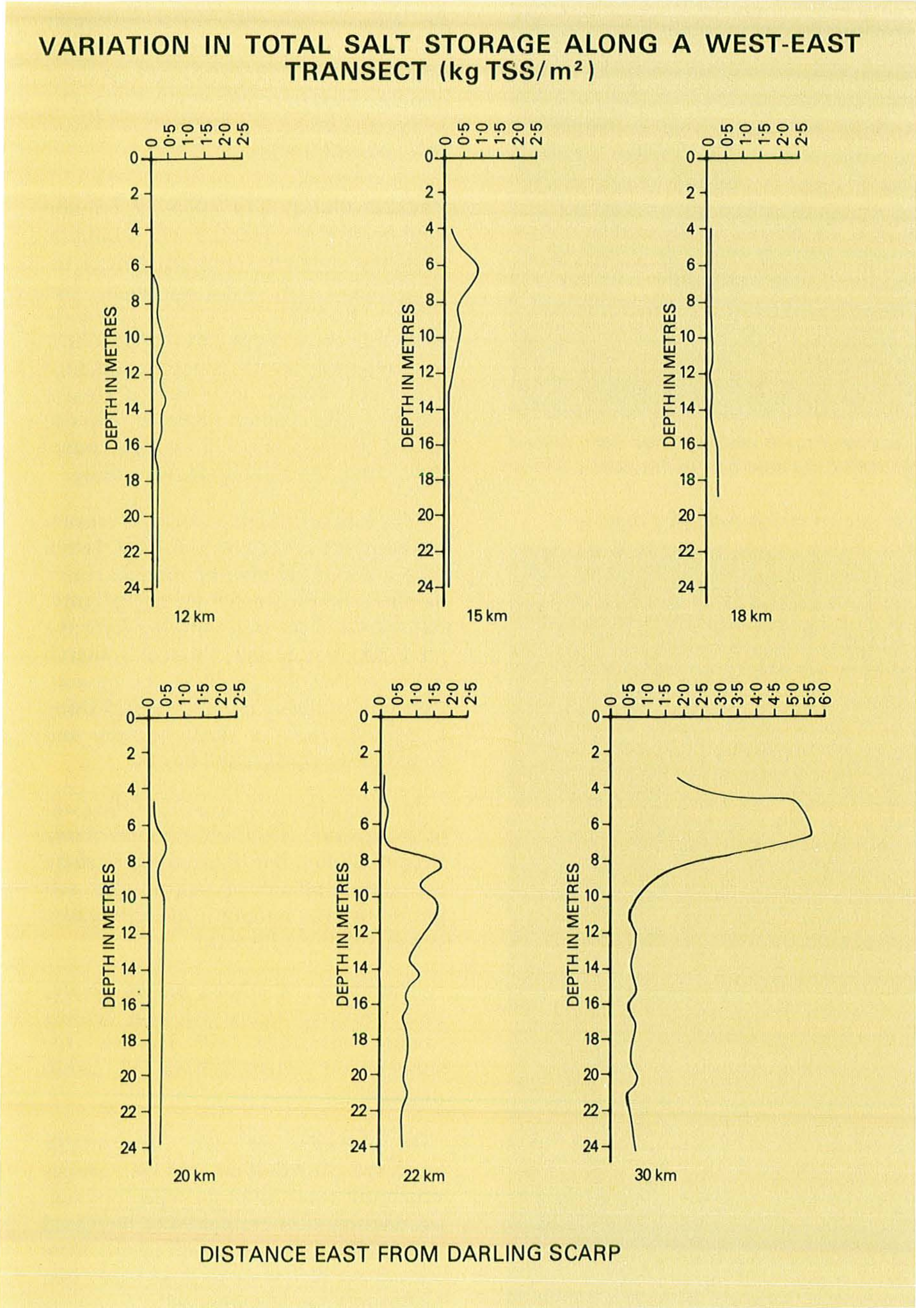
Fortunately, the main areas of diseased forest have been confined to the western, relatively salt-free zone, of the forest. Hence, in terms of water production, jarrah dieback could be said to be having a positive effect (see below).

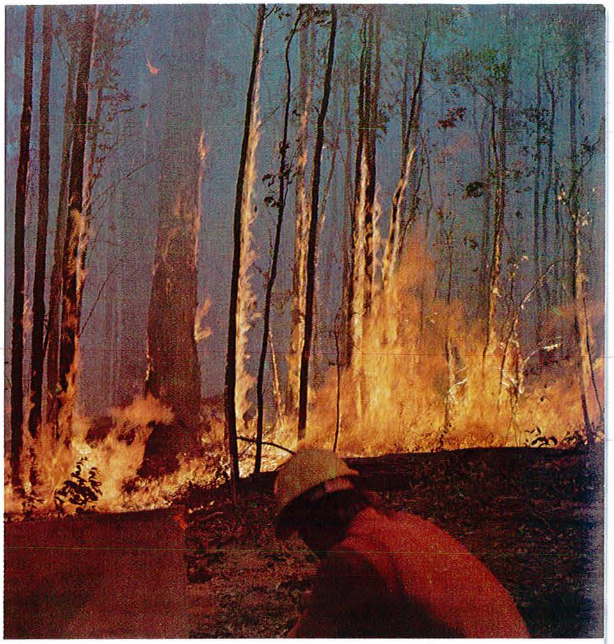
However, the impact of jarrah dieback in salt-prone areas is potentially catastrophic. Although the distribution of advanced dieback in the central and eastern zones of the forest where salt is present is relatively small, there are forest areas where salination of streams can be directly attributed to the disease.

The restriction of the disease principally to the western non-saline zone of the forest appears to be largely fortuitous. Logging and roading activity (which is the principal method by which the fungus is spread) was less intensive in the intermediate and eastern zones of the forest and occurred before the fungus was widespread.

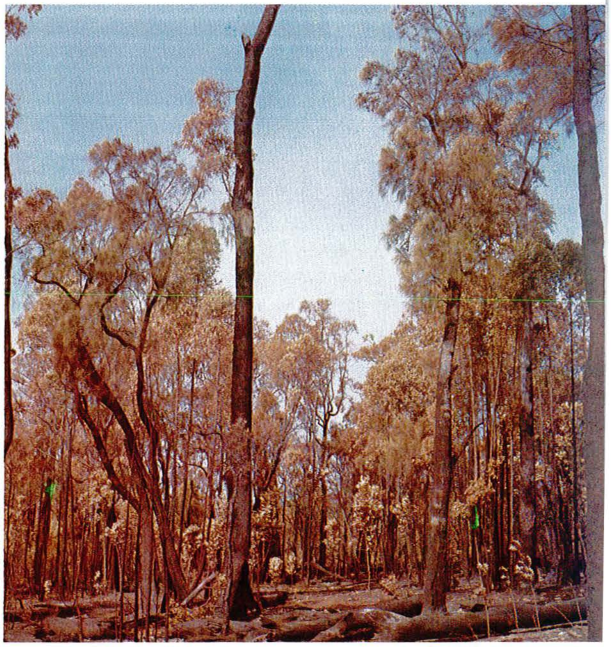
Lower rainfall and the presence in the eastern valleys of tree species which are resistant to the fungus, such as wandoo,

▼ *Salt accumulation generally increases with distance from the Darling Scarp. These salt profiles were determined by analyses of soil samples obtained by drilling.*

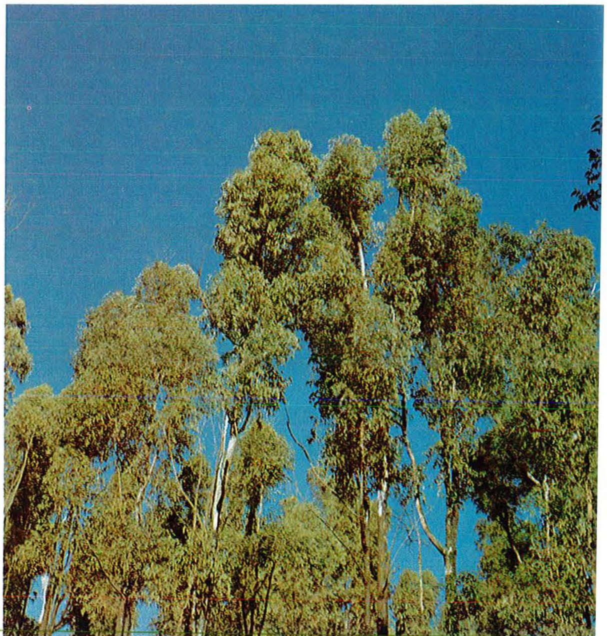




The jarrah forest is adapted to fire and the vegetation regrows rapidly even after high intensity fire. Picture above shows a hot fire. ▲



Scorched crowns. ▲
New regenerated crown. ▼



▲ *Forest being cleared for agriculture in the Murray catchment. An embargo has been placed on forest clearing in the Wellington catchment because of the association between clearing and salination.*

▼ *Regrowth from lignotubers and cut stumps (coppice) occurs rapidly following logging.*

will contribute to a lessening of the impact of the disease in these areas. However, there are sufficient examples of active dieback in the intermediate and eastern forest zone to demonstrate that the fungus can destroy the vegetation.

If the fungus becomes widely distributed in this salt-prone area it is highly probable that there will be a significant decrease in the quality of water in the reservoirs.

Since the fungus causing the disease can be carried in small quantities of soil, any land use practice which involves disturbance of the soil can result in spread of the disease. The effect of a particular activity in the forest such as logging, roading, construction of power lines and mining is multiplied manyfold if it results in the spread of the fungus (see *Forest Focus* No. 14, 1975).

Bauxite mining. The effect of bauxite mining on water quantity and quality is similar to agricultural clearing until rehabilitation has been achieved (see below). Bauxite mining is currently located in the western forest zone which has a relatively low salt storage and hence it has not resulted in increased stream salinity. Like jarrah dieback, bauxite mining in this zone will increase water yield without increasing stream salinity.

This is beneficial provided that erosion on the pit surface can be controlled. In the initial bauxite mining operations considerable erosion occurred during high rainfall years and the water flowing from the mine pits was turbid. Current research indicates that this problem can be controlled by applying mulches, establishing a ground cover of shrub species and constructing rip lines and drains.

In non-saline areas bauxite mining will increase water yield without increasing stream salinity. But in areas where there are accumulations of salt in the soil profile bauxite mining is likely to cause stream salinity to increase.

The impact of mining will be greater than the area mined because bauxite mining operations will increase the spread and intensification of jarrah dieback.

In addition to the unavoidable increased distribution of the fungus which will result from movement of soil, the disruption of drainage and increased throughflow of water which results from mining will favour survival and infection by *Phytophthora cinnamomi.*

REHABILITATION

Increases in stream salinity result from reduction in water consumption. Hence, replacement of the forest which has been disturbed with one which has the same capacity to consume water would eventually reduce salinity.

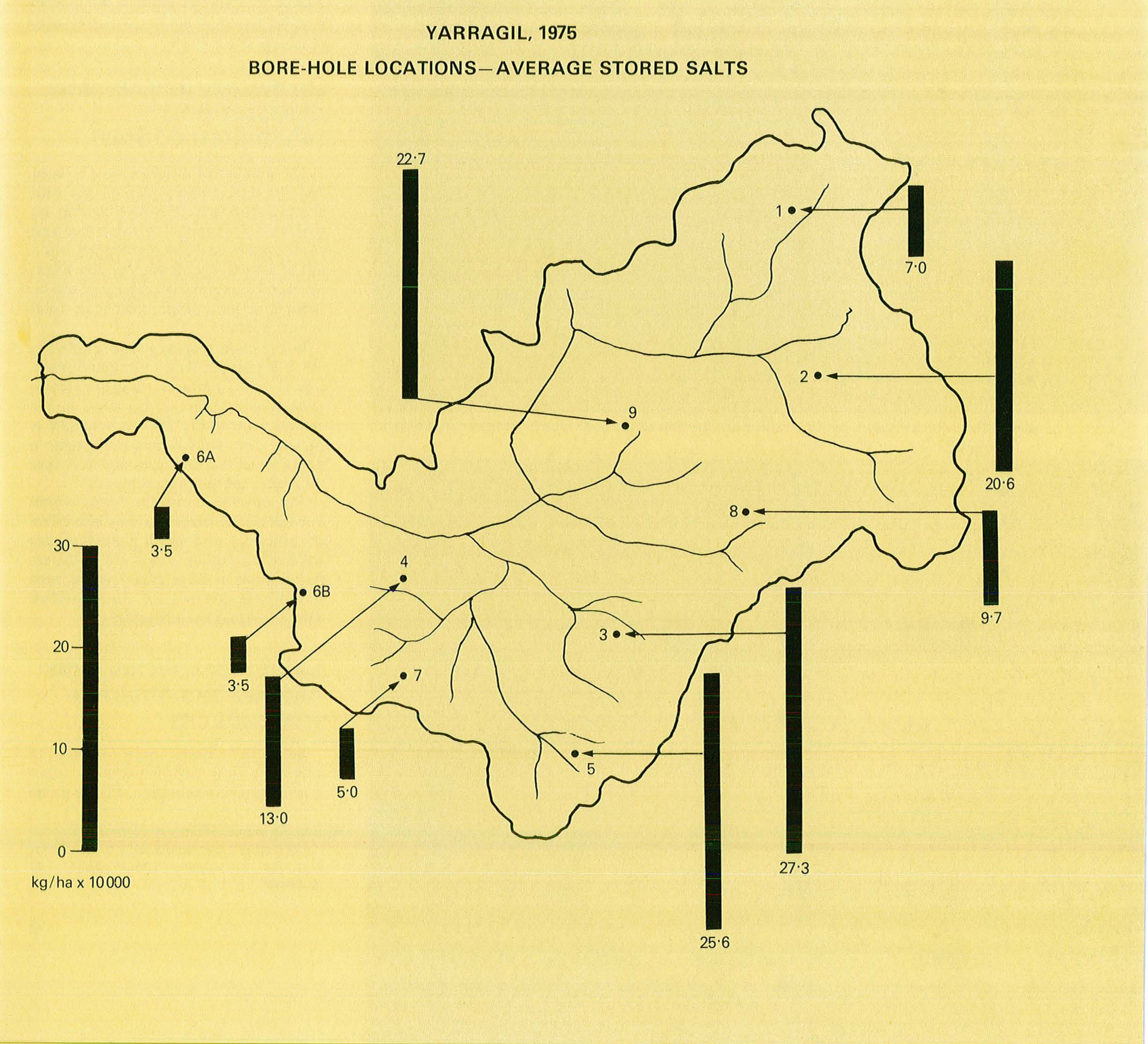
However, before broad-scale rehabilitation can proceed many complex technical, social and political problems must be resolved. Ideally, regeneration of the native forest in the disturbed areas would be the most simple procedure to follow. However, it is not possible to ensure that native forest would not be destroyed by *Phytophthora cinnamomi.*

Re-establishment of native forest in areas cleared for agriculture would result in a decrease in stream salinity but the process of re-establishment would be slow and the rehabilitated forest would not be compatible with current agricultural practices.

Jarrah, the dominant tree species over most of the catchments, has been able to survive and form a dense high forest in an environment which is unfavourable for forest growth. The species used to replace jarrah must be able to cope with adverse environmental factors such as infertile, dense, acidic and saline soils; fire and drought; it must be able to duplicate the capacity of jarrah to consume water; and be resistant to *Phytophthora cinnamomi.* In agricultural areas rehabilitation must be at least partially compatible with agricultural practice and/or have an additional economic return which would compensate for the loss of agricultural land.

A number of state authorities and the C.S.I.R.O. are conducting research to determine both the species which could be

▼ *Distribution of salt in the Yarragil catchment. In the intermediate rainfall zone salt-free micro-catchment and micro-catchments with large accumulations of salt may occur within a few kilometres of one another.*



used for rehabilitation and the type, structure, distribution and the density of forest which will be necessary to rehabilitate catchments which are discharging salt.

▲ *Jarrah dieback affected forest. In some diseased areas the reduction in canopy resulting from the disease has caused salination.*

Matching species with site

It is unlikely that any *single* species or rehabilitation technique will be applicable throughout the forest. For example, it would be counter productive to replant a dense forest in the western low-salt zone because it would reduce the yield of high quality water.

Tree species that will grow successfully in the moist valleys will not necessarily grow on drought-prone ridge sites. Similarly, a species suitable for use in forested areas may not be compatible with agricultural production.

Structure, density and distribution of rehabilitated forest

The number of different species used and the total number planted per unit area will also vary. It is possible that on some sites a number of different tree and shrub species could be planted to form a mixed forest. The density of the forest necessary to prevent salt discharge will be dependant to a large degree on total annual rainfall.

In the eastern areas where rainfall is low it is possible that a woodland (open forest) would consume enough water to prevent salt discharge. However, in the central zone of the forest where salt is present and rainfall relatively high, a dense forest may be necessary to ensure that water consumption is high.

The distribution of the forest within any one micro-catchment may also effect the efficiency with which predisturbance water consumption levels are achieved. For example, in some areas trees planted in widely spaced rows (i.e. the shelterbelt formation) may be satisfactory.

Selecting species with high water consumption capacity

Some tree species have adapted to survive in arid environments by minimising water consumption. In salt-prone

◀ *Bauxite mine. Mining is currently located in the western non-saline zone of the forest and has not caused stream salinity to increase.*

jarrah forest sites tree species which have a high capacity to use water are required. Many species are currently being screened to select those which have the capacity to consume large amounts of water.

One method of determining water consumption capacity is to measure the water status of leaves of trees planted in the field. In one co-operative study, C.S.I.R.O. research workers are measuring water loss from native species while, simultaneously, identical monitoring of exotic eucalypt species which are growing on an adjacent bauxite pit is being undertaken by Forests Department officers. Other C.S.I.R.O. workers are making a detailed study of water consumption rates of a number of tree species which have been planted on agricultural land to the east of the jarrah forest.

The ability of trees to form an extensive vertical root system is one of the most important factors influencing the capacity to consume water and survive on jarrah forest sites. Preliminary studies on bauxite mine sites have shown that the root development of many of the species which have been planted is poor relative to that of jarrah. But spotted gum (*E. maculata*) and wandoo which are both highly resistant to *Phytophthora cinnamomi* have demonstrated a capacity to penetrate the dense clay layer of the laterite profile.

Establishment and management

A large number of different tree species have been established on dieback and bauxite mined sites. The establishment techniques used have been successful but they are expensive and have usually involved planting a single species at a regular spacing.

Recent research has shown that direct seeding of a mixture of tree and shrub seeds, if used in conjunction with correct site preparation, can result in the establishment of a dense mixed forest of a variety of species. Apart from being less expensive this technique results in rapid cover of the soil and the mixed forest which results is ecologically more desirable.

One of the most difficult problems associated with rehabilitation is ensuring that the species used will survive in the long term. Unlike agricultural crops, trees respond differently to environmental stresses as they increase in size. For example, a drought during the first ten years after establishment may have negligible effects on survival, whereas a drought of similar intensity when the tree is larger and the canopy closed may result in catastrophic collapse of the whole stand. Several years growth and a large investment in establishment may be lost in one year.

There are sufficient long term trial plots in the forest to indicate that it is possible to grow trees successfully on the moist valley sites provided that salt has not moved to the soil surface. However, there is not sufficient long term data available to allow selection of a tree species which would grow, survive and perform the same hydrological function as jarrah on the drought-prone laterite ridge sites in the forest.

Timing of rehabilitation

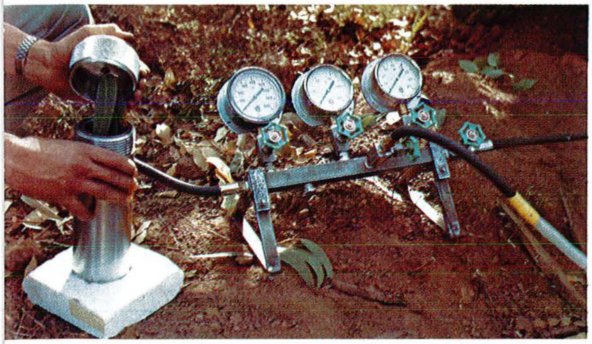
The timing of rehabilitation following a disturbance in a salt-prone area is critical. For example, it is unlikely that it will be possible to restore native forest in areas where jarrah dieback has reached the overstorey mortality stage. At this stage organic matter levels are low, the fungus widely distributed and the remaining vegetation severely stressed. Current research indicates that it may be possible to reduce disease severity by manipulation of the forest during the initial phase of the disease.

Similarly, if salination progresses to the stage where the salt has moved to the soil surface rehabilitation will be much more difficult.

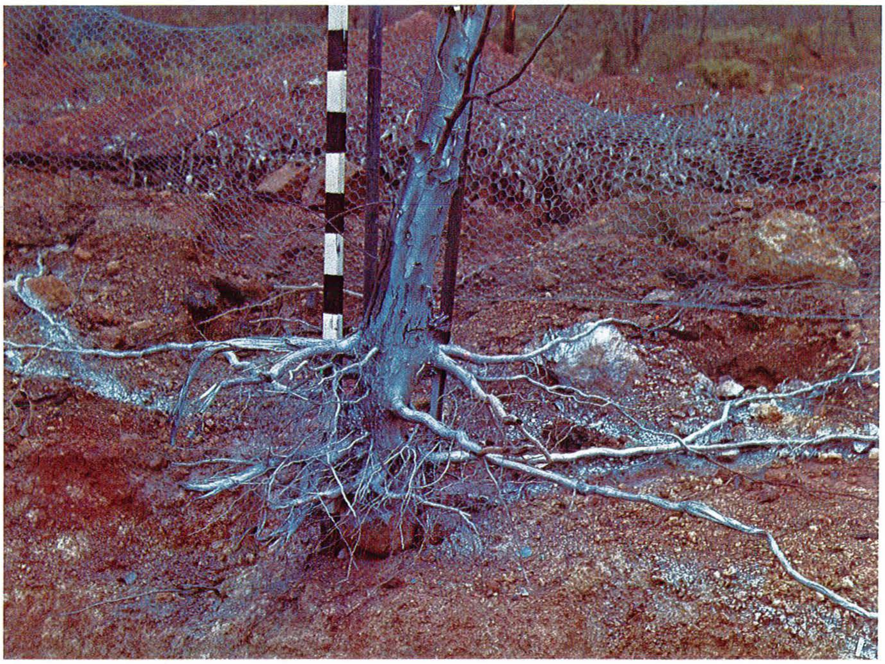
Spotted gum planted at Willowdale in 1935. On favourable sites such as this it is possible to plant species which will grow vigorously and remain healthy. ▼

▲ *Detailed monitoring of rate of water loss is being carried out on native and introduced species to identify those with high*
▼ *water consumption rates.*

▼ *Pressure bomb measurement of plant water potential. (This is a measure of plant water stress.)*

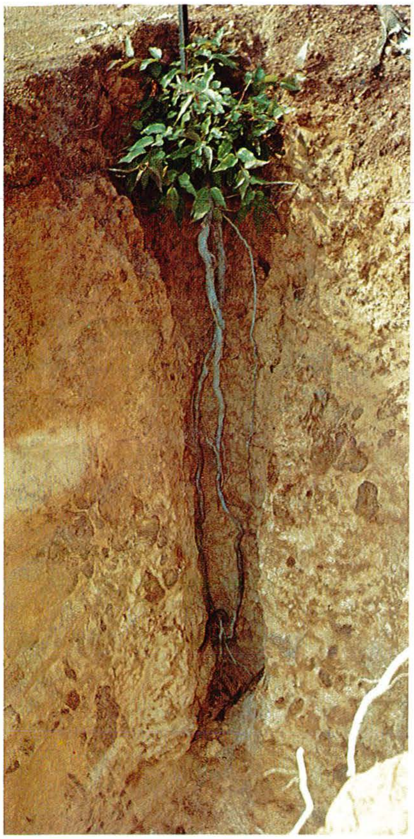


▼ *Stomatal resistance meter estimates rate of leaf transpiration.*



▲ *Almost all of the tree species planted on bauxite mined sites have root systems which are poor in comparison with jarrah. Extensive trials are being carried out, but no species has been found which will adequately replace jarrah on these sites.*

▼ *It is possible to establish a dense forest of a mixture of trees and shrub species by direct seeding on to prepared sites. On this site over 20 different tree and shrub species have been established.*



MANAGING THE FOREST TO INCREASE WATER YIELD

Forests do consume large amounts of water and so logically one way to increase water yield is to reduce forest cover. But it has been shown in many areas throughout the world that the removal of forest from water catchments can be disastrous. Floods, severe erosion and, as shown by the early attempt to increase water yield in the Mundaring catchment, salination have followed indiscriminate removal of forests.

Also, although water is a major and vital product, forests have other values such as timber production, conservation and recreation, which could be severely impaired if forests were indiscriminately removed.

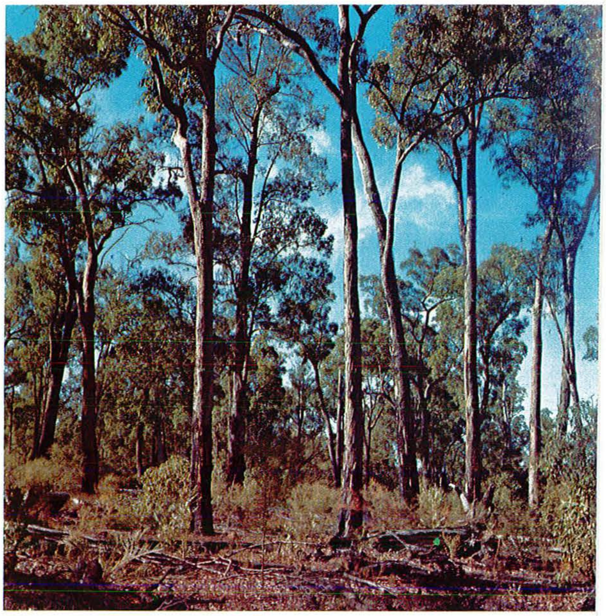
It is possible, however, that the yield of water from Western Australia's jarrah forest catchments could be significantly

◄ *Spotted gum is one introduced tree species which has a capacity to form a deep root system on lateritic soils but even this species failed to form a deep root system in 50 per cent of trees studied.*

Dense young jarrah regeneration which has not been thinned. ▲

▼ *Tallowwood mortality on bauxite mine site caused by drought. Rapid early growth rates do not necessarily mean that trees will survive in the long term.*

Previously dense jarrah forest which has been thinned and burnt to remove undesirable jarrah and to reduce the understorey component of bull banksia. It may be possible to significantly increase water yield in non-saline forest areas by reducing canopy cover while improving other forest values. ▼



increased by management without deleterious side-effects.

Identification of salt-free areas

Reduction of forest cover to increase water yield can only be safely carried out in areas where no salt is present in the soil.

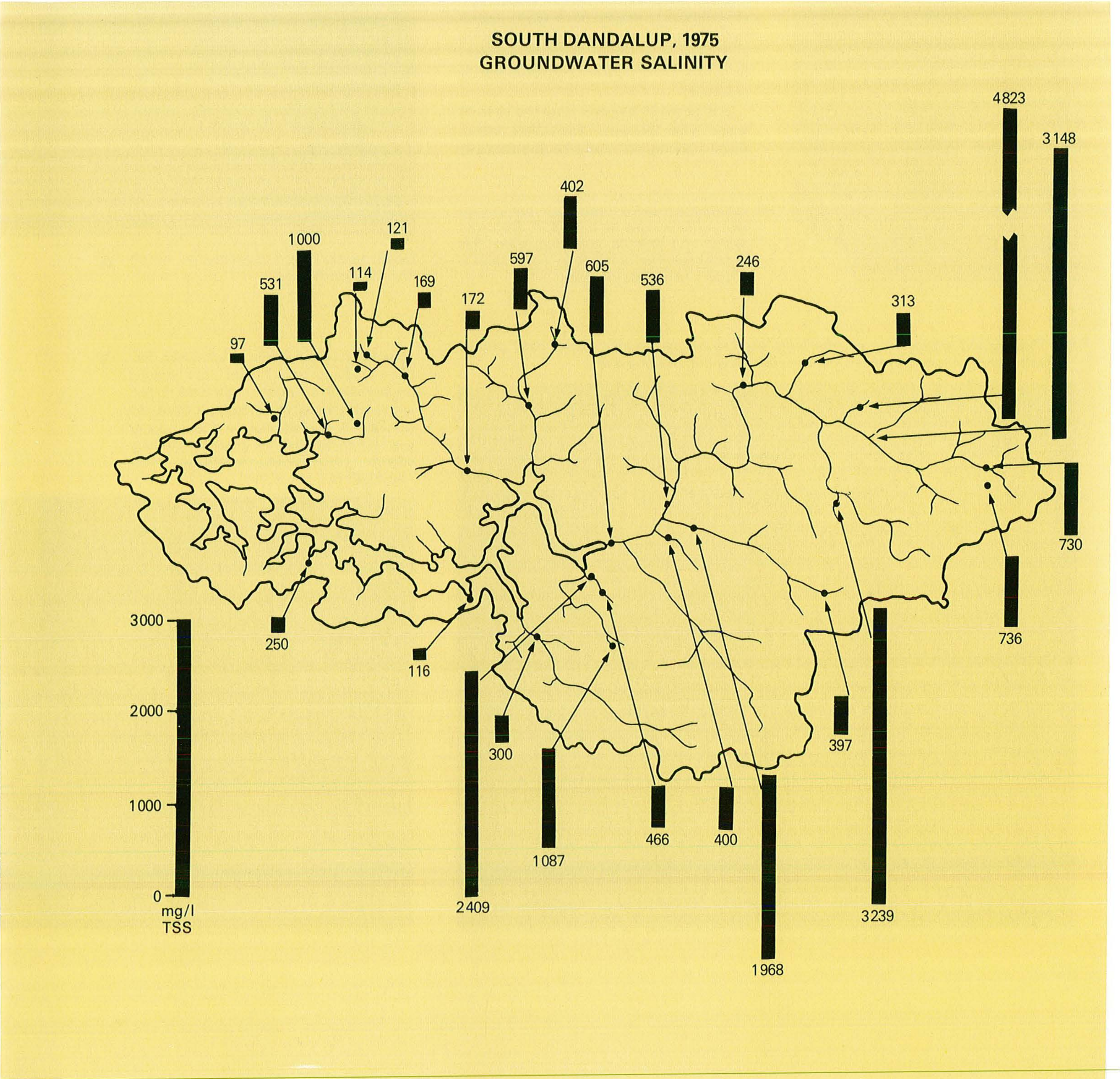
Ring-barking in the Mundaring catchment failed because it was carried out in areas where salt accumulation in the soil profile had taken place. Research carried out over the last decade has identified forest areas where there has been no salt accumulation.

There is not sufficient data to map the total area of forest which is not salt-prone but relatively detailed surveys in the catchment of the South Dandalup, Little Dandalup, North Dandalup and Serpentine have identified an area of approximately 25000 hectares adjacent to the western scarp which is relatively salt-free. In fact, some micro-catchments within this zone have been markedly disturbed by jarrah dieback and yet are yielding high quality (low salt) water. Therefore, reduction of the forest canopy in this area so that less water is consumed will result in increases in water yield without a corresponding increase in salinity.

Potential increases in water yield

There is no precise data on the relationship between forest density and water production in the jarrah forest. However, some indication can be obtained by

South Dandalup catchment estimated groundwater salinity levels.



comparing the yield of water from a number of different catchments, that water production from forested catchments could be significantly increased by reducing the density of the forest canopy. For example, a dense forest in this western rainfall zone may yield between 10-15 per cent of the rain that falls on it each year, whereas catchments where the density of the forest canopy has been significantly reduced typically yield in excess of 30 per cent of rainfall.

If it is assumed that the percentage of rainfall that flows from streams in the salt-free forested area between the Serpentine and South Dandalup catchment can be increased by about 10 per cent by reducing the density of the forest, treatment of 25000 hectares would result in an additional 32000000 cubic metres of water per annum. This is approximately equal to the annual yield of the South Dandalup catchment.

Methods of reducing forest canopy

Some of the techniques which are required to bring about a reduction of canopy cover have already been devised. The jarrah forest, unlike many other forests, does not naturally thin itself. Hence, to prevent stagnation, which follows when a forest is over-stocked, and to ensure that growth is concentrated on the most desirable trees, thinning has been carried out. This is achieved by injecting herbicides into the stem, a procedure which has been applied as a silvicultural treatment in areas of high quality jarrah forest for a number of years.

The cutover jarrah forest in most areas has a dense understorey composed principally of bull banksia (*B. grandis*). This is in contrast to virgin forest areas which have only a scattered understorey component. To ensure that the increase in water yield which would result from reduction of the overstorey canopy would not be lost by an increase in the understorey, it would be necessary to carry out treatments that would maintain understorey canopy cover at a low level. Current research indicates that this may be achieved by strategic use of prescribed burning.

Potential economic gain

The potential economic gain from forest management procedures which are designed to increase water yield is large. An increase in yield of 10 per cent on one hectare of forest in the 1300 mm rainfall zone will result in an additional 1300 m^3 of water per hectare flowing into streams.

Previously it has been estimated that it would cost between 15 cents to 50 cents per cubic metre to obtain water from sources other than the existing catchments. Hence, 10 cents per cubic metre is a conservative estimate of the value of the additional water which could be produced by managing the forests for water production.

At this price, treatment of one hectare of forest so that an additional 1300 cubic metres of water was produced would be worth $130 per hectare per annum. Current estimates of treatment cost are in the range of $80 to $100 per hectare, so that the cost of catchment treatment would be more than returned in the first year following treatment.

Effects on other forest values

Most of the jarrah forest has been disturbed and the current forest is different from original virgin forest. One of the consequences of logging has been the regeneration of dense stands of jarrah and a dense understorey.

This type of forest has little potential for timber production unless it is thinned. Hence, thinning of the forest to increase water yield, provided it is not too severe, will also enhance timber values.

Similarly, other forest values such as conservation and recreation need not necessarily be adversely affected by reducing the forest canopy.

There is considerable evidence to indicate that management of areas of the jarrah forest to increase water yield is a viable proposition. But major changes to the forest cannot be made without careful evaluation of the costs and the benefits.

This is the aim of an intensive research programme being jointly undertaken by the Forests Department and Public Works Department water resources section. Six small catchments are being intensively monitored for water quality and yield. Following a calibration period the forest on three catchments will be treated to determine precisely the effect of canopy cover reduction on yield and salinity. In addition, the effects on potential timber production, animals and plants, and the aesthetic character of the forest will be monitored.

TOTAL CATCHMENT MANAGEMENT

Ultimately, the success of any catchment management programme is measured by the quantity and quality of the water in the reservoir. This means that the effect of any land use practice of forest management strategy on water quality and yield must be evaluated in terms of its effect on the total catchment.

In a simple hydrological system the effects of changes in the structure and composition of a forest on a catchment would be related directly to the area of forest which has been changed and so relatively easy to predict. But the hydrological cycle in Western Australia's jarrah forest catchments is complex and a number of factors, in addition to area, will determine the impact of changes in the forest on the quality and quantity of water in the reservoirs.

The South Dandalup catchment, which is one of the four major catchments supplying the metropolitan area of Perth, has been intensively monitored to determine the total hydrological characteristics of an operational catchment. The data which has been obtained, although preliminary, does illustrate the complexity of the hydrological system.

The catchment currently yields water of acceptable quality but on average only 11 per cent of the rainfall that falls on the catchment runs off into the reservoir. The yield of water per unit area throughout the catchment is very variable. Currently, on average, one hectare of the catchment in the most western portion yields nine times the amount of water that a hectare in the eastern zone of the catchment would yield.

Salinity is also variable. In the western zone of the catchment very little salt has accumulated but over two-thirds of the catchment has a groundwater salinity which is above acceptable limits. In some parts of the catchment there are over 300000 kg of salt stored in the soil and watertable beneath one hectare of forest.

The forest structure, density and composition also varies from dense stands of high quality jarrah forest to large treeless flats. The intensity of jarrah dieback is also different in different parts of the catchment. In some western catchments the disease is severe while in other parts of the catchment only the valley systems have been infected. In other areas the potential for expansion of the disease is large because new infections have become established on ridges and are extending rapidly downslope.

The heterogenity of the catchment means that the effect of a disturbance of the forest in one area of the catchment may have a completely different effect on another. For example, in one western micro-catchment jarrah dieback has reduced average density of the forest to between 20-30 per cent of the original density. Minimal salt was present in the soil and it is estimated that the yield of water has doubled without an increase in salinity.

This micro-catchment, although it represents only 1·6 per cent of the total catchment area, now contributes 12 per cent of the total yield of the catchment.

By contrast, the disturbance in a saline eastern micro-catchment would increase the salinity of the reservoir.

INTEGRATED MANAGEMENT

Although water is the most important product of jarrah forest catchments, catchment management is not concerned only with water production. Logging, recreation, mining and agricultural production all take place on catchments and the forest is also an invaluable resource of plant and animal life.

Reconciliation of all these uses with water production, in a forest which is being attacked by a devastating disease, presents one of the most challenging forest management problems in the world.

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