MANAGEMENT OF TREE COVER ON WATER SUPPLY CATCHMENTS IN WESTERN AUSTRALIA

by

J.R. Bartle, S.R. Shea and P.C. Kimber

Forests Department of W.A., R and I Bank Building,
Hay Street, Perth, W.A.

INTRODUCTION

Conditions suitable for forest growth and surface water catchment occur in the southwest corner of the Darling plateau of Western Australia. This region extends from Perth on the west coast to Albany on the south coast. The plateau is elevated some 300 m above a broad (20-30 km) western coastal plain and narrow (5-10 km) southern coastal dunes and swamps. Annual rainfall reaches a maximum of 1400 mm on the western and southern margins of the plateau and declines steeply with distance inland. This rainfall gradient parallels gradients of decreasing forest height and density, moderating topography, declining stream flow and increasing salinity (Shea and Herbert 1977).

Commercial forest, predominantly native eucalypts under State forest tenure, makes up some 2 x 10^6 ha, or about 80%, of the lands in the 800-1400 mm rainfall zone. Some of the uses of the forest are very intensive. Bauxite mining is carried out in the north, and in the south, forest management is based on clearfelling. The forest is also affected by the fungus Phytophthora cinnamomi Rands, which attacks the major species, jarrah (Eucalyptus marginata Sm.), causing a disease which has become known as jarrah dieback (Podger 1972).

Inland from the 800 mm rainfall isohyet the land is predominantly freehold and is extensively cleared for agriculture based on annual crops and pastures. The large area of uncleared freehold land remaining on many catchments is being slowly cleared for agriculture.

The water resources of this region make up some 75% of those available for public use in the populated southwest of Western Australia. Current and potential catchments have an area of approximately 2.5 x 10^6 ha. Some catchments are entirely contained within the higher-rainfall forest belt. Others extend inland beyond the 800 mm rainfall isohyet to the agricultural areas.

An exceptional feature of this region is the substantial accumulation of salt which occurs in subsoils and groundwater. It ranges from about 3 kg m^{-2} at 1300 mm rainfall to 35 kg m^{-2} at 800 mm (Public Works Department of W.A., unpublished summary of data). Under forest cover this storage is a stable pool in an equilibrium salt balance (Peck and Hurle 1973; Peck 1975).

Alteration of the hydrologic balance by forest clearing or decline can mobilise this pool. The effect on streamwater quality varies from insignificant under high rainfall/low salt storage to very serious under low rainfall/high salt storage. Approximately 50% of the usable water resource has already suffered adverse effects, and to avoid further deterioration, control measures have been introduced (Public Works Department of W.A. 1979a).

Maintenance of the quality of the water resource is the over-riding land-use objective in the region (Forests Dept of W.A. 1977). The most effective method of achieving this objective is to control the vigour, density and area of tree cover. This is complicated by past and projected disturbance to the natural forest ecosystem which has given rise to decline in two of the four major eucalypt species. To restore and maintain tree cover in this altered environment will require increased understanding of eucalypt ecology so that decline in local species can be prevented and suitable replacement species can be identified. In this paper we outline the scope of this problem and consider some priorities for research.

SALINITY ZONES

The potential for stream salinity increases across the gradient of declining rainfall. The W.A. Forests Department (1977) identified the 1150 mm and 1025 mm rainfall isohyets as the boundary of a zone of intermediate risk lying between non-saline and saline zones. This was used as a basis for land use planning in northern jarrah forest catchments. This zoning was modified and extended by the Public Works Department of W.A. (1979a) to provide a rational basis for control of clearing of freehold land which had become necessary to protect water quality in five particularly vulnerable catchments. They adopted four zones (A to D) of diminishing salinity hazard aligned approximately with rainfall isohyets, each zone having appropriate clearing regulations (Table 1).

Table 1. Salinity zones for clearing controls

Zone	Rainfall	Control
A	< 900 mm	no clearing permitted
B	900-1000 mm	small areas only
C	1000-1100 mm	small areas only
D	> 1100 mm	no clearing restrictions

These zones can be extended to provide a framework for the management of all catchments. This has been done in Table 2, where the percentage area in each salinity zone for all present and potential catchments is listed. In addition, the percentage of alienated and cleared land and the present salinity are listed. In Figure 1, catchment boundaries, State forest and rainfall isohyets are shown.

The concept of catchment zoning is being progressively incorporated into land-use practice. This has required alteration to many major policies and statutory provisions governing land use. For example:

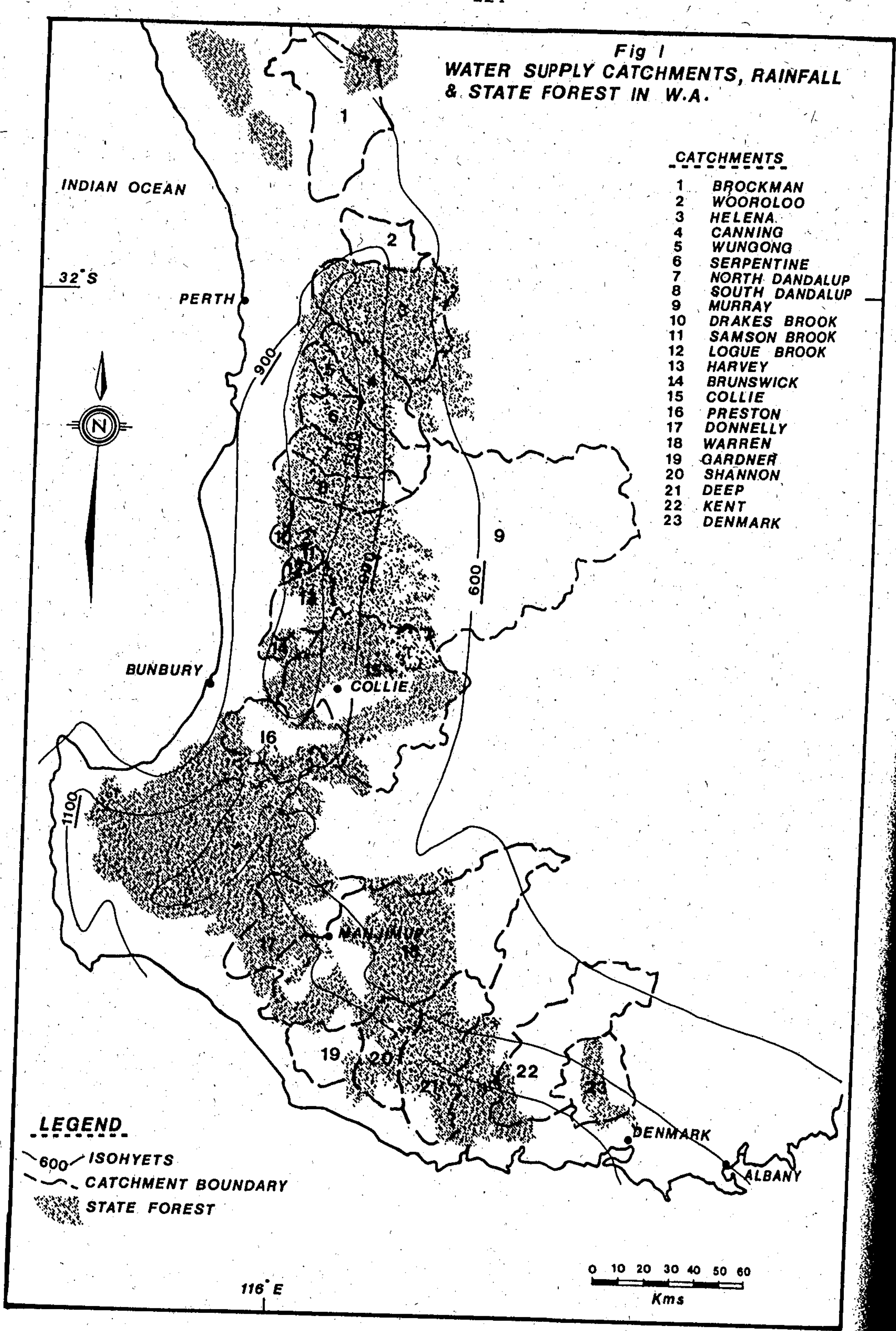
Fig I
WATER SUPPLY CATCHMENTS, RAINFALL & STATE FOREST IN W.A.
CATCHMENTS
1 BROCKMAN
2 WOOROLOO
3 HELENA
4 CANNING
5 WUNGONG
6 SERPENTINE
7 NORTH DANDALUP
8 SOUTH DANDALUP
9 MURRAY
10 DRAKES BROOK
11 SAMSON BROOK
12 LOGUE BROOK
13 HARVEY
14 BRUNSWICK
15 COLLIE
16 PRESTON
17 DONNELLY
18 WARREN
19 GARDNER
20 SHANNON
21 DEEP
22 KENT
23 DENMARK
INDIAN OCEAN
32° S
PERTH
BUNBURY
COLLIE
MANJIMUP
DENMARK
ALBANY
900
600
1100
N
LEGEND
600 ISOHYETS
CATCHMENT BOUNDARY
STATE FOREST
116° E
0 10 20 30 40 50 60
Kms

Table 2. Salinity characteristics of present and potential catchments

River	Catchment	Area in salinity zone (%) A	B	C	D	Alienated (%)	Cleared (%)	Present salinity $mg\ l^{-1}$
Wungong*	132				100	3		200
Nth Dandalup	153				100			200
Drakes Bk*	42				100			130
Sampson Bk*	65				100			130
Logue Bk*	38				100			200
Harvey*	380			30	70			200
Brunswick	213			7	93	45	25	230
Donnelly	805	9	17	27	47	18	15	230
Gardner	414				100	36	29	200
Shannon	337	4	14	18	64	10		220
Canning*	754	42	23	16	19	4		400
Serpentine*	694	15	19	20	46			200
Sth Dandalup*	319	4	27	27	42			200
Preston	603	12	70	18			40	250
Deep	1500	35	12	13	40	36	14	200
Helena*	1580	73	14	9	4	5	3	360
Collie*	2830	71	14	8	7	35	23	750
Warren	3870	65	9	8	18	44	31	730
Kent	1590	57	12	17	14	60	33	1100
Denmark	603	38	33	27	2	32	14	570
Murray	6900	88	6	3	3	70+	70	1800
Brockman	1360	100				85	39	1350
Wooroloo	536	82	18			88	48	1450

* Presently harnessed catchments

Source: Public Works Dept (1978, 1980)

- clearing control is a reversal of previous government policy to encourage agricultural development;

- land acquisition in conjunction with clearing control is being used to protect existing forest and to reforest some areas previously developed for agriculture;

- bauxite mining agreements had to be renegotiated to place conditions on previous open access to ore in zones A, B and C;

- the area committed to clearfelling operations was reduced to exclude some zone A forest.

Catchment zoning was formally adopted for management of State forest in 1977. It included a major upgrading of the importance of water quality and yield in forest production and led, for example, to an intensification of effort to reduce the impact of jarrah dieback in the A, B and C zones.

IMPACT OF DISTURBANCE ON THE NATURAL ENVIRONMENT

The natural environment of the region is a difficult one for forest growth (Bartle and Shea 1979). It is subject to pronounced summer drought, with only 10% of annual rainfall occurring in the 5 summer months. The soils, though deep, have adverse physical and chemical characteristics. They are predominantly of lateritic origin with coarse gravelly upper horizons and dense kaolin clay subsoils. The subsoils have a macro-structure of vertical channels, enabling deep penetration of rainfall (Hurle et al. 1979). The soils have a low nutrient status, low pH and high subsoil salt concentration. In addition, the region is prone to occasional intense summer wildfire.

Four major eucalypt species occur in this region. Jarrah (E. marginata Sm.) is the major species over some 80% of the area, frequently occurring as nearly pure stands on the lateritic uplands. On the more fertile soils formed over exposed basement rock in the southern D zone, karri (E. diversicolor F.Muell.) is the dominant species, occupying some 10% of the region. In low landscape positions in the A zone, wandoo (E. wandoo Blakely) becomes the dominant species, occupying the remaining 10% of the region. Marri (E. calophylla R.Br. ex Lindl.) extends over all sites, generally as a minor overstorey component, but becomes more common on low landscape positions and in southern forests.

There are four major types of disturbance:

(i) Agricultural development - which involves the removal of native vegetation with the exception of some scattered shade trees. Annual legumes and grasses are introduced and grazed in rotation with cereal crops. Superphosphate fertiliser is applied regularly. Reduced evapotranspiration leads to rising water-tables, mobilisation of stored salts, and the development or expansion of areas of permanent saturation in low landscape positions. Marked decline of residual wandoo trees occurs under this treatment. Natural recolonisation by native species in established annual plant swards is extremely slow, even in the absence of grazing or cultivation.

Agricultural development is most extensive in the A zone of catchments, but also extends into the main forest belt, particularly along the more fertile soils of the river valleys.

(ii) Phytophthora cinnamomi - an introduced soil/water-borne fungus which can cause death or decline in a wide range of native species, most importantly in jarrah (Podger 1972). The other major eucalypt species are relatively resistant. It has maximum impact on upland depressions in the northern D zone, where it can cause rapid devegetation, reducing jarrah forest to an open marri woodland with sparse ground cover. It has slower and/or less severe impact on other sites, with trees growing on the fertile valley soils not expressing any symptoms. The impact of the fungus on eucalypts diminishes in lower rainfall areas, but it is not known whether this is due to slower rate of development of the disease in the changed environment, or to the historical accident of more limited introduction of the fungus.

The fungus has become widely dispersed throughout the region, spread commonly being down drainage lines. A major concern with the fungus is its potential to amplify the impact of other types of intensive disturbance, such as bauxite mining and clearfelling.

(iii) Bauxite mining - a quarrying operation centred in the northern forest area. Bauxite occupies the coarse gravelly upper horizons of the laterite profile.

Average thickness of the bauxite deposit is 4.5 m, and commercial grades occur as discontinuous pods from 2-200 ha in area on mid- and upper-landscape positions. The total area of ore varies from 20% of the landscape in the D zone to a few per cent in the A zone, averaging some 6% overall (Alcoa of Australia 1978).

After mining, pits are rehabilitated by a procedure including earthworks to reshape the pits and build surface drainage control structures; replacement of topsoil; ripping to break the compaction of the pit floor, and revegetation with mixtures of local and introduced eucalypts and local legumes (Bartle and Shea 1979).

The disruption to normal drainage patterns and the scope for transport of infected soils suggest that bauxite mining could cause major intensification and spread of jarrah dieback (Bartle 1976). It is possible that devegetation due to the disease may be a larger source of salt flow than that due to actual mining.

Bauxite mining is at present confined to the D zone. No general extension of mining into the A, B and C zones will be permitted until it has been demonstrated that rehabilitation procedures will prevent salinity (Technical Advisory Group Report 1978; Department of Conservation and Environment 1978). A more localised bauxite mining operation has been approved in the A zone since it is sited on the already extensively cleared Murray catchment where it will not greatly add to the existing salt load.

(iv) Clearfelling - an intensive forest management method used in the southern karri and karri/marri forest. All wood suitable for saw milling or chipping is removed in a single operation. This permits even-aged regeneration which duplicates the natural system and has management advantages (White and Underwood 1974).

The intensity of the operation can cause soil disturbance and compaction and also has scope to spread P. cinnamomi. Stockpiling of logs has been adopted to avoid operations in wet weather and will reduce these problems.

The regeneration method includes high intensity fire to remove trash and natural seeding from seed trees or artificial seeding and planting where natural seeding is inadequate. On some areas ripping is necessary to break soil compaction (Schuster 1979).

In 1969, an area of 9000 km^2 was committed for clearfelling operations. With the subsequent concern over salinity risks and clearing controls, some 1200 km^2 of A zone has been excluded from this area. Clearfelling in the B and C zone is not expected to cause a salinity problem due to the rapid regeneration methods employed (Public Works Department of W.A. 1980).

OPTIONS FOR MANAGEMENT OF WATER QUALITY

A range of treatments is being developed by water resource managers to be applied in various combinations to produce water of acceptable quality in any given catchment. These treatments fall into two categories:

(i) Engineering treatments - these involve mechanical or physical works to improve water quality. One such treatment is used in the Wellington Dam on the Collie River. Due to stratification of water of different salinity, the more saline layers can be discharged. A 10% reduction in reservoir salinity has been achieved by this treatment (Public Works Department of W.A. 1979b). Other engineering treatments are possible, for example diversion of saline headwaters to prevent contamination of fresher downstream flow; desalination; and blending of fresh and brackish water.

(ii) Vegetation treatments - two opposing strategies are possible, depending on the salinity zone. In zones likely to yield flow more saline than the stream average, the vigour, density and area of tree cover can be favoured so that salt and water yield are disfavoured. Alternatively, in areas likely to yield stream flow less saline than the stream average, tree cover can be reduced to favour water yield (Shea et al. 1978).

It appears that vegetation treatments will generally be more economical methods of water quality control than engineering treatments (Public Works Department of W.A. 1979a,b, 1980).

DEVELOPMENT OF VEGETATION TREATMENTS

The integration of vegetation treatments for water quality control into land-use practice is being rapidly developed (Institution of Engineers 1976; Forests Department of W.A. 1977a,b, 1980; Technical Advisory Group Report 1978; Department of Conservation and Environment 1978). It is a complex process which involves not only considerable change in past practice, but also technical aspects which are not yet fully understood, especially in the case of areas already subject to disturbance.

In this section the development of vegetation treatments is discussed in relation to land use and salinity zone. Major technical problems are identified.

(i) Forested freehold land in salt zones

The earliest moves to protect forest on catchments as a salinity control measure date from 1961, when further release of crown land for agricultural development was banned on the Collie, Denmark and Kent Rivers. Bans were progressively imposed on other catchments until, by 1978, no further land release on any vulnerable catchment was permitted (Public Works Department of W.A. 1979a).

In 1976, legislation was enacted to control clearing of alienated land on the Collie River catchment. This was extended to include the Helena, Warren, Denmark and Kent catchments in 1978. It can be seen in Table 2 that these five catchments, with their extensive saline zones containing freehold land, would be particularly vulnerable to quality loss if clearing were allowed to proceed.

The clearing control legislation contains various provisions for compensation. By a combination of cash payment, purchase of land subject to controls, purchase of whole farms, and exchange of uncleared land for cleared land, the legislation should lead to the consolidation of existing cleared land into fewer holdings and permanent protection of forested land from further pressure for agricultural development.

An alternative to clearing control is to change the agricultural system that gives rise to the salinity problem. It is possible that forms of agriculture could be developed which retain a sufficient cover of perennial vegetation to maintain the hydrologic balance, thereby preventing salt mobilisation. Various forms of 'agroforestry' have been proposed for this purpose (McKinnell and Batini 1978). The most simple form would be to leave the existing overstorey intact and convert the understorey to pasture. Other forms could include reduction in the density of trees ('parkland' clearing), reduction in the area of trees ('strip' clearing), or conversion to more productive species of trees or shrubs. These systems would require research to establish their viability. One obvious problem would be the use of the major A zone species, E. wandoo, in agroforestry systems, since it appears to be undergoing decline as a shade and shelter tree in present agricultural land.

(ii) Agricultural land in salt zones

On partially cleared catchments, salinity could be reduced by reforestation. This treatment is being carried out on repurchased farmland on the Helena and Collie catchments. The Collie catchment has the most serious salinity problem of any presently used catchment in Western Australia. It is expected that salinity could rise as high as 1600 mg l^{-1} as a direct result of land clearing already completed. This is well above accepted water supply standards. A major reforestation exercise has been initiated to reduce the salinity to the World Health Organization's desirable limit of 500 mg $litre^{-1}$. This will involve the expenditure of about $12 million over 10 years to reforest some 200 km^2 of farmland (Public Works Department of W.A. 1979b).

Present reforestation practice is described by Spriggins et al. (1979). It involves the planting of mixtures of eucalypt species, both in an attempt to get better matching of species to site and also to spread risk in the event of failure of one species. Only some 30% of the landscape is planted, with lower slopes and valley floor positions being favoured, as this is where it is expected that trees will have greatest impact on water quality. Agroforestry is favoured as the long-term use of the partially reforested landscape, with the land remaining in public ownership but being leased back to farmers.

Though it is expected that any increase in tree cover will improve water quality, further research is required on species selection, distribution of replanted trees in the landscape, and management of stands for long-term health and production.

(iii) State forest in saline zones

In its multiple-use management plan the Forests Department of W.A. (1977) has given forest in the A, B and C zones a 'catchment protection' priority use, i.e. the dominant use of the forest is to prevent degradation of water supply and no secondary use which conflicts with this priority will be permitted.

The most important action required to meet this priority is to minimise the impact of jarrah dieback. In 1976 and 1978, most of the A, B and C zones were placed under quarantine. The purpose of this was to allow for disease expression in the absence of further man-aided spread so that detailed mapping of all points of infection could be carried out.

An aerial photographic technique to enable the location and mapping of individual infected trees has been developed (Bradshaw and Chandler 1978; Bradshaw 1979). With these maps, secondary uses will be planned according to rigid hygiene specifications. A trial logging project is currently in progress using such specifications. However, hygiene cannot be expected to be totally effective in preventing new infections.

Another method of reducing the impact of the disease is to improve the resistance of the forest to infection. There is evidence to suggest that the conversion of the forest understorey from dominance by bull banksia (Banksia grandis Willd.) to dominance by leguminous species, by increasing the intensity of prescribed burning, could create a soil environment unfavourable to the fungus (Shea 1979,1980). This possibility is being actively researched.

It is possible that both hygiene and improved resistance to infection will be inadequate to prevent some impact of the disease. For this reason it will be necessary to develop revegetation treatments using dieback-resistant species.

Perhaps the major impetus to develop such revegetation treatments is the projected extension of bauxite mining into the saline zone in some 30 years time, subject to satisfactory rehabilitation procedures being developed. A major research objective is to develop rehabilitation treatments appropriate to pit areas and to adjacent forest which may be exposed to dieback infection during mining. A trial mining exercise is planned to test these treatments in about 10 years' time.

(iv) State forest in the non-saline zone

On harnessed catchments in the non-saline zone, the Forests Department has allocated a 'water production' priority use to the forest. To date this has only been applied in a passive way, i.e. by not aiming for full restocking in reforestation of degraded areas, such as dieback-infected areas and bauxite mine pits. Active treatments, such as a reduction in the density of the forest have not yet been attempted. Such treatments could immediately help to ameliorate salinity in the Wellington reservoir on the Collie River. However, active treatments cannot be adopted until research better defines the relationships between forest density/distribution and stream yield, and until the methods for management of reduced-density forest are developed (Shea et al. 1978).

RESEARCH PRIORITIES

(i) Species selection

The native species displaced or rendered unthrifty by disturbance to the natural environment leave a gap into which replacement species must be fitted. A comprehensive screening of the genus *Eucalyptus* to identify suitable replacement species has commenced (Bartle and Shea 1978). Since 1976, some 360 ha of tree plots have been established. More than 70 species of eucalyptus, with an average of two provenances per species, have been established in replicate blocks on the five major site types (Table 3).

Table 3. Species screening plots

Location		Site type	Planting year	Area	No species
Del Park	Zone D	bauxite pit	1976	35	35
Marrinup	Zone D	P.c.* infected upland	1978	80	70
George A	Zone A	upland	1979	90	70
George B	Zone A	P.c.* infected lowland	1979-80	80	70
Stenes	Zone A	agric. lowland	1979	80	70

* *Phytophthora cinnamomi*

In this work the choice of species was confined to eucalypts. Though eucalypts may be desirable for aesthetic reasons, they are not the only prospective species. Furthermore, the common occurrence of problems of decline in this genus in rural environments in Australia may indicate some basic inability to tolerate the effects of disturbance, or at least of agricultural development. In the absence of any detailed understanding of this problem it would be prudent to expand species testing to include exotics. This would be especially appropriate for agroforestry development, where species with non-timber forms of production may integrate more readily with existing agricultural systems.

(ii) Method of evaluation

The primary ranking of potential vegetation treatments will be according to hydrologic performance. The standard technique for assessing the hydrologic effect of vegetation is by catchment (or sub-catchment) water balance measurements. Such studies are large in scale and of long-term duration. There are a number of vegetation treatments which can be expected to affect water yield and quality. These include the selection and planting of suitable tree species, the optimum distribution of these species over the landscape, and the subsequent management of tree cover. Small scale evaluation of these treatments will be needed to give an early indication of those justifying more intensive study.

Shea et al. (1978) report some such screening work where leaf water pressure potential and leaf diffusive resistance were used to infer the period of transpirative activity of different species. This type of work was considered incapable of providing sufficient resolution between treatments, and a major research project has recently commenced using the ventilated chamber method to quantify transpiration of whole trees (Greenwood and Beresford 1979, 1980; Bartle 1979).

(iii) Agroforestry

An agroforestry system for saline areas must achieve two objectives. Firstly, it must maintain or restore acceptable water quality, and secondly, it should have sufficient agricultural and tree crop production to make it attractive. It is apparent that in some catchments tree cover could be justified by the benefit to water quality alone. However, an acceptable level of production could expand the scope for agroforestry to be used for the rehabilitation of catchments currently considered unusable.

Pinus radiata is the tree species with the most promising timber potential for an agroforestry system. It is already used in a large conventional plantation in the A zone and is the species currently being given most attention in agroforestry research. This aims to quantify timber and pasture production from P. radiata/annual pasture mixtures with various tree densities, spacings and ages (Anderson and Batini 1979). Some work has commenced on the hydrologic impact of P. radiata), but needs to be expanded.

Other species subject to some investigation include Pinus pinaster, E. wandoo and E. camaldulensis. Species with non-timber forms of production, such as perennial grazing shrubs, have not yet received any attention. The work can only be considered exploratory at this stage. It would need to be considerably expanded to address such basic questions as the decline of E. wandoo under agricultural conditions.

(iv) Trial mining

A considerable bauxite resource occurs in the A, B and C zones of northern catchments. This resource will not be mined unless research can demonstrate that rehabilitation will be successful in preventing deterioration in water quality. A trial mining exercise is planned for this investigation. Current research in the D zone aims to devise an appropriate set of treatments for this trial. The major treatments are:

- species selection: trees and understorey;

- nutrition: the value of fertiliser in increasing the growth rate of replanted vegetation;

- ripping: amelioration of the compaction of the pit floor and the adverse physical nature of the subsoils;

- drainage method: infiltration into pit floor or overland drainage.

In addition, the most advanced methods of minimising the impact of P. cinnamomi, both in the pits and in the adjoining forest, will need to be built into this trial.

There is substantial commitment to this work. Since it involves nearly all aspects of the ecology and hydrology of catchments, it would provide spin-offs to other research. For example, the species selection and methods of evaluation arising from research into the rehabilitation of areas mined for bauxite have general application.

(v) Stand management

Since broad-scale rehabilitation of disturbed areas within the jarrah forest has only recently begun, there are little data available on stand management strategies. Extensive research is required to develop techniques which will ensure the maintenance of tree vigour as the stand develops, while at the same time ensuring that the objectives of rehabilitation are met.

Preliminary analysis of growth data of some species in early bauxite pit plantings has shown an abrupt decrease in height growth at the age of 4 to 7 years. This may indicate possible future decline or mortality in the stand. It is necessary to determine the main factors contributing to this condition. It may be due to inherent limitations in the species or to inadequate site preparation and fertilisation. It is also possible that aspects of subsequent management of the stand could be manipulated to improve performance, e.g. thinning, fire and nutrition.

The development of thinning regimes appropriate for long term survival as well as salinity control will require detailed research. For example, the heavy thinning regime applied to P. radiata plantations on drought-prone sites in Western Australia may allow too much deep infiltration of water if used in stands established to control salinity.

Fire is a major factor of the environment in the southwest of Western Australia Stand management must allow for the impact of fire, either as wildfire or prescribed burning. Research has a major role to play in devising desirable fire regimes for the management of stands on disturbed areas. For example, the establishment of a dense understorey of native shrubs, predominantly legumes, has been adopted for rehabilitation of bauxite pits (Bartle et al. 1978). This leads to rapid development of a litter layer, natural recolonisation by small plants and animals (Majer 1978) and to nutrient recycling. However, the legumes are short-lived and constitute a major fire hazard. In addition, the regeneration of legumes is dependent on the occurrence of fires of high intensity (Shea et al. 1979).

REFERENCES

Alcoa of Australia, 1978: Wagerup alumina project - environmental review and management program.

Anderson, G.W., and Batini, F.E., 1979: Clover and crop production under 13-15 year old Pinus radiata. Aust. J. Exp. Agric. Anim. Husb. 19, 362-8.

Bartle, J.R. 1976: Rehabilitation of the Seldom Seen catchment. Report to the Project 5 working group of the Hunt committee.

Bartle, J.R. 1979: Jarrah forest evaporation. In 'Water Resources and Land Management Issues in the Darling Range'. Field tour guide, Institution of Engineers symposium, Perth.

Bartle, J.R., McCormick, J., and Shea, S.R., 1978: Direct seeding of native species - a technique for revegetation of disturbed jarrah forest. Proc. Rehabilitation of Mined Lands in Western Australia. W.A.I.T. 99-104.

Bartle, J.R., and Shea, S.R., 1978: Selection of tree species for rehabilitation of degraded areas in the northern jarrah forest. Proc. Rehabilitation of Mined Lands in Western Australia. W.A.I.T. 7-16.

Bartle, J.R., and Shea, S.R. 1979: Development of the ecosystem after mining. Proc. Aust. Mining Industry Council Workshop, Bunbury, W.A.

Bradshaw, F.J., 1979: Low level aerial photography. Proc. Prospect 2000 Conference: Landscape Planning, Recent Advances. Aust. Inst. Ag. Sci. and A.N.Z.A.A.S., Perth.

Bradshaw, F.J., and Chandler, R.J., 1978: Full coverage at large scale. Proc. Seminar Remote Sensing for Vegetation Damage Assessment. Am. Soc. Photogrammetry, Washington, U.S.A.

Department of Conservation and the Environment, 1978: Wagerup alumina refinery proposal by Alcoa of Aust: Report and recommendations by the Environmental Protection Authority. Bull. No. 50.

Forests Department of Western Australia 1977a: General Working Plan No. 86 of 1977, Part 1.

Forests Department of Western Australia 1977b. A perspective for multiple-use planning in the northern jarrah forest.

Forests Department of Western Australia 1980: Land-use management plan, northern jarrah forest management priority areas.

Greenwood, E.A.N., and Beresford, J.D., 1979: Evaporation from vegetation in landscapes developing secondary salinity using the ventilated chamber technique. Part I. Comparative transpiration from juvenile Eucalyptus over saline groundwater seeps. J. Hydrol. 42, 369-82.

Greenwood, E.A.N., and Beresford, J.D. 1980: Evaporation from vegetation in landscapes developing secondary salinity using the ventilated chamber technique. Part II. Evaporation from Atriplex plantations over a shallow saline water-table. J. Hydrol. 45, 313-19.

Hurle, D.H., Yendle, P.A., and Height, J.I., 1979: Groundwater studies in bauxite mining areas. In 'Water Resources and Land Management Issues in the Darling Range'. Field tour guide, Institution of Engineers symposium, Perth.

Institution of Engineers, 1976: Land-use conflicts in the southwest, A symposium to explore methods of planning for the future. Bunbury, W.A.

McKinnell, F.H., and Batini, F., 1978: Agroforestry trials in the southwest. Forest Focus No. 20. Forests Department of Western Australia.

Majer, J.D., 1978: The importance of invertebrates in successful land reclamation, with particular reference to bauxite mine rehabilitation. Proc. Rehabilitation of Mined Lands in Western Australia. W.A.I.T. 47-61.

Peck, A.J., 1975: Effects of land use on salt distribution in the soil. In 'Plants in Saline Environments'. (Eds A. Poljokoff-Mayber and J. Gale.) (Springer-Verlag: Berlin.)

Peck, A.J., and Hurle, D.H., 1973: Chloride balance of some farmed and forested catchments in south Western Australia. Water Resources Res. 9, 648-57.

Podger, F.D., 1972: Phytophthora cinnamomi. A cause of lethal disease in indigenous plant communities in W.A. Phytopathology 62, 972-81.

Public Works Department of Western Australia, 1978: Effects of land use on the salinity of streams in the southwest of Western Australia. Unpublished report to the Salinity Committee of the Western Australian Water Resources Council.

Public Works Department of Western Australia, 1979a: Clearing and stream salinity in the south of Western Australia. Document No. MDS 1/79.

Public Works Department of Western Australia, 1979b: Collie River salinity control.

Public Works Department of Western Australia, 1980: Report by the steering committee on research into the effects of the woodchip industry in southwest of Western Australia.

Schuster, C.J., 1979: Rehabilitation of soils damaged by logging in southwest Western Australia. Research paper 54. Forests Department of Western Australia.

Shea, S.R., 1975: Environmental factors of the northern jarrah forest in relation to pathogenicity and survival of Phytophthora cinnamomi Forests Department of Western Australia. Bull. No. 85.

Shea, S.R., 1979: An ecological approach to the control of jarrah dieback. Forest Focus No. 21. Forests Department of Western Australia.

Shea, S.R., 1980: Forest management and Phytophthora cinnamomi in Australia. Report of a conference held at CSIRO Div. Forest Research, Canberra. (Ed. K.M. Old.)