Report by the
Steering Committee
on

Research into the effects of the Woodchip Industry on Water Resources in South Western Australia

April
1978

DEPARTMENT OF
CONSERVATION & ENVIRONMENT
WESTERN AUSTRALIA

BULLETIN № 31

CONTENTS

SUMMARY AND CONCLUSIONS

The Woodchipping Industry Agreement Act came into force in September 1969. In October 1973 shortly after the W.A. Chip and Pulp Co. Pty. Ltd. had been granted an export licence by the Commonwealth Government, the then Minister for Environmental Protection arranged for the formation of a technical Steering Committee to monitor the quality of the valuable water resources in the Woodchip Licence Area, and to initiate research to determine areas which might be sensitive to salinity increase. Although it had been expected that the cutting operations could be controlled without placing at risk the quality of the water resources, the expressed intention for setting up the Steering Committee was to provide the Conservator of Forests with technical data on which to base his management plan.

This report reviews progress to April 1978 of the work undertaken by the Steering Committee.

In undertaking its activities, the Steering Committee has worked with appropriate government departments through supervisory panels to establish four research and monitoring projects within the Woodchip Licence Area. The Steering Committee has also obtained additional information on related activities from other organisations - particularly CSIRO, and it has had access to the studies initiated by a similarly constituted committee, known as the Hunt Steering Committee which is directing research into the effects of bauxite mining on water resources.

The research projects initiated within the Woodchip Licence Area have adopted a variety of approaches, including a historical review of the effects on water quality of changing land use, the checking of salinity in small streams draining both forested and agricultural land, and the long term monitoring of rivers in the area. Two of the projects involve studying the effects of timber cutting operations on water quality within carefully selected experimental catchments.

One of these projects is directed towards long term objectives, and involves the use of three sets of paired catchments distributed throughout the Licence Area so as to be representative of the differing rainfall pattern, land form, soils and forest types. After a calibration period of four to five years, it is proposed to cut one catchment of each pair in accordance with normal woodchip operations, and intensively monitor it right through the regeneration period, while its paired catchment is left uncut to act as a control for comparison purposes. No cutting has yet been undertaken on this project, and conclusive data are not expected for a period of around ten to twelve years. However the bore holes which have been drilled as observation points have already provided valuable sub-surface data.

The other project involving experimental catchments is less sophisticated, and has been planned to provide a means of identifying, in the shorter term, any effects that heavy cutting practices might have on either ground water or stream flow. It involves the use of four single coupes 100 to 200 hectares in size, which have been strategically located throughout the Licence Area. The coupes were established and instrumented in 1974-75, and following a calibration period of at least twelve months they were logged prior to the 1977 winter.

The project which involves the comprehensive monitoring of rivers in the Licence Area has been adapted to the existing Public Works Department network of stream gauging stations. This has been regularly gathering data on the quantity and quality of the surface water resources on a comprehensive basis in the Manjimup Region for at least fifteen years. Longer records are available for some rivers.

The historical surveys conducted by the Steering Committee have shown that where any salinity increase has been reported within the Manjimup district over past years, it has been associated with permanent clearing - generally for agriculture, as distinct from normal forestry operations which provide for regeneration. In the case of the Warren River, the observed quality deterioration has been mainly attributed to widespread permanent clearing for agriculture which has occurred since 1945 on highly salt susceptible areas within the upper sections of the catchment of the Warren River and its tributaries. Much of this area is within the Shire of Kojonup and is well outside the Woodchip Licence Area.

From the time that field activities were initiated by the Steering Committee, the rainfall throughout the region has been below average, and the limited information so far obtained in respect of ground water and surface run off must be interpreted accordingly. The available borehole data have confirmed that on the broad scale, the predicted trend of increased soil salinity with decreasing annual rainfall is valid. However, the data also show that on small catchments there can be departures from this generalisation particularly if the catchment is incised deeply into the landscape. It has also been observed that within a single catchment, individual bore holes can produce quite significant variations from the average. On the experimental catchments which have been cleared, there has been a slight rise in water table but no salinity increase in either groundwater or streamflow has been noted. However, in uncleared forest areas there has been a general drop in ground water levels over the last three years, due no doubt to the dry seasons. The comprehensive monitoring of rivers within the Licence Area has not detected any adverse changes in salinity or turbidity since cutting for woodchips commenced in 1975.

The salt pollution of previously fresh rivers, which has been noted for more than 50 years to follow the removal of forests in many parts of the south west of Western Australia, is mainly attributed to an increase in net soil water recharge through reduced evapotranspiration. The variable factor which mainly controls evapotranspiration is leaf area.

Studies of leaf area measurements conducted in the Manjimup region by CSIRO have shown that the evaporative capacity of the regenerated forest will progressively increase until it equals that of the original in approximately five years. This indicates that forest regrowth, five years after regeneration, will be transpiring water into the atmosphere at a rate equal to that of the original forest, and this should be sufficient to prevent excessive ground water flow, with its contained salt, to the stream system. This work by CSIRO has therefore identified the vulberable period during which water resources could be at risk during the woodchipping operations.

Proven techniques for regenerating the forest have been developed over a number of years by the Forests Department. These all encourage the natural processes. However, when delays occur in the natural karri seeding cycle, regeneration is hastened by the planting of seedlings which are grown in the Forests Department nursery near Manjimup.

The Steering Committee is very much aware of the threat to the forests of the jarrah dieback disease, but the problem in the Woodchip Licence Area is seen as being potentially less serious than in the northern forests. Quarantine regulations were introduced by the Forests Department in December 1977 mainly in peripheral sections of the Licence Area. The areas of forest to be cut for woodchip production have been programmed by the Forests Department to minimise conflict with quarantine zones, and the overall situation has been assisted by the fact that greater production of chips than originally anticipated is being obtained per unit of forest area and also from sawmill refuse.

In summary therefore, the studies carried out to date have detected no deterioration in the quality of water resources which can be attributed to woodchip operations - all of which are being strictly controlled. However, the Steering Committee does note with concern a potential threat to some of the water resources within the Woodchip Licence Area, because of the absence of any control over those uncleared areas of private land on catchments which are vulnerable to salinity - particularly the upper sections of the Warren and Donnelly.

The Steering Committee will continue to supervise the research programme it has initiated, and will report at regular intervals. Apart from their application to the woodchip industry, the committee believes that the studies are providing valuable information on rainfall distribution, soil types, land form, salinity and water resources which will be of significant value whenever any changes in land use are contemplated for the region in the future.

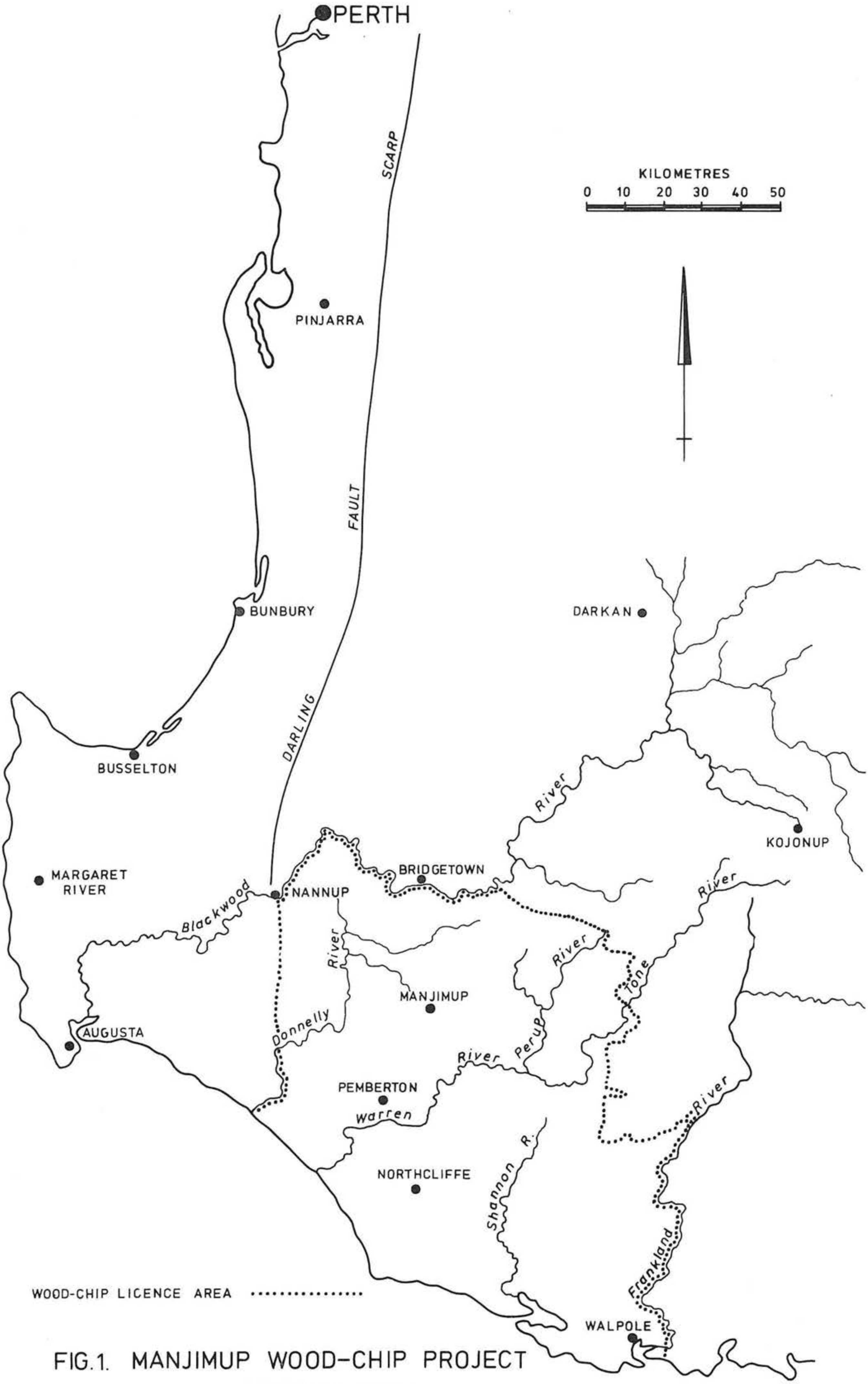


FIG.1. MANJIMUP WOOD-CHIP PROJECT LICENCE AREA

1. INTRODUCTION

The Licence Area under the Wood Chipping Industry Agreement covers 9000 km^2 of the lower south west portion of Western Australia and is centred on the town of Manjimup. It extends from the south coast northwards as far as the Blackwood River. On the west it is bounded by an extension of the Darling Scarp and on the east by the Frankland River (Figure 1). Most of the Licence Area is still under forest, and much of the land in private ownership has not been cleared.

The Licence Area contains the catchment areas of some of the State's major freshwater rivers (for example Donnelly, Warren, Gardner, Shannon, Weld and Deep). Although the Warren River is still classified as "fresh", its long term status is somewhat uncertain. This is because three of its major tributaries, the Tone (which originates outside the Licence Area), the Perup and the Wilgarup, have already been rendered brackish by permanent clearing for agriculture. However, the Warren is a high yield river which obtains a major portion of its flow from the high rainfall country in the western section of its catchment, and the overall quality of the water is still satisfactory.

The Environmental Impact Statement which was prepared by the Forests Department for the woodchip project recognised that, under certain conditions, cutting of timber might adversely affect the quality of surface water resources - particularly in respect of increased salinity and turbidity. The Statement proposed action which is very important for the control of water quality. This included restrictions on the size of coupes as well as dispersal of logging operations, rapid regeneration after cutting and measures to control soil erosion. The Statement also provided for the excision from the Licence of areas suspected of being salt sensitive.

Although very little hydrological research work had been attempted in the actual Manjimup area, the State Government (principally through the Department of Agriculture and the Public Works Department) had gained considerable experience throughout the south west and particularly in the wheatbelt, with the problems of increasing salinity following the clearing for agriculture of the perennial vegetation. In addition, extensive studies had been undertaken recently by State Government departments and the CSIRO in similar country within the Darling Ranges which included the catchment of the Wellington Dam and also in areas to be mined for bauxite.

On the basis of this experience, and from a knowledge of the general land form, rainfall pattern, soils, etc., it had been assessed that the effects of logging activities on water resources would be minimal within the Woodchip Licence Area. This was particularly so in the southwest sector of the area which experienced the higher rainfall (greater than 1250 millimetres (mm) *per annum*) and was more effectively drained. However, at the same time, it was recognised that salinity problems could occur, particularly in the north east.

corner, roughly bounded by the 1000 mm isohyet which had been specially identified in the Environmental Impact Statement. Provision was made to excise this salt sensitive area from logging operations for the first 15 years pending research.

On August 9, 1973, the Director of the then Department of Environmental Protection called a meeting of technical officers from relevant departments to discuss the concern expressed by the Environmental Protection Council that an increase in the intensity of forestry operations brought about by the introduction of a woodchip industry could result in an increase in the salinity of surface water resources. In a report dated August 21, 1973 the Public Works Department reviewed the situation and stressed the need to prepare adequately documented proposals for determining sensitive areas and for effectively monitoring any changes in water quality.

In October 1973, the Minister for Environmental Protection requested the Minister for Works to arrange for the Chief Engineer, Public Works Department (Mr K.J.Kelsall), to convene a technical committee to advise the Conservator of Forests on salinity aspects in relation to forestry management of the area.

The technical committee is now known as the "Steering Committee on Research into the Effects of the Woodchip Industry on Water Resources in South Western Australia", but for brevity has become known as the "Kelsall Steering Committee". The research and monitoring required for the woodchip assignment was expected to follow closely along the same lines as that which was being arranged by the Steering Committee set up some months earlier by the Minister for Industrial Development to investigate the effects on water supplies caused by bauxite mining and which was chaired by Mr H.E.Hunt, Chief Engineer of the Metropolitan Water Board.

In order to obtain a free interchange of information, the membership of the two committees was made up of the same officers where practicable (Figure 2). The first meeting of the Kelsall Steering Committee was held in January, 1974.

This report reviews the progress to April 1978 in research projects instigated by the Kelsall Steering Committee and several related projects, largely under the auspices of the CSIRO Division of Land Resources Management in Perth. Earlier reviews have been published by Collett (1976) and by the Kelsall Steering Committee itself (1976). A similar review of progress in the bauxite research projects has been published by the Hunt Steering Committee (1976).

2. GENERAL DESCRIPTION OF THE WOODCHIP LICENCE AREA

Data collection and analysis

In Section 4 of this report, the initial design and progress made to date in four major research projects is described. Two of these projects involved the drilling of grids of bore holes across the areas under study in order to provide a means of easily measuring changes in depth to the water table and to enable the collection of groundwater samples. The cores extracted during the drilling of these holes were retained and analysed for moisture, density and salt content to provide extra information on the soil and rock profiles. Other bore-holes have been drilled throughout the area by the CSIRO Division of Land Resources Management, but in this case these were single holes in locations chosen to provide information on the soil and rock profiles in different landscape positions, and not as part of future groundwater monitoring programmes.

During 1977 the data obtained from a total of 161 boreholes was pooled and analysed statistically to provide the most comprehensive picture to date of soil types, soil water contents and salinities in relation to surface vegetation and landscape position in the Woodchip Licence Area. This analysis which was undertaken by Johnston *et al* (1978).

Distribution of rainfall, soil types and major vegetation zones

Precipitation in the Woodchip Licence Area is dominated by winter rainfall related to frontal activity associated with low pressure systems originating in the Southern and Indian Oceans. Cold moist winds from the west and south rise as they reach the edge of the dissected plateau, causing a band of high rainfall (1200 - 1450 mm *per annum*) some 10-20 km inland from the coast. Further inland rainfall decreases rapidly and by the north eastern boundary of the area some 80 km from the coast is only 700 mm *per annum*. Over 75% of annual rainfall occurs between May and October inclusive emphasising the seasonal nature of the rainfall and consequently the stream flow response in the region.

The variability of annual rainfall is low relative to other regions of Australia but does gradually increase with decreasing rainfall over the Licence Area. Standard deviations vary from around 15% of the mean in the high rainfall region (1200 - 1450 mm *per annum*) to 20% of mean in the low rainfall region (700 - 900 mm *per annum*) (Loh and King, 1978).

McArthur and Clifton (1975) have described the soils and forest types of part of the area, and a very broad scale soil map of the whole is available (CSIRO, 1975).

In the drier inland plateau area with sluggish drainage lines gravelly lateritic soils predominate. These are underlain by "pallid zone" clays and deep zones of weathering in which considerable amounts of soluble salts have accumulated. In

STEERING COMMITTEE ON RESEARCH INTO THE EFFECTS OF THE WOODCHIP INDUSTRY ON WATER RESOURCES IN SOUTH WESTERN AUSTRALIA

CHAIRMAN	K.J. Kelsall	Public Works Department
	D.B. Collett	Public Works Department
	J.J. Havel *	Forests Department
	J.G. Kuehne	Department of Industrial Development
	J.H. Lord	Mines Department
	M.J. Mulcahy	Department of Conservation and Environment
	I.J. O'Hara	Metropolitan Water Board
	R.H.B. Hebbert	University of W.A.
	R.A. Perry **	C.S.I.R.O.
	T.C. Stoneman	Department of Agriculture
SECRETARY	J.R. Watson	Department of Conservation and Environment

PROJECT 1

IDENTIFICATION OF AREAS VULNERABLE TO SALINITY INCREASE

STUDY GROUP

T.C. Stoneman (Convener)	Agriculture
P.R. George	Agriculture
D. Carter	Agriculture
C.V. Malcolm	Agriculture
A.B. Hatch	Forests
B.J. White	Forests
T.T. Bestow	Mines
W.M. Mc Arthur	C.S.I.R.O.
K.L. Barrett	P.W.D.

PROJECT 2

PAIRED CATCHMENT STUDY

SUPERVISORY PANEL

D.B. Collett (Convener)	P.W.D.
K.L. Barrett	P.W.D.
J.J. Havel*	Forests
T.T. Bestow	Mines
A.J. Peck	C.S.I.R.O.

WORKING GROUP +

I.C. Loh	P.W.D.
P. Hulbert	P.W.D.
P. Kimber	Forests
L.J. Furness	Mines

PROJECT 3

MONITORING AT STREAM GAUGING STATIONS

SUPERVISORY PANEL

D.B. Collett (Convener)	P.W.D.
K.L. Barrett	P.W.D.

WORKING GROUP

I.C. Loh	P.W.D.
P. Hulbert	P.W.D.
B.L. Chester	P.W.D.

PROJECT 4

MONITORING OF GROUND WATER HYDROLOGY

SUPERVISORY PANEL

J.J. Havel* (Convener)	Forests
T.C. Stoneman	Agriculture
D.B. Collett	P.W.D.
T.T. Bestow	Mines
A.J. Peck	C.S.I.R.O.

WORKING GROUP +

P. Kimber	Forests
D. Whiteley	Forests
L.J. Furness	Mines

* E.R. Hopkins up to February, 1978.
** A.J. Peck up to March, 1978.
\+ Analysis of Projects 2 and 4 Core data - W.M. McArthur (C.S.I.R.O.) and C.D. Johnston (Forests)

FIGURE 2. MEMBERSHIP OF STEERING COMMITTEE AND RESEARCH PROJECT SUPERVISORY PANELS (AS AT MARCH, 1978.)

lower topographic situations the soils are determined by geology; podzolic soils develop on acid and intermediate gneiss and red earths on basic gneiss.

Distribution of native vegetation is dependent upon soil type, landscape position and climate. Karri forest is mainly restricted to the red earths (karri loams) of the more deeply dissected valleys extending inland from the heaths of the coastal dune areas. Jarrah forest occurs more frequently in drier areas and in the high rainfall zone is restricted to infertile lateritic soils. Marri may be co-dominant in either karri or jarrah forest.

Soil water contents

In general terms the average quantity of soil water tends to increase with annual rainfall, although the trend is less marked at annual rainfalls above 1150 mm. However, there is considerable variability between individual boreholes of the catchment grids, especially in the lower rainfall areas (Table 1) where unexpectedly high soil water contents can occur. The effect of landscape position on soil water is minor, although the measured level of water in boreholes tends to be closer to the ground surface in the lower landscape positions.

Several specific trends are also observed in individual soil profiles. The more important of these include:

- a roughly linear increase in water content with depth throughout the first six metres of soil which often comprises lateritic gravels.
- abrupt changes in water content at or near the depths where major changes in soil structure occur; for example, at the interface between the weathering zone and overlying material.
- apparent water tables or aquifers indicated by sudden increases in water content to saturation.

Further comments relating to observations obtained during subsequent borehole monitoring are discussed later in this report.

Soil Salinity

In general the quantities of total soluble salts (TSS) in the soil profiles which were examined show a strong inverse relationship with average annual rainfall. (Figure 3). This is indicated both on the experimental catchments (Table 2), and by the individual CSIRO boreholdes. Average soil solute concentrations show the same relationship with annual rainfall (Table 3) as well as a sharp increase in concentrations at rainfalls below 1050 mm (Figure 4). One

Average rainfall (mm/yr)	Catchment	No. boreholes used	Catchment average water content (m^3/m^3)	Range in profile averages		
				Max. (m^3/m^3)	Min. (m^3/m^3)	C.V.+ (%)
1380	Crowea	12	.330	.450	.217	18
1290	Poole	4	.386	.424	.347	8
1200	Iffley	6	.366	.422	.314	10
1220	Lewin N. & S.	6	.378	.436	.317	13
1080	April Road S.	7	.386	.421	.351	7
1060	April Road N.	8	.307	.363	.210	17
1050	March Road E.	9	.323	.393	.213	21
900	Mooralup	12	.230	.327	.127	24
850	Yerraminnup N. & S	6	.258	.273	.247	4

\+ Coefficient of variation

Table 1. Variations in profile average water contents (by volume) observed in Project 2 and Project 4 experimental catchments

Average rainfall (mm/yr)	Catchment	Average TSS content (kg/m³) *	Average profile depth (m)	Average TSS storage (kg/m²)
850	Yerraminnup S.	1.78	21.5	38.3
1200	Iffley	1.58	19.7	31.1
900	Mooralup	1.50	15.1	22.7
850	Yerraminnup N.	1.18	19.2	22.7
1050	March Road E.	.80	16.1	12.9
1220	Lewin N. & S.	.77	17.6	13.6
1060	April Road N.	.76	14.3	10.9
1080	April Road S.	.58	13.2	7.7
1380	Crowea	.36	17.6	6.3

* Values joined by a line are not significantly different at a 95% confidence level.

Table 2. Total soluble salts content and salt storages in Project 2 and Project 4 catchments.

Average rainfall (mm/yr)	Catchment	No. profiles used	Average TSS concentration (mg/l) *
850	Yerraminnup S.	3	6960
900	Mooralup	9	6120
1200	Iffley	5	4570
850	Yerraminnup N.	3	4550
1060	April Road N.	7	2560
1050	March Road E.	9	2480
1220	Lewin N. & S.	5	2090
1080	April Road S.	6	1500
1380	Crowea	8	1090

* Values joined by a line are not significantly different at a 95% confidence level.

Table 3. Total soluble salts concentrations in Project 2 and Project 4 catchments

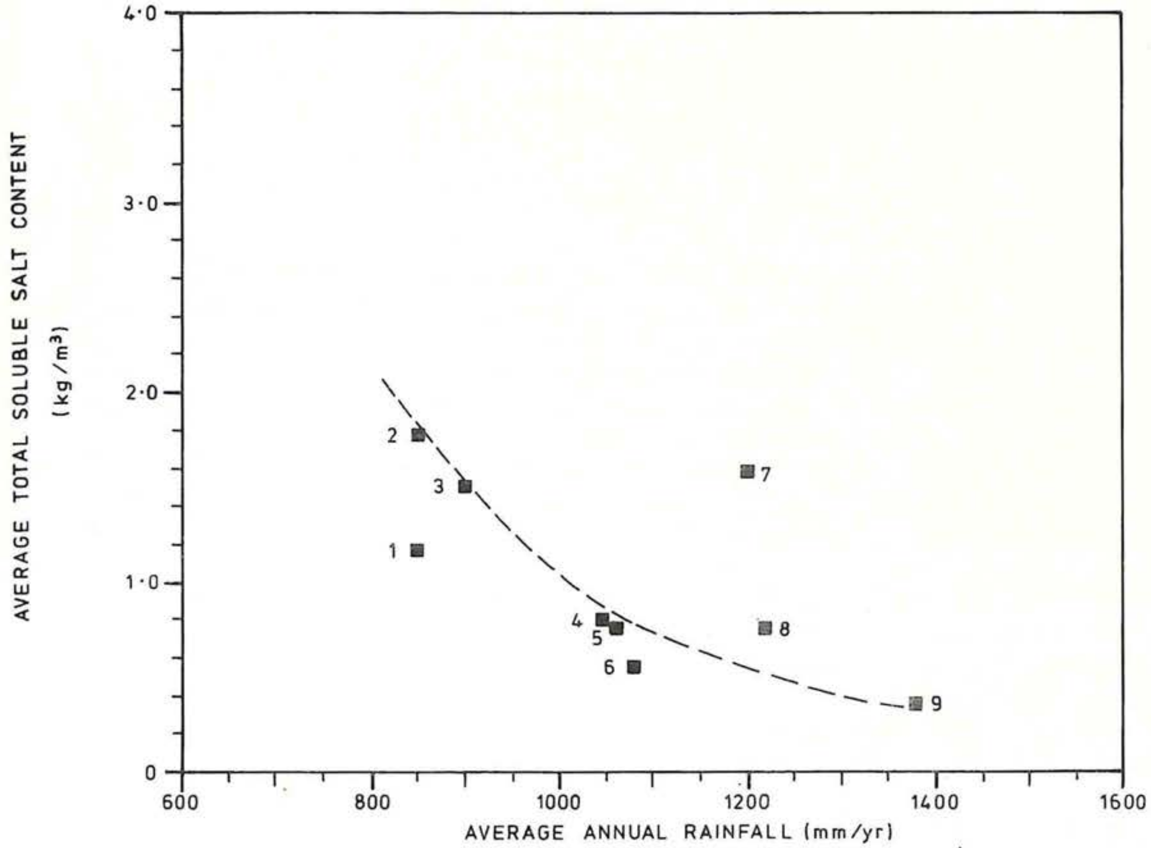


FIGURE 3. DISTRIBUTION OF AVERAGE SOLUBLE SALTS CONTENT WITH AVERAGE ANNUAL RAINFALL FOR SMALL CATCHMENTS IN THE WOOD-CHIP LICENCE AREA.

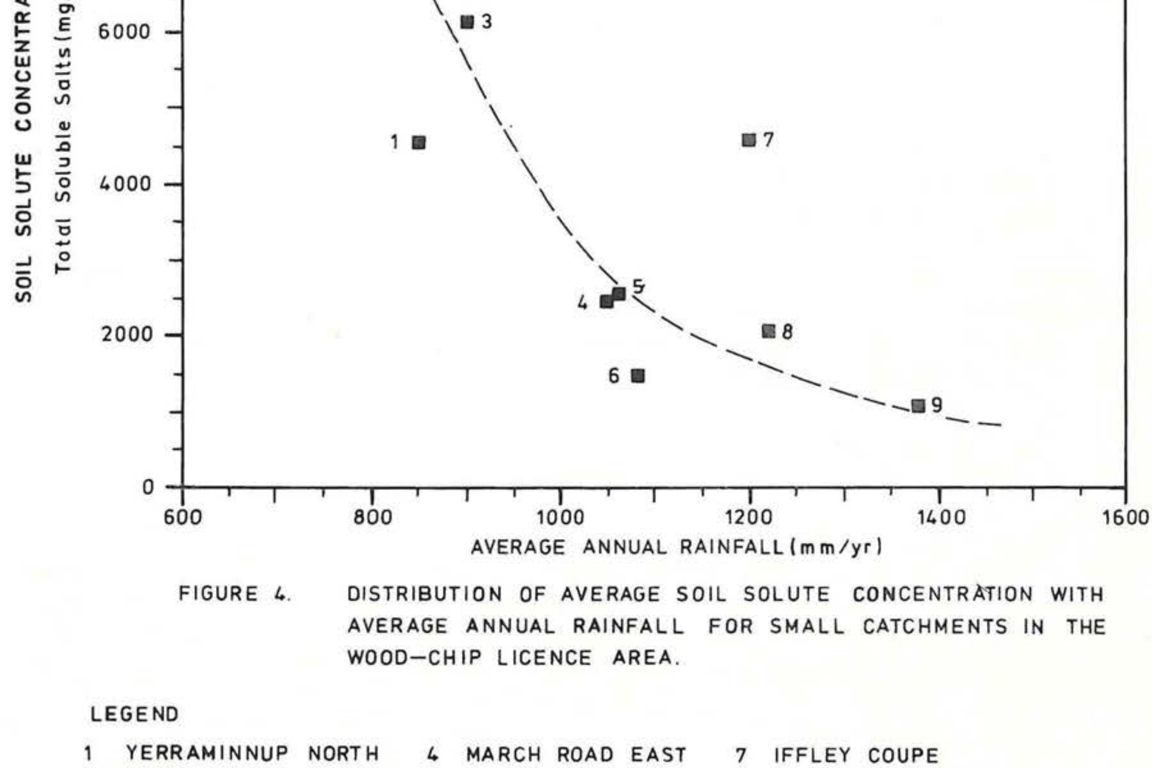


FIGURE 4. DISTRIBUTION OF AVERAGE SOIL SOLUTE CONCENTRATION WITH AVERAGE ANNUAL RAINFALL FOR SMALL CATCHMENTS IN THE WOOD-CHIP LICENCE AREA.

LEGEND

1	YERRAMINNUP NORTH	4	MARCH ROAD EAST	7	IFFLEY COUPE
2	YERRAMINNUP SOUTH	5	APRIL ROAD NORTH	8	LEWIN NORTH & SOUTH
3	MOORALUP COUPE	6	APRIL ROAD SOUTH	9	CROWEA COUPE

of the Project 4 experimental catchments, namely Iffley coupe, is an exception to this general trend with anomalously high total soluble salts concentrations. As with water content, there is great variability between individual bores in the grid, with values typically varying by a factor of 5 to 10. Thus, reliable estimation of the average for a 100-200 ha catchment would require data from at least 12-15 bores, and estimation by single observations must be assigned a large degree of uncertainty.

One of the major objectives of the review of all borehole data was to establish whether any correlations exist between the site characteristics - *viz* landscape position, forest type, soil type - and the quantities of salt observed in the soil. Neither the forest type nor surface soil type were found to have a significant effect although the karri loams (red earths) do have a relatively low quantity of salts when compared with other soil types in the same rainfall zone.

By contrast, landscape position does have a marked effect with greater amounts of salts occuring in lower parts. Many of the upper slope sites have unusually high salt contents, but closer examination shows that these are located in upper landscape drainage lines (*i.e.* gullies). When these sites are classified separately, it is found that the "true" upper slope sites have the lowest salt contents. (Table 4).

There are also systematic changes with depth in the quantities of salts in individual soil profiles. Two basic patterns are commonly observed (Figure 5). First there is frequently an obvious "salt bulge" occurring in the unsaturated soil profile the size and shape of which is related to annual rainfall and landscape position. For example, in valley sites and upper landscape drainage lines, a very sharp maximum is often observed in the first 4 to 5 metres of profile. The second pattern is found in divide and upper slope landscape positions where the low salt content shows only a small relatively linear increase with depth.

In summary, there is great variability in soil salt content which depends on the landscape position. In more general terms, there is a decrease in salt content with increasing rainfall and towards upper slopes and divides.

Forestry operations in the Licence Area

Only a minor portion of the productive forest within the Licence Area is cut over each year. Originally the operation was planned to produce 750,000 tonnes of woodchips *per* year, and it was anticipated that 11,000 ha (or 2.7% of the Licence Area) would need to be cut for this purpose.

Landscape position	No. profiles	Profile average TSS concentration (mg/l) *
Middle slope	1	3506
Valley	5	2727
Upper slope/gully	7	2392
Lower slope	5	2276
Divide	2	1456
Upper slope	2	541

* Landscape positions joined by a line are not significantly different at 95% confidence level.

Table 4. Average total soluble salts concentrations in landscape positions of March Road East, April Road North and April Road South catchments, Project 2.

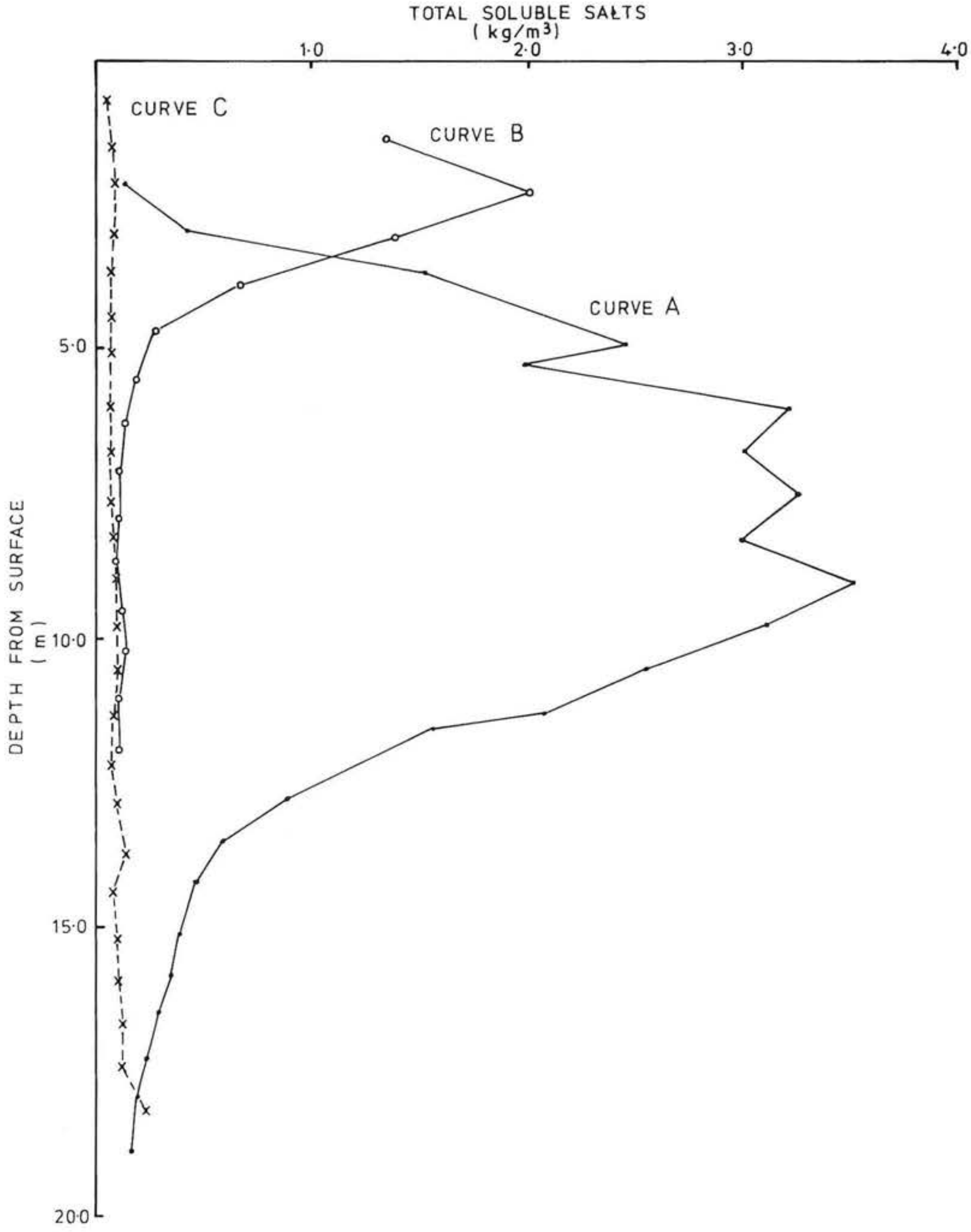


FIGURE 5. TWO BASIC DISTRIBUTIONS OF SUB-SURFACE SALTS

1. OBVIOUS "SALT BULGE" OCCURRING IN THE UNSATURATED SOIL PROFILE

   A — MID SLOPE, C.S.I.R.O. BORE No. 109.

   B — VALLEY FLOOR, CROWEA COUPE BORE No. 6078611

2. SMALL RELATIVELY LINEAR INCREASE OF SALINITY WITH DEPTH

   C — UPPER SLOPE, C.S.I.R.O. BORE No 105

Actual removal for the year ending 30 June, 1977, the first complete year of operation, was approximately 500,000 tonnes taken from only 2,458 ha of forest. The reduced production and even more pronounced reduction in area used are due to several factors which were not anticipated. These include:

- a greater weight of chips *per* volume of wood;
- a greater volume of wood *per* hectare,
- more chips produced from sawmill wastes;
- marketing problems in Japan having direct repercussions on the demand for woodchips from Western Australia.

Cutting for woodchips is not the only forest production. In the year ending 30 June, 1977, approximately 510,000 tonnes of sawlogs were produced by cutting from State Forest and Crown Lands within the Licence Area. This is a slightly greater production than that for woodchips.

After cutting operations, regeneration of the forest is carried out as quickly as possible using techniques developed by the Forests Department and which encourage the natural processes (Watkins, 1973; White and Underwood 1974). When delays occur in the natural karri seeding cycle, regeneration is undertaken by planting karri seedlings obtained from a special Forest Department Nursery near Manjimup.

The most recent major development in forest management within the Licence Area has been the introduction of quarantine regulations in December 1977 in order to minimise the spread of jarrah dieback disease caused by the fungus *Phytophthora cinnamomi*. Extensive areas of jarrah forest in other regions of the South West, particularly in the Darling Range, were quarantined early in 1976. However, the situation in the Woodchip Licence Area is potentially less serious because:

(i) based on experience from elsewhere, spread of the disease is largely caused by its movement downslope from upland infected areas. However in much of the central part of the Licence Area the valleys are dominated by non-susceptible species such a marri and karri.

(ii) the physical and biological environment in these areas (steeper slopes, well drained soils of moderate fertility, tall dense leguminous under-storey) generates conditions which do not favour activity of the fungus (Christensen, 1975).

(iii) the main threat is only around the periphery of the Licence Area where jarrah is dominant on the less fertile and more poorly drained lateritic soils.

Thus, vehicular access has only been restricted in the north eastern sector, in the western zone adjacent to the Darling Escarpment, and in parts of the eastern zone. The areas of forest to be cut for sawlogs and subsequent woodchip production have been programmed to minimise conflict with quarantine zones. Some of the experimental catchments described later in this report are, of necessity, located within quarantine zones. However, vehicle hygiene precautions are taken and much of the monitoring work is undertaken on foot.

3. SCOPE OF THE RESEARCH PROGRAMME

The Kelsall Steering Committee is responsible for a group of monitoring and research projects concerned with environmental effects of the woodchip industry related to water quality. The terms of reference of the Committee were stated as follows at its inaugural meeting on 15 January, 1974:

> *"To report on what measurements and predictive modelling would be required to determine sensitive areas, where problems might arise, and to determine what on-going monitoring would be needed to provide the Conservator of Forests with technical data, on which to base his management and control of operations".*

The Committee recognised the need not only to identify short term effects of clearing for woodchips but also to assess long term changes through the complete forest regeneration cycle. Four special study projects were therefore proposed:

Project 1

The identification of vulnerable areas by studying effects caused by previous land use changes and using predictive modelling, landform surveys, and stream water sampling.

Project 2

The monitoring of surface and underground water on adjacent paired catchments of minor streams, one of which would be cut over and regenerated and the other remain uncut.

Project 3

The monitoring of run-off from major catchments within the Woodchip Licence Area to detect any measurable changes in water quality.

Project 4

The monitoring of both surface and underground water in areas which were to be cut over and regenerated during early stages of the Woodchip Industry. This would provide an "early warning" of any major and readily detected changes.

Project 4 was to be a less precise and simpler experiment than Project 2 aiming to provide qualitative rather than quantitative information.

Each project was to be concerned primarily with water quality, especially salinity levels and turbidity of surface run-off. It was recognised that, as has been found in the bauxite research projects, the risk of increasing salinity would probably be greatest in the lower rainfall regions and therefore the study areas comprising a mixture of landscape units were distributed throughout different rainfall regions of the Licence Area. The 1977 review of borehole data discussed in section 2 above has clearly confirmed this rationale.

The Kelsall Steering Committee arranged for each project to be undertaken by field staff under the guidance of its own particular supervisory panel. The members of the Kelsall Steering Committee, each panel and related research projects are shown in Figure 2.

Progress on all projects is reviewed regularly by the supervisory panels and the Kelsall Steering Committee itself.

4. MAJOR RESEARCH PROJECTS

Project 1 - Identification of areas vulnerable to salinity increases

Two major approaches have been used to identify vulnerable areas. The first of these involved a historical assessment of land clearing and its effects on salinity, while the second concerns a stream sampling project in two major part-cleared catchments near Manjimup.

The historical evidence has been reviewed in a published Bulletin (Department of Agriculture, 1974). This Bulletin indicated that the major land use changes from forest to agriculture occurred before 1929. Since then there has been a general overall increase of cleared land of about 10%, to a total of about 70,000 ha within the Manjimup Shire. However since 1945 there has been a surge of clearing within the Kojonup Shire on the driest parts of the Tone River Catchment which is a principal tributary of the Warren River. Permanent clearing for agriculture was recognised as being likely to produce a greater increase in salinity than the same area of logging followed by regeneration. Nevertheless, the two effects may be cumulative within any given area, and if the effect of clear-felling for woodchips is to increase an already existing high stream salinity, then there is quite rightly concern over the extra salinity contributed. This situation could be further complicated by possible future clearing of privately owned land within catchments.

Using this historical approach, the catchments of the Donnelly and Warren Rivers, in the "intermediate zone" with a mean annual rainfall of between 1,000 and 1,200 mm *per* annum, were identified as areas in which adverse salinity changes might possibly occur. Those parts of the Woodchip Licence Area with mean annual rainfall less than 1,000 mm were regarded as clearly prone to salinity increase following clearing, while areas with greater than 1,200 mm were generally considered to be not vulnerable to salinity increase.

Consequently, during 1977 a stream sampling programme was implemented for Smith Brook, which drains into the Warren River, and Manjimup Brook, a tributary of the Donnelly River (Figure 6). The catchments of these two brooks are approximately the same size, and have similar amounts of clearing and both lie between the 1,000 mm and 1,250 mm *per* annum isohyets.

The programme has involved fortnightly sampling of the two brooks and their side streams at a total of 60 points. Each water sample collected has been analysed in the laboratory for electrical conductivity, total dissolved solids by evaporation, and for chloride ion content by titration with silver nitrate. The resulting measures of salinity levels, together with estimated flow rates, have allowed the estimation of the total salt load of each individual stream over the 1977 season's flow.

The data obtained up to the end of September 1977 show that after an initial high salinity period at the start of the season, the stream salinities fall as surface salt, accumulated over the dry summer season, is washed into the streams (Figure 7). Salinity levels continue to fall until the end of winter when the stream flows decrease and the salinities rise slightly. Manjimup Brook appears to have a significantly lower salinity than Smith Brook (Figure 7) with the values for flow weighted averages being 156 and 297 milligrams *per* litre (mg/l) chloride respectively. This difference could be due to the fact that Smith Brook is more deeply incised into the pallid zones of the weathered landscape, with the result that seepages and streams issuing from them tend to increase salinity.
By comparing the water samples from different locations within each catchment, a tendency has been noted for more salt to enter the main brooks from the drier eastern, and to a lesser extent, the northern margins of both catchments.

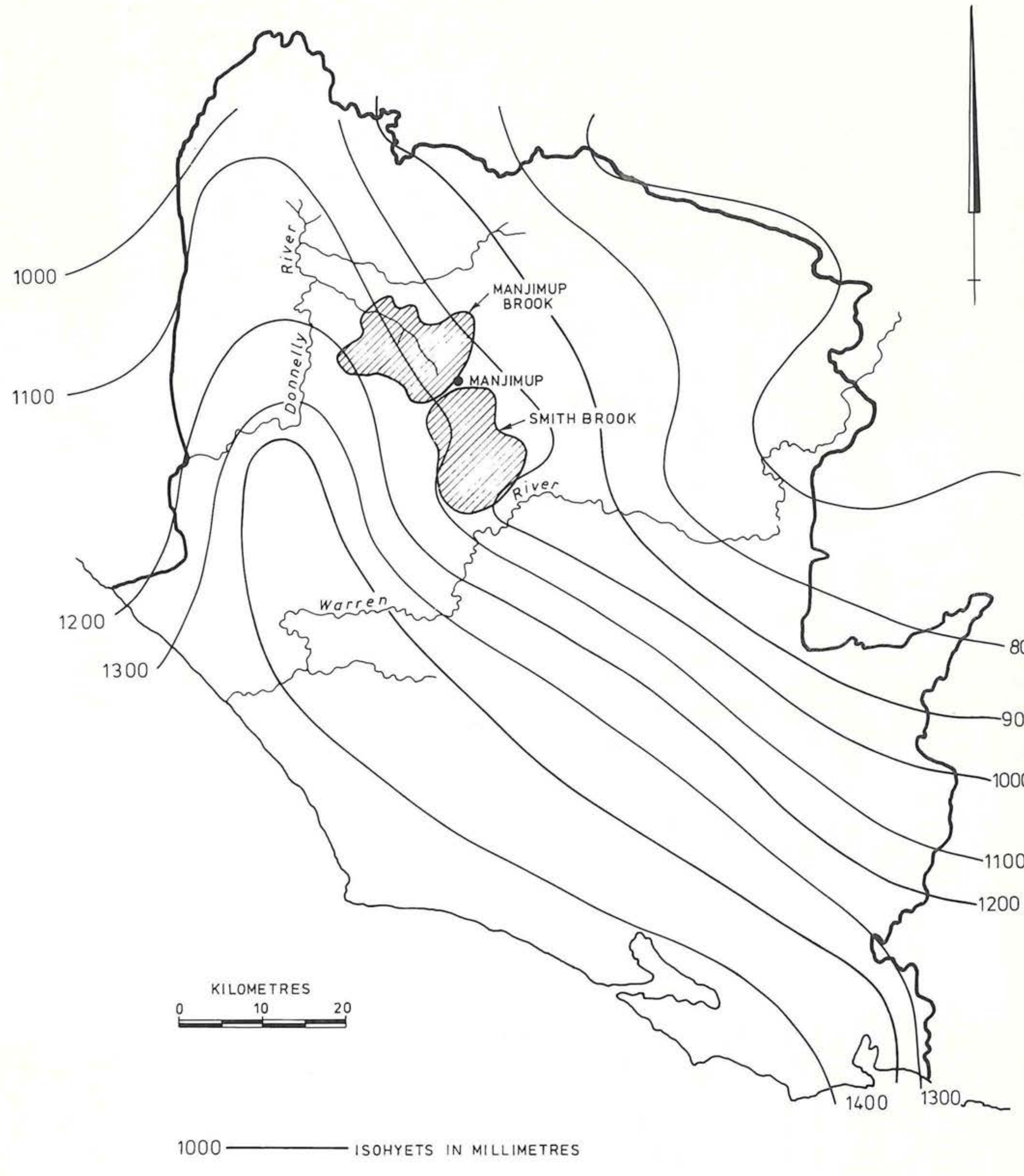
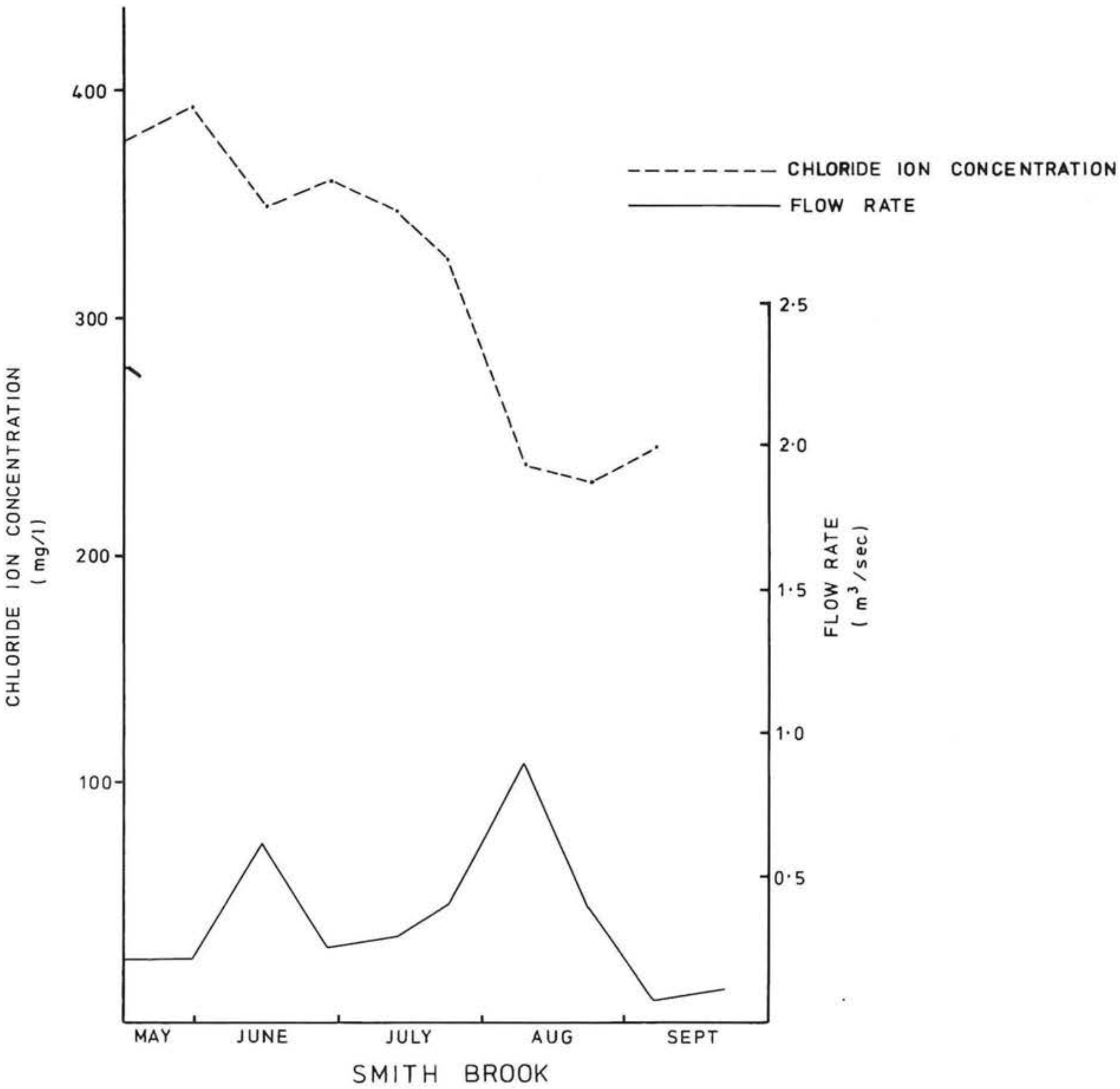


FIG. 6. LOCATION OF ISOHYETS AND PROJECT 1 STREAM SAMPLING STUDY AREA (1977)



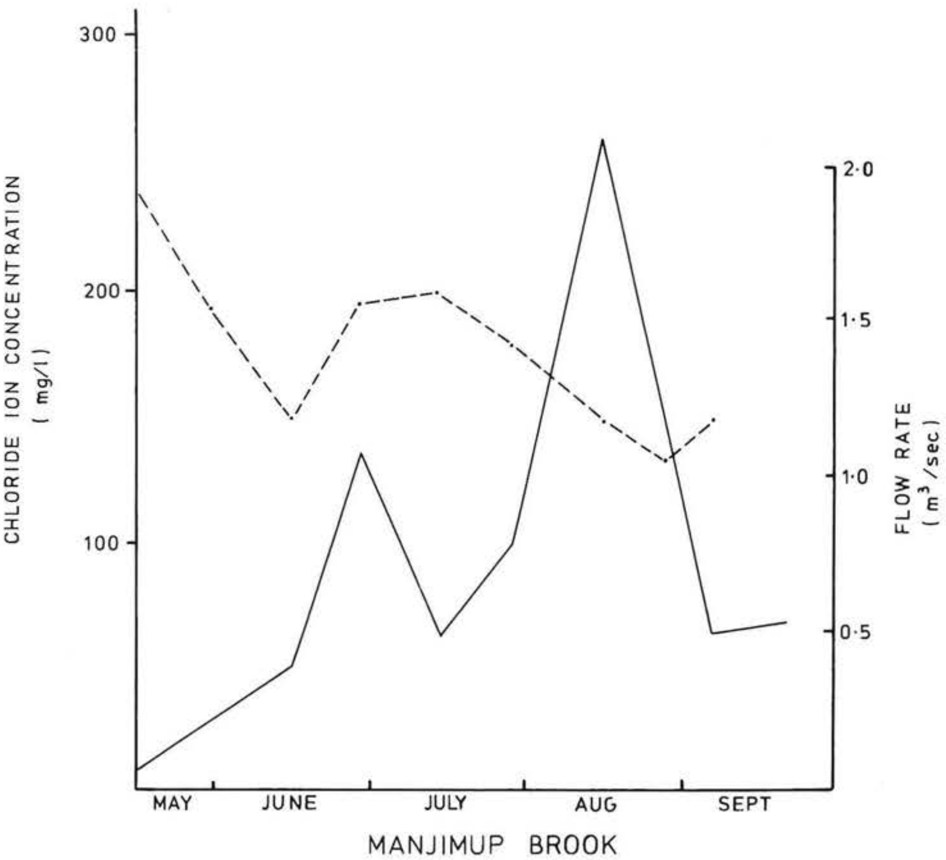


FIGURE 7. FLOW RATE AND CHLORIDE ION CONCENTRATION OF SMITH BROOK AND MANJIMUP BROOK 1977, PROJECT 1. (AS MEASURED AT LOWEST SAMPLING POINT.)

Stream salinity data collected for the full year are now being subjected to statistical analysis in the hope of relating stream salinity to readily measurable catchment and land use features.

Project 2 - Monitoring of surface and underground water changes in "paired catchments"

This project is essentially a long term one and the aim is to gain a detailed knowledge of water and salt balances in representative areas so that changes can be demonstrated and predictions made about the effects of the Woodchip industry on hydrology throughout the Woodchip Licence Area. Both surface and ground water hydrologies are being intensively monitored on seven catchments (two pairs and one group of three) throughout the region for a calibration period of 4-5 years. After this time a single catchment (two in the case of the group of three) will be cut over and regenerated using the normal operational practice. A similar adjacent catchment will be left uncut to act as a control so that the effects of cutting the first catchment can be accurately assessed. On the basis of the results it should be possible to make reliable predictions of hydrologic changes induced by the woodchip industry.

Location and characteristics of catchments

The catchments, each 100-250 ha in area, have been established to cover the range of climatic conditions, soil and forest types considered to be at some degree of risk. (Figure 8). Full details of the catchments in use are presented in Table 5.

Measurements and Instrumentation

The surface water monitoring comprises measurement of the quantity and quality of rainfall and streamflow. The instrumentation used is basically the same for all of the catchments.

At the discharge section of each catchment a V-notch weir with a floatwell has been constructed and equipped with a Leupold and Stevens A35 graphical recorder which continually records stage height. A pumping sampler collects samples from the stilling basin of the gauging weir at 0900 hours each day. These samples are analysed for chloride ion, conductivity, sediment and colour. The amount of sediment deposited in the stilling basins is measured at the end of each winter and the stilling basin emptied.

Rainfall is measured by a Leupold and Stevens Q.A.C. pluviometer located at the top of each catchment and a tilting bucket pluviometer adjacent to each gauging station recording onto the A35 recorder.

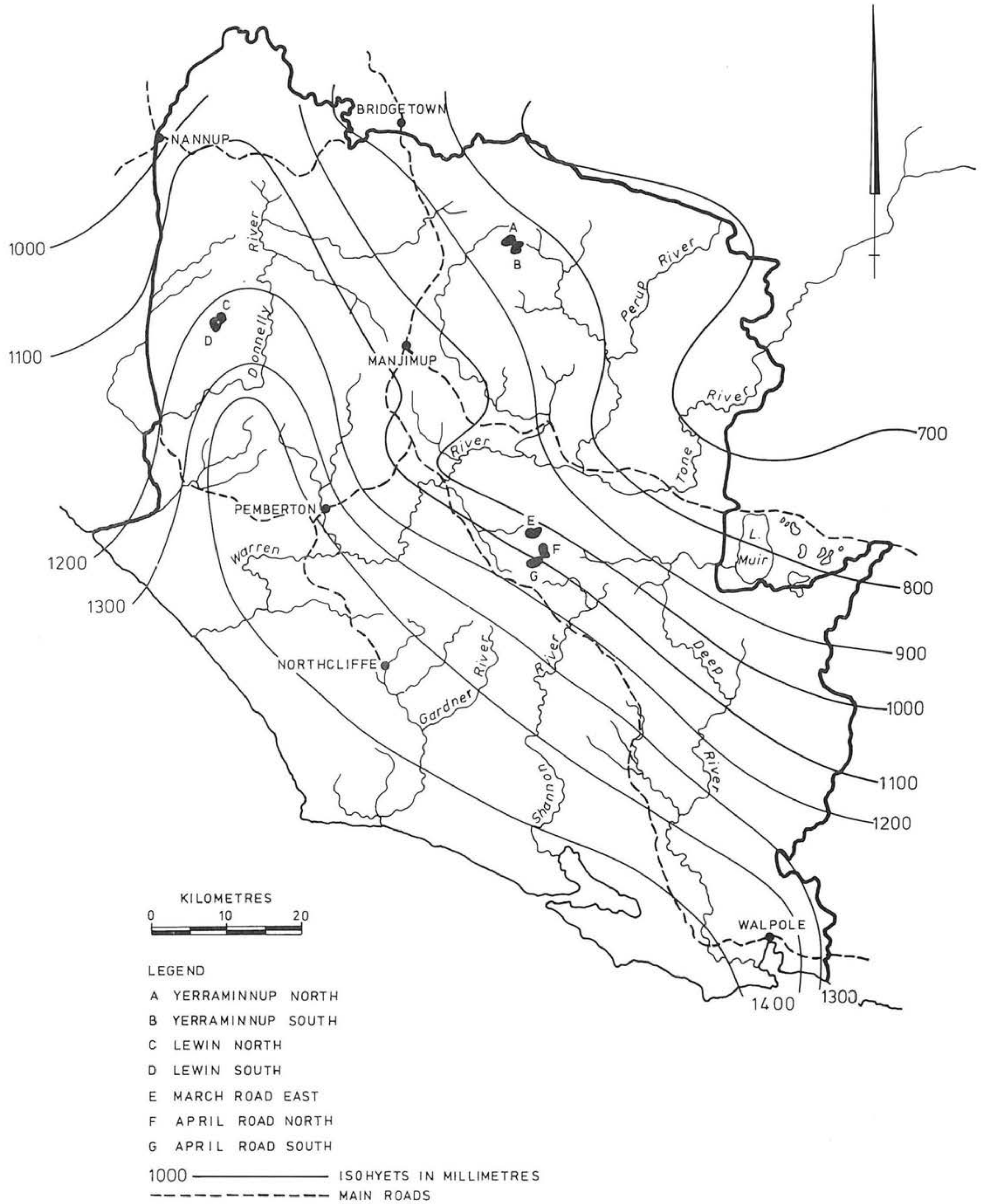


FIG. 8. LOCATION OF EXPERIMENTAL CATCHMENTS PROJECT 2.

The groundwater system is monitored by 9 to 15 bores distributed uniformly throughout each catchment, with additional bores in some catchments where necessary to assess groundwater flow beneath the gauging station.

Results

Rainfall

Table 5 compares the 1976-77 (two-year) and 1975-77 (three-year) mean rainfalls for the three groups of catchments with the long term mean rainfall. The severity of the recent series of dry years is clear, especially for the Yerraminnup catchments.

Groundwater observations

Figure 9 shows the fluctuations in water table levels of three representative bores in one of each of the three groups of catchments. Each graph includes a lower, middle and upper slope bore to represent the general range of groundwater response over the catchment. Plotted on the same time scale are the monthly rainfall data for each catchment.

It is clear that fluctuations in water level are considerably smaller in the low rainfall Yerraminnup catchments than in the higher rainfall catchments. Also, there are generally smaller fluctuations during the year where the water table is deep, such as the upland areas of a catchment.

An increased lag between rainfall input and groundwater response is apparent with depth to water table (or with valley position). It is also possible to detect a general trend of decreasing water levels over the period of record.

These observations indicate that some recharge from rainfall to depths of twenty metres does occur even in the low rainfall areas. Considerably higher recharge at mid-slope locations generally occurs within six months, and major recharge occurs on the lower slopes within four or even less months of the seasonal winter rains.

Streamflow

Despite significant variations from year to year a general gradation of increasing streamflow yield with increasing rainfall is reflected in the ratios of annual stream outflow to rainfall input shown in Table 6. For example the Yerraminnup Catchments yielded only 0.4%, the March and April Road Catchments between 3.8 and 9.8% and the Lewin Catchments between 6.1 and 15.5% over the 1976-77 year period.

Catchment name	Forest block	Soil type	Forest type	Mean rainfall (mm)		
				Long term	Two year (1976-77)	Three year (1975-77)
Yerraminnup North Yerraminnup South	Warrup	laterites podsolics	jarrah-marri	850	743	730
Lewin North Lewin South	Lewin	laterites podsolics red earths	jarrah-marri karri	1220	1098	1080*
March Road East April Road North April Road South	Sutton	laterites podsolics red earths laterites upland swamps laterites podsolics	marri-karri karri jarrah-marri some karri on slopes jarrah marri-karri	1070	997	1033*

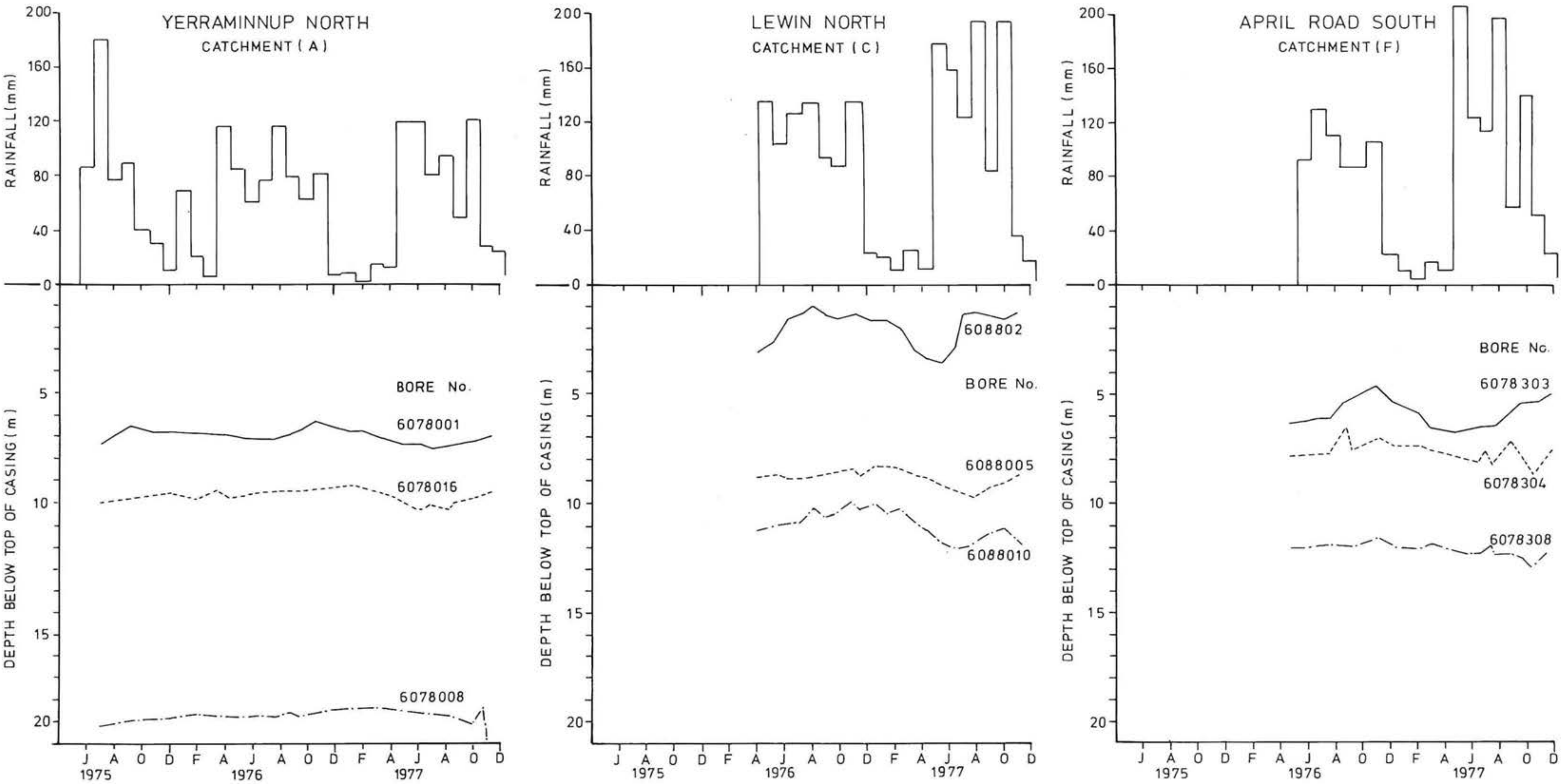
* Estimated using nearby rainfall stations for 1975

Table 5 Description of Project 2 "Paired Catchments" and mean rainfall data

It is also clear that from the ground water responses discussed above and from soil moisture measurements (McArthur & Johnston) (pers, comm.) that significantly more water is active in the soil profiles of the Lewin catchments than those of the Yerraminnup catchments. This suggests that the additional rainfall available in the higher rainfall areas influences the complete soil profile and is, not surprisingly, a major factor governing the higher stream flows of these areas. However, other closely related factors such as landform, soils and vegetation distribution throughout catchments also influence streamflow response. For example, the steep topography of the Lewin catchments and their high proportion of karri loam soils (red earths) relative to the low relief and high proportion of lateritic soils of the Yerraminnup catchments contributes to the difference in their respective stream flow responses. However, significant differences in stream flow yield have also been observed between catchments in the same rainfall zones, for example the two Lewin catchments.

Lewin North catchment produces both larger flood flows and base flows than Lewin South catchment with greater percentage differences occurring in the base flows of the two catchments. This indicates the problems of selecting paired catchments and emphasises that minor catchment differences can have a large effect on the surface water hydrology of small sized catchments. However such problems can be minimised in the detailed calibration phase by using a number of techniques for modelling the rainfall-streamflow process. These techniques include computer simulation models which use daily rainfall and potential evaporation as input to moisture accounting schemes and thereby enable predictions of both rapid streamflow response (direct runoff) and delayed response (baseflow) to rainfall to be made on a daily basis.

It is also clear from Table 6 that there are significant variations in the annual streamflow response from individual catchments from year to year. Both the Lewin catchments and the triple in Sutton Block yielded considerably more streamflow in 1977 than in 1976 despite the fact that annual rainfall was less. This was due to a more advantageous temporal pattern of daily rainfall with associated higher intensities during the important winter flow months in 1977. Such variable behaviour, characteristic of the rainfall-streamflow process generally, but particularly marked on small catchments, necessitates detailed study on a daily basis at the pretreatment calibration phase of the catchment pairs. Experience gained from research catchments elsewhere in South Western Australia has indicated that despite these limitations, major increases in stream flow can be observed in as little as six months after total vegetation removal for agriculture.



BORE No.	TOP OF CASING (A.H.D.)*
6078001	264·06
6078016	267·87
6078008	292·12

BORE No.	TOP OF CASING (A.H.D.)*
6088002	182·56
6088005	197·31
6088010	208·96

BORE No.	TOP OF CASING (A.H.D.)*
6078303	200·75
6078304	203·57
6078308	215·29

LANDSCAPE POSITION

- ——— VALLEY
- - - - - MID SLOPE
- —·—·— UPPER SLOPE

FIGURE 9. MONTHLY RAINFALL AND WATER TABLE FLUCTUATIONS IN REPRESENTATIVE BORES FROM THREE PROJECT 2 CATCHMENTS

*AUSTRALIAN HEIGHT DATUM (m)

TABLE 6 : ANNUAL CHLORIDE ION AND WATER BALANCES FOR THE SURFACE WATERS OF PROJECT 2 CATCHMENTS

CHMENT	YEAR	RAINFALL INPUT			STREAM OUTFLOW			STREAM OUTFLOW / RAINFALL INPUT		RAINFALL LESS STREAM OUTFLOW		TOTAL CATCHMENT CHLORIDE STORAGE 10^6Kg
		WATER		CHLORIDE 10^3Kg	WATER 10^3m^3	FLOW WTD CHLORIDE mg/l	TOTAL CHLORIDE 10^3Kg	WATER %	CHLORIDE %	WATER 10^3m^3	CHLORIDE 10^3Kg	
		mm	10^3m^3									
RAMINNUP	1975	703	1700	10.0	54.9	57.0	3.16	3.2	31.5	1650	6.88	
TH	1976	780	1890	11.1	6.75	174	1.17	0.4	10.5	1880	9.97	29.7
7 005)	1977	706	1710	10.1	6.57	121	0.80	0.4	7.9	1700	9.29	
RAMINNUP	1975	699	1370	8.08	38.0	46.8	1.78	2.8	22.5	1330	6.31	
H	1976	786	1540	9.09	8.91	74.0	0.66	0.6	7.3	1530	8.43	40.5
7 006)	1977	701	1370	8.11	3.46	105	0.36	0.3	4.4	1370	7.75	
N NORTH	1976	1130	1390	11.1	147	61.9	9.10	10.6	81.8	1240	2.02	9.0
3 004)	1977	1066	1310	10.5	203	37.5	7.61	15.5	72.5	1110	2.88	
N SOUTH	1976	1131	1190	9.50	72.8	55.7	4.05	6.1	42.1	1110	5.45	7.7
3 005)	1977	1043	1100	8.76	108	55.3	5.97	9.9	68.1	987	2.79	
H RD	1976	988	2700	18.9	103	118	12.2	3.8	64.3	2590	6.73	19.0
	1977	956	2610	18.3	256	72.7	18.6	9.8	101.7	2350	-0.31	
7 010)												
L RD	1976	1010	2380	16.7	92.2	45.2	4.17	3.9	25.0	2290	12.52	13.7
H	1977	990	2340	16.4	167	49.5	8.29	7.2	50.7	2170	8.06	
011)												
L RD	1976	1048	2180	15.3	111	69.1	7.67	5.1	50.3	2070	7.59	8.6
H	1977	988	2060	14.4	171	66.4	11.4	8.3	79.0	1880	3.02	
012)												

<u>Salinity Measurements</u>

The annual flow weighted chloride concentration for each year of record is listed in Table 6. The two Yerraminnup catchments and March Road East catchment are more saline than the others. A similar trend was noted by Johnston *et al* in their analysis of core data from the catchments.

Table 6 also lists the difference in the cubic metres of water and kilograms of chloride input to the catchments through rainfall and discharged from the catchments through surface streamflow. For comparison an estimate of the current chloride storage in the soil profile of each catchment is presented in the last column. The estimate of chloride ion input is based on an average rainfall concentration of chloride determined from the distance of each catchment from the coast. (Hingston and Gailitis, 1977).

The difference between input and output surface water is a combination of water lost to evapotranspiration, deep drainage, flow seepage beneath the gauging weir and changes in the saturated and unsaturated groundwater storages. It is likely that the measured differences in input and output water are slight underestimates of the total evapotranspiration, since the saturated groundwater storage has decreased over the period of record (see previous section) and the seepage under the gauging weir is negligible (see below). This suggests that evaportranspiration is the dominant factor in the water balance with greater than 84% of incoming water being evaporated or transpired on all catchments for each year of record to date. More reliable estimates of evapotranspiration will be possible when storage coefficients of the aquifers under consideration are known and estimates of changes in the water held in the saturated zone can be made from water table variations. Despite the limitations of the difference between rainfall input and stream outflow as a measure of evapotranspiration it is apparent from Table 6 that more water is transpired in the higher rainfall catchments where more moisture is available and higher forest densities occur. The higher rainfall areas, therefore, have the potential to produce a larger increased recharge to and subsequent discharge from the groundwater systems if significant reductions in the evapotranspiration occur following woodchipping.

However, because the high rainfall areas generally have less soluble salt in their soil profile and because they have larger streamflows the effect on surface water salinity is not likely to be as high as that in the drier catchments (Figures 3 and 4; Peck and Hurle, 1973).

The most significant point to note about the chloride balances is that when the available data is averaged out it shows that all catchments are apparently accumulating chloride. It is thought however that this is primarily related to the bias towards years of below average streamflow rather than any inherent chloride imbalance. Also the chloride ion export is underestimated because seepage beneath the gauging weir has not been considered. (see Table 7 for correction for Yerraminnup Catchments).

March Road East catchment produced a small excess of chloride ion in 1977 as a consequence of its high chloride ion concentration relative to its streamflow yield. It is likely that this catchment will in fact have a net export of chloride in average flow years.

Sub-Surface water flow and chloride export

To assess the magnitude of flow and chloride export beneath the gauging stations on the Yerraminnup catchments, additional drilling and pump testing was carried out by the Mines Department. Details are included in Hydrology Report No. 1498 (Furness, 1977a). Holes were drilled into both the overburden and permeable bed-rock and both draw down and injection tests undertaken to obtain a number of estimates of hydraulic conductivity for the two materials. Results indicate that although the overburden differs considerably from the weathered bedrock, the estimates obtained for the two layers were similar (0.148 and 0.094 cubic metres *per* day *per* metre for overburden and bedrock respect-ively on Yerraminnup North Catchment). The range of hydraulic conductivities obtained varied between 6.5×10^{-3} and 1.4×10^{-2} cubic metres *per* day *per* square metre for the North and South catchments respectively. From seismic traverses the total cross sectional areas under the stations were determined. Corrections were then made for the direction of groundwater flows and the monthly values of water and kilograms of salt passing through the sections were calculated for 1976. Details are included in Hydrology Report No. 1499 (Furness, 1977b).

Annual salt and water balances which included the groundwater seepage component were then calculated (Table 7). This additional subsurface water has a negligible effect on the annual water balance and does not affect the ratio of output to input water by more than 0.1%. However changes to the chloride ion balance were significant. The ratio of output changed from 10.5 to 22.5% and 7.26 to 34.5% for the North and South catchments respectively. Associated reductions in the chloride accumulation were 87% and 71%. Such small quantities of water have a large effect on the chloride balance because chloride concentrations in the underground waters are over 10 times as large as those in the surface waters.

The observed groundwater salinities in the lower slopes of the other catchments are not as high, rarely over five times as large as those of surface waters. This, together with the fact that these catchments have higher streamflows, indicates that the significance of underflow to the chloride balances is much smaller than for the Yerraminnup catchments. However, it is hoped to quantify this underflow in the near future.

Catchment	RAINFALL INPUT		OUTPUT				OUTPUT / INPUT		INPUT MINUS OUTPUT	
			Streamflow		Groundwater					
	Rain $10^3 m^3$	Chloride $10^3 Kg$	Water $10^3 m^3$	Chloride $10^3 Kg$	Water $10^3 m^3$	Chloride $10^3 Kg$	Water %	Chloride %	Water $10^3 m^3$	Chloride $10^3 Kg$
Yerraminnup North	1890	11.1	6.75	1.17	0.19	1.33	0.4	22.4	1880	8.64
Yerraminnup South	1540	9.09	8.91	0.66	0.35	2.48	0.6	34.5	1530	5.95

TABLE 7 : 1976 CHLORIDE ION AND WATER BALANCES OF YERRAMINNUP CATCHMENTS CORRECTED FOR UNDERFLOW

Summary

The limited results to date, all of which are during the "pretreatment stage" (i.e. before clearing one catchment of the pair) indicate the following trends:

1. All three years of measurement (1975-1977) have shown lower rainfall than the long term averages. The run of "dry" years has been especially severe in the Yerraminnup catchments.

2. In general, there has been a slight decrease in measured groundwater levels within the uncleared forest areas, during the past three years.

3. Recharge from rainfall occurs in all the study areas and has the quickest response in lower slope positions.

4. Whereas in general terms streamflow increases with rainfall, the relationship is by no means simple since it depends, for example, on the temporal pattern of daily rainfall.

5. All the stream catchments being monitored in this project appear to be currently accumulating chloride ion but this is probably due to the series of low rainfall years and is compatible with experience in other regions in low rainfall years.

6. Subsurface water flow has a negligible effect on the water balance but a significant effect on the chloride balance of the Yerraminnup Catchments because of the low surface streamflow and highly saline groundwater discharge from these catchments.

Project 3 - Monitoring of major catchments of rivers draining the Woodchip Licence Area for changes in water quality

This project is designed to detect any significant long term changes in the quality and quantity of water in the major rivers flowing through the Licence Area. The nine rivers are the Donnelly, Barlee Brook, Warren and its tributary the Wilgarup, Dombakup, Gardner, Shannon, Weld and Deep. The locationsof the gauging stations in relation to areas already cut or planned to be cut in the first five years of operation are shown in Figure 10. The stations collectively measure run-off from about 80% of the Licence Area.

Measurements and Instrumentation

The gauging stations were already established as part of the State stream gauging network. Automatic pumping samplers have now been added to the instrumentation, thereby providing daily water samples. These are collected by field staff at four to six week intervals for analysis for chloride ion, conductivity, sediment and colour.

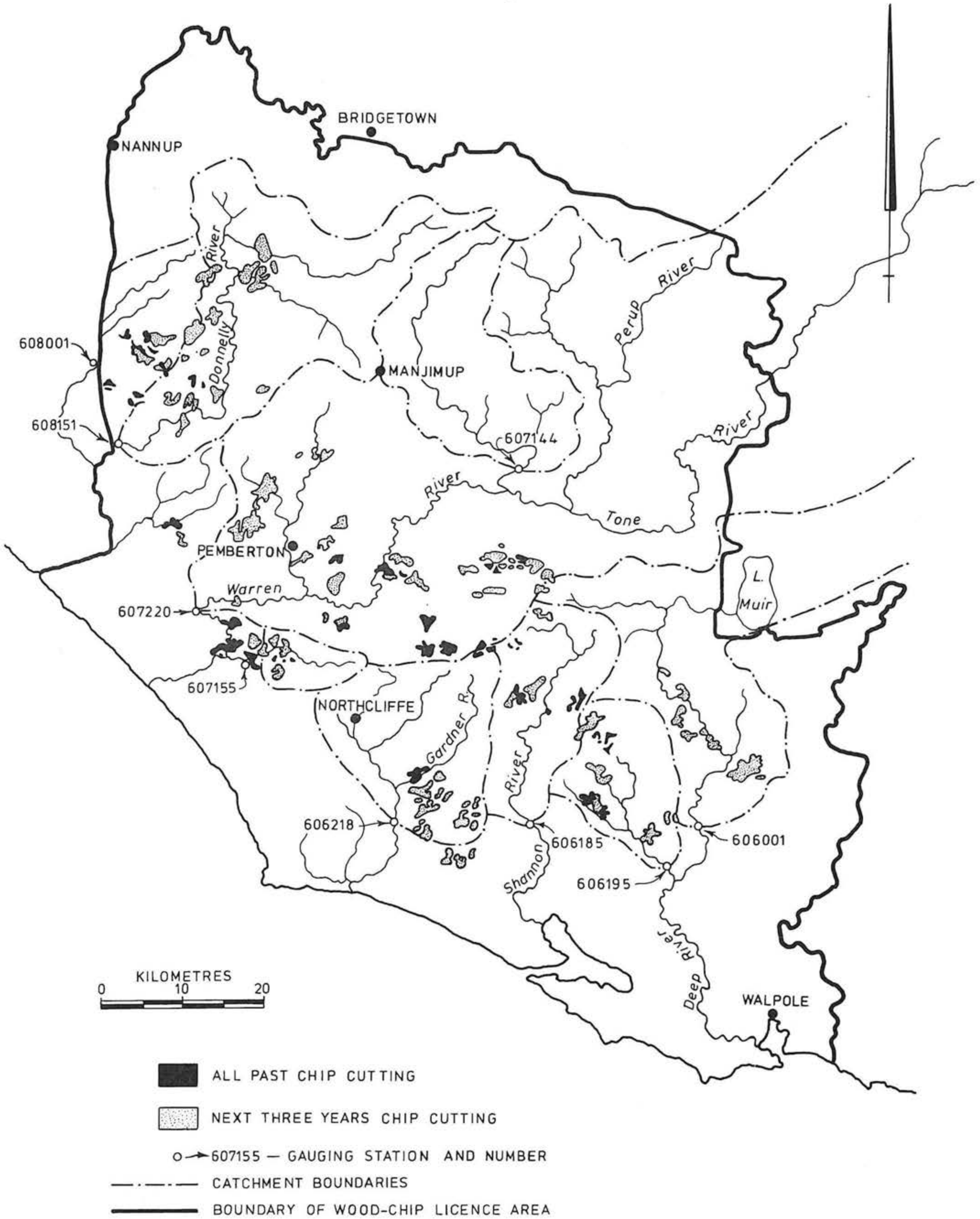


FIG.10. STREAMS MONITORED IN PROJECT 3.

Results

It is very difficult to identify the effects of woodchipping over and above other natural and man made factors that change water quality. This is particularly so on river catchment areas where large spatial variations of soils, landforms, land use and meteorology give rise to large natural temporal variations in streamflow and water quality.

Figures 11 and 12 show the strong inverse relationship between annual flow weighted chloride ion content and annual flow for the main Warren River. This river has both past and present agricultural clearing in its catchment as well as woodchipping. Factors contributing to the scatter of points in Figure 12 include variations in the hydrologic conditions of the catchment. These can produce significantly different proportions of stream flow, and therefore water quality, from different areas of the catchment for approximately the same gross annual flow. Also, the effect of a previous year's rainfall on the groundwater system may influence the salinity of the subsequent year's stream-flow.

A trend towards increasing salinity is reflected in Figure 13 which illustrates the two year moving average flow weighted chloride ion concentration for the Warren River. This stastistic is considered to approximate the likely concentration that would have been supplied from a large reservoir at the gauging station site (607220). Data on the flow weighted chloride ion levels for all nine rivers studied are presented in Figure 14. The high salinities of both the Warren and Wilgarup over a period long before the advent of the woodchip industry are clearly indicated. The Warren and its tributaries the Tone and Perup head in extensive areas of cleared agricultural land beyond the boundaries of the Licence Area and the Wilgarup drains large areas of cleared land to the north east of Manjimup.

Fluctuations in the annual chloride ion concentration of the streams shown in Figure 14 are primarily related to variations in annual streamflow and are of similar form to the relationship shown for the Warren River (Figures 11 and 12). For example, all streams except the Weld River show their highest annual concentration in 1969, the year of lowest measured streamflow. Years of high streamflow, such as 1963, 1967 and 1973 generally have low chloride concentrations. Other factors mentioned above, however, complicate the relationship between chloride ion concentration and annual flow. For example, the high flow years of 1964 and 1974 (both of which followed wet years) do not have low concentrations considering the magnitude of their associated annual streamflow. Such random variations in chloride ion concentration must be expected particularly in data prior to initiation of the daily sampling programme (1975). Detailed statistical analysis of factors affecting annual chloride ion concentrations will be carried out when four to five years daily sampling data are available.

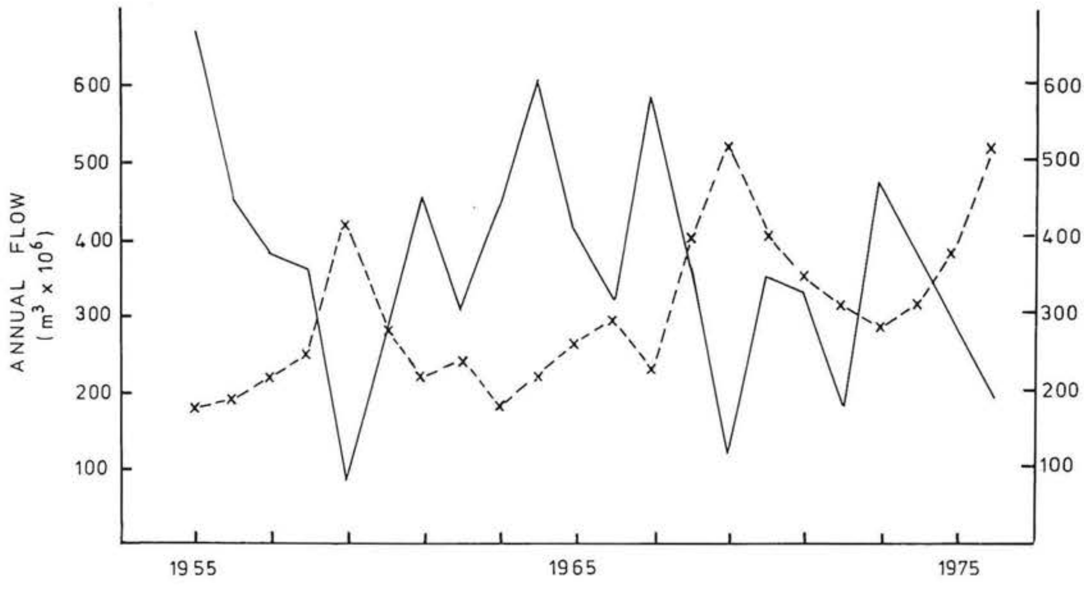


FIGURE 11. FLOW WEIGHTED CHLORIDE ION (x------x) AND ANNUAL FLOW (————) FOR THE WARREN RIVER, 1955 1975. (607220)

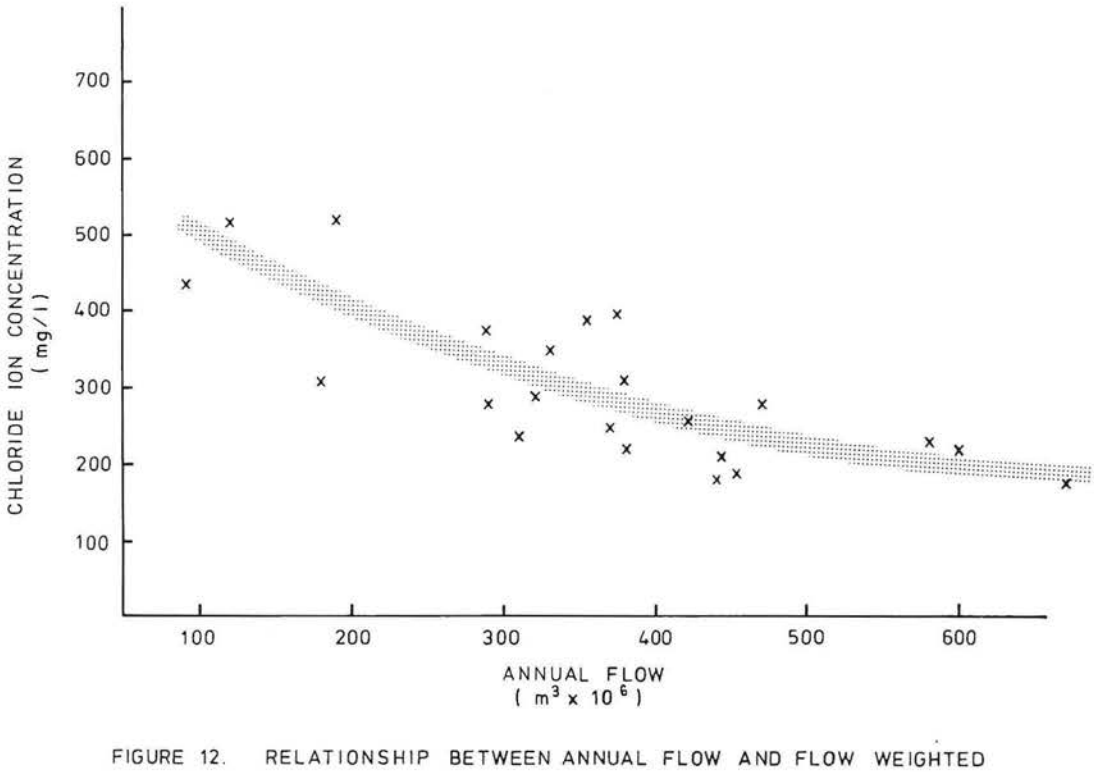


FIGURE 12. RELATIONSHIP BETWEEN ANNUAL FLOW AND FLOW WEIGHTED CHLORIDE ION CONCENTRATION, WARREN RIVER. (607220)

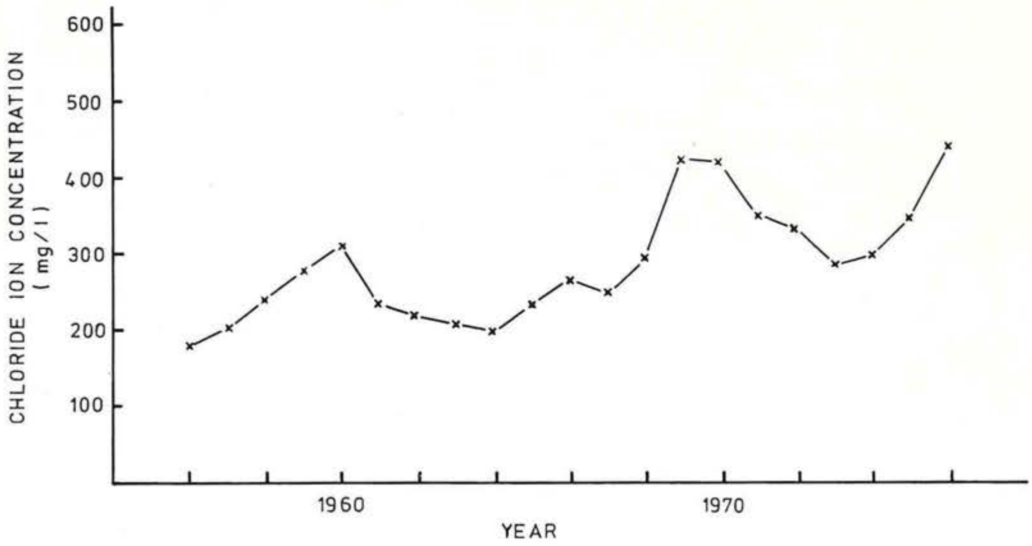


FIGURE 13. TWO YEAR MOVING AVERAGE FLOW WEIGHTED CHLORIDE ION CONCENTRATION,* WARREN RIVER, 1956 – 76. (607220)

* CALCULATED FROM $$\frac{F(i-1)\ S(i-1) + Fi\ Si}{F(i-1) + Fi}$$

WHERE Fi IS THE ANNUAL FLOW IN YEAR i AND Si IS THE AVERAGE CL^- ION CONCENTRATION (WEIGHTED BY THE FLOW RATE AT THE TIME OF SAMPLING) OF SAMPLES TAKEN IN YEAR i.

AS THIS STATISTIC ESSENTIALLY REPRESENTS THE TOTAL SALT LOAD DIVIDED BY THE TOTAL STREAMFLOW OVER A TWO YEAR PERIOD IT APPROXIMATES THE AVERAGE CONCENTRATION OF A WATER STORAGE WITH A NOMINAL RETENTION TIME OF 2 YEARS.

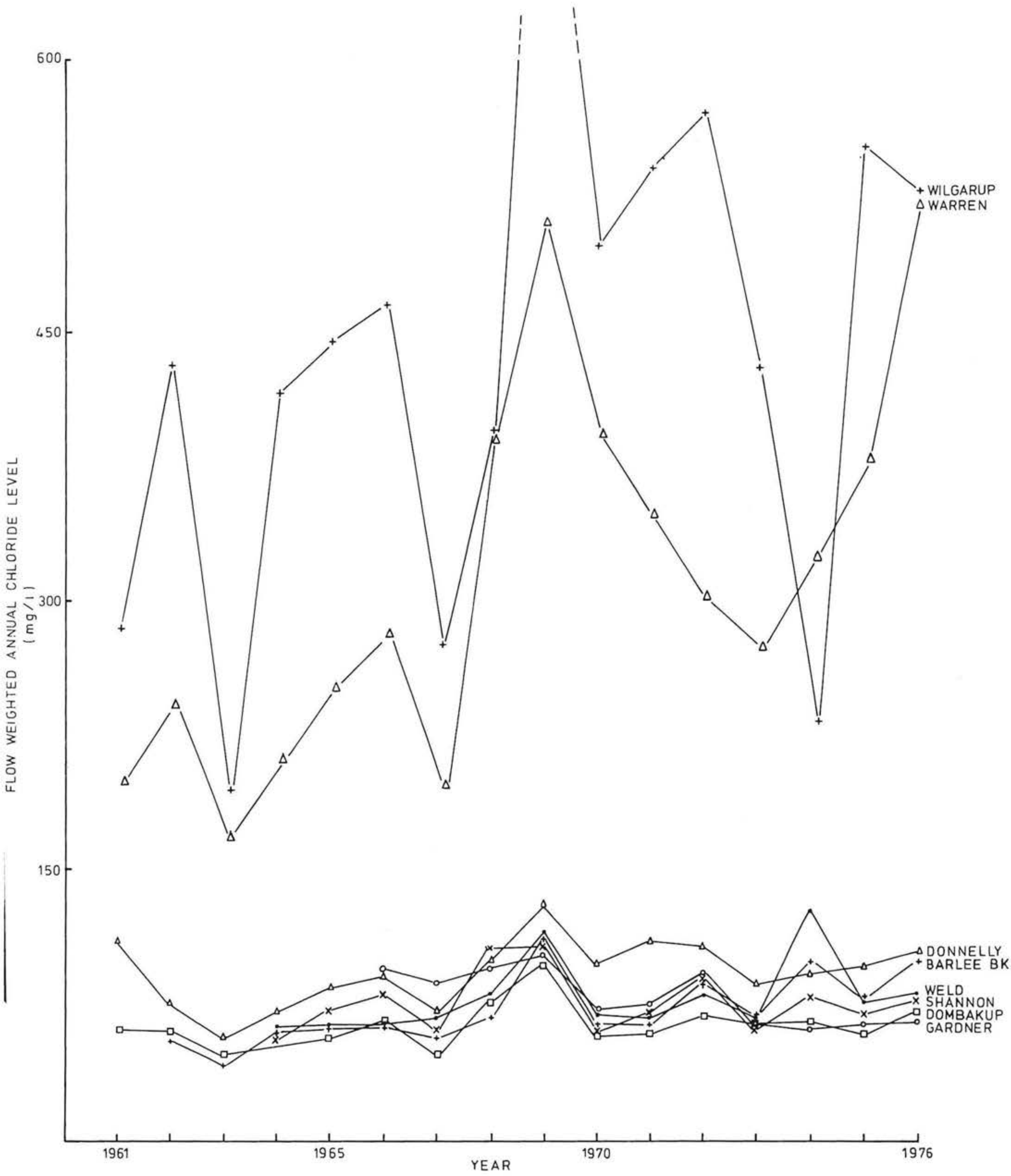


FIGURE 14 FLOW WEIGHTED CHLORIDE ION LEVELS FOR PROJECT 3 SAMPLING STATIONS 1961 — 1976

It should be noted that all the rivers monitored have shown salinities in the past higher than those measured during 1975 and 1976. This does not mean to say that the advent of the woodchip industry has caused a reduction in salinity but rather emphasises the point made above that seasonal variations due to various factors, particularly annual streamflow, must be clearly identified before any inference about effects caused by cutting for woodchipping can be made.

Project 4 - Monitoring of underground and stream water in selected operational coupes

The Project 4 studies began in 1975, their objective being to provide an "early warning system" of any effects that the heavy forest cutting practices used in the Manjimup Woodchip Licence Area might have on ground or stream waters. Four study areas ("coupes") have been chosen so as to represent different conditions of rainfall, soils and forest types (Figure 15, and Table 8). In each case the coupe covers between 100 and 200 hectares in area in order to sample the complete range of topographical situations and associated forest types from ridge top to valley bottom. The catchments have been equipped with rain gauges, a simple V-notch weir to measure stream flow and boreholes to enable the measurement of groundwater changes. All four coupes were cut during the 1976/77 summer, that is after at least one year of prior monitoring in each case.

Measurement and Instrumentation

Rainfall on each coupe is measured by means of up to six rain gauges to check the general level of precipitation and its seasonal distribution. The V-notch weir is used to measure stream flow but in addition provides a sample collection point for analysis of water salinity and suspended sediment.

Ten boreholes have been drilled in each coupe so as to cover different topographic locations. A further two boreholes have been located close by but outside the actual coupe area so as to provide controls for comparison. All bores have been visited regularly and frequently in order to measure the depth to the water table and to collect samples of groundwater for laboratory analysis.

The salinity of both stream and ground water samples is measured using a conductivity meter and the sediment load is estimated by filtration on a 0.45 μm millipore filter.

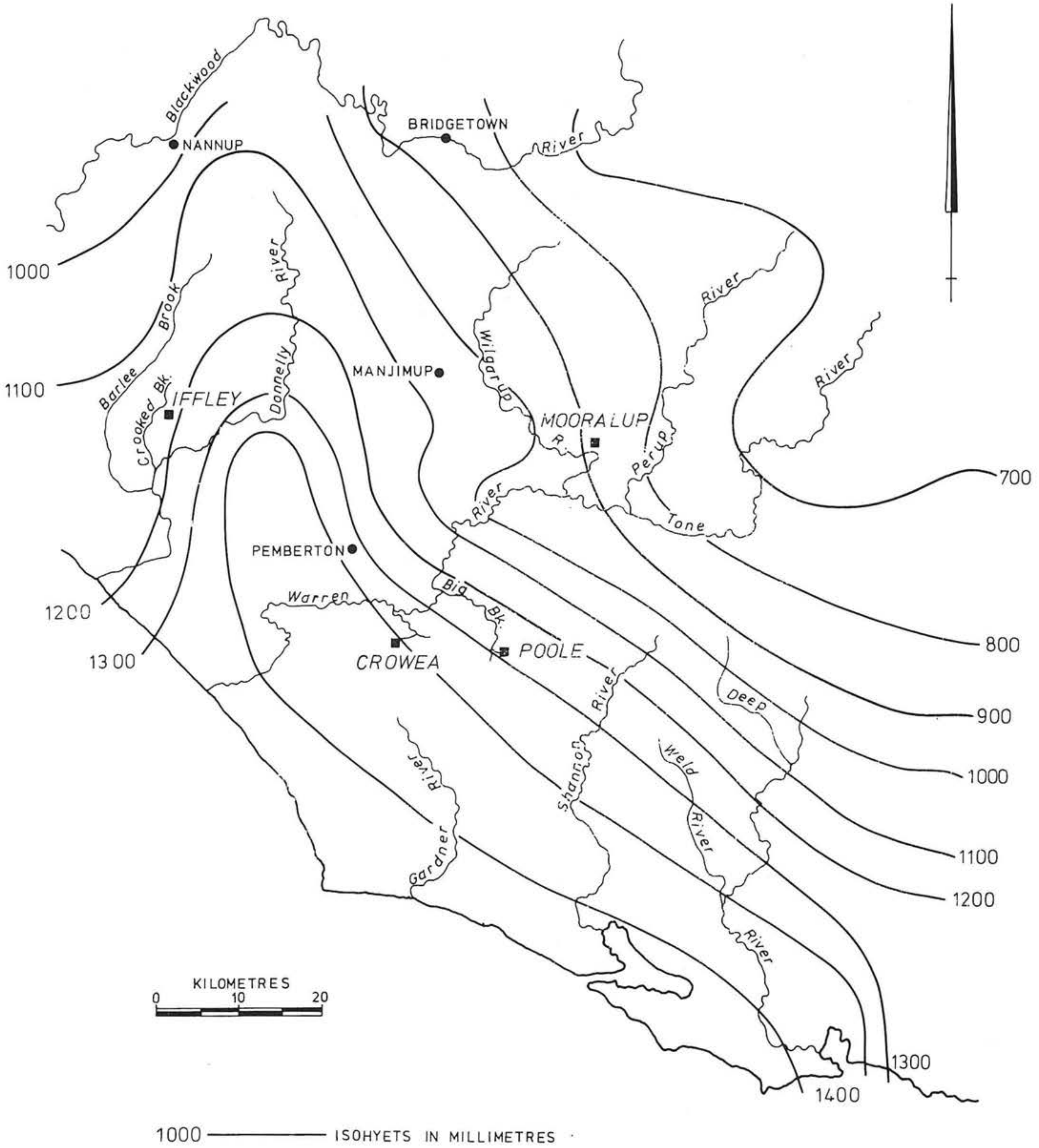


FIG. 15. LOCATION OF THE PROJECT 4 COUPES.

Coupe & Location (Forest block)	Mean Annual Rainfall (mm)	Soil Types	Forest Types
Crowea	1380	podsolics on upper slopes red earths in valleys	jarrah-marri karri
Poole	1290	podsolics red earths	jarrah-marri karri
Iffley	1200	laterites (extensive) red earths	jarrah-marri
Mooralup	900	podsolics	jarrah-marri

Table 8 Project 4 Experimental Coupes

Soil moisture has been measured using a neutron probe meter. In each coupe pairs of access holes have been located in ridge top, midslope and valley bottom situations within the cutting area, with an additional pair, as controls, located in an adjoining area which is left uncleared. The results to date have been of limited value due to difficulties in being able to interpret the data quantitatively. Until these problems can be successfully overcome it is not possible to comment further.

RESULTS AND DISCUSSION

Rainfall

Analysis of rainfall data for the three nearest long-term recording centres to the experimental coupes (Nannup, Pemberton and Manjimup) clearly shows that for 1975, 1976 and 1977 rainfall in the area has been below the long term average (Table 9). It must be further noted that the ratio of 1977 rainfall to that recorded in 1976 was almost identical for each centre. However, this is a most unusual situation and generally one would expect greater variability between centres due to localised storms, for example.

In Table 10 the rainfall recorded at each of the experimental coupes during 1976 and 1977 is listed, along with the predicted 1977 rainfall as calculated from the 1977/1976 ratios discussed above. In all four cases the rainfall recorded exceeded that which had been predicted. This indicates that after cutting the forest during the 1976/77 summer less interception occurred and more rainfall reached the soil surface. The calculations based on data in Tables 9 and 10 indicate that a mean value of approximately 10% more rainfall was recorded after cutting. While no great confidence can be placed in the absolute value of this figure it does nevertheless approach values obtained in carefully designed studies of rainfall interception in *Pinus pinaster* plantations (Butcher, 1977) and in eucalypt forest (Smith, 1974).

Groundwater levels

Water levels in individual boreholes varied considerably. Some remained dry throughout the period of observation, some were dry for part of the year only and some contained water the whole year round. The most common pattern of seasonal water level movement in boreholes was a steady rise during winter and spring to reach a peak followed by a steady fall during summer and autumn. Another common pattern was a sharp rise at the beginning of winter to reach a plateau which lasted until summer when a steady fall started.

There are some indications that there is a slight increase in groundwater level following clearing (Figure 16). In Mooralup coupe six bores which had previously been dry throughout the year were found to contain water during 1977. However, data from the 1978 and 1979 winters will be required before any

TABLE 9*

ANNUAL RAINFALL (mm) AT LONG TERM RECORDING CENTRES IN THE WOODCHIP LICENCE AREA.

	Nannup	Pemberton	Manjimup
1975	851	1117	922
1976	832	1124	1022
1977	739	984	898
Long term average	985	1258	1056
Ratio 1977/1976	0.89	0.88	0.88

* data supplied by Bureau of Meteorology, Perth.

TABLE 10

RECORDED AND PREDICTED ANNUAL RAINFALL (mm), PROJECT 4 COUPES 1976-1977.

	Iffley	Crowea	Poole	Mooralup	Mean
1976	888	1077	1110	658	-
1977 (recorded)	910	1063	1009	625	-
1977 (predicted from Table 9)	781	947	976	579	-
1977 recorded/predicted	117%	112%	103%	108%	110%

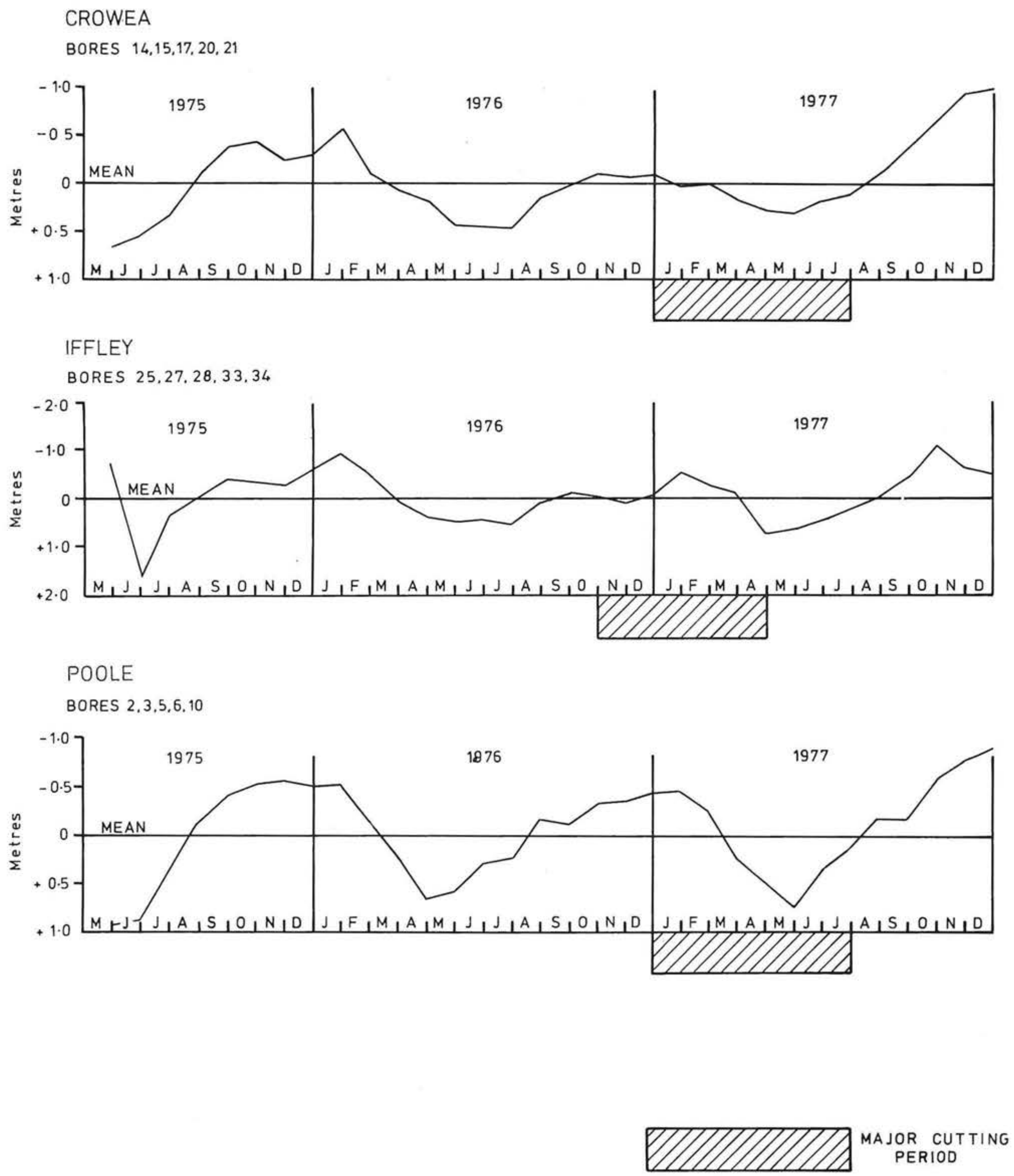


FIGURE 16. CHANGES IN PROJECT 4 GROUNDWATER LEVELS, 1975–1977 (MEANS OF SELECTED BORES)

increases in the amounts of groundwater in each catchment can be properly substantiated.

Streamflow

The volumes of monthly rainfall and monthly streamflow for each coupe are illustrated in Figure 17.

The volume of rainfall was estimated by multiplying the average rainfall recorded by the size of the catchment area. Streamflow volumes for 1975 and 1976 were obtained using staff gauge readings taken at the weir. Each gauge reading was then converted to a rate of flow which was multiplied by the length of time since the previous reading was taken to obtain the total volume on streamflow in the interval. Herbert and Ritson (1976) have shown that if the measurements are taken three times per week a reasonably accurate, though conservative, estimate of streamflow is obtained. In 1977 the streamflow was measured more accurately using a Leupold Stevens automatic water level recorder which estimated the volume of flow at hourly intervals.

For each of the four catchments both the maximum monthly streamflow and the total streamflow for the year were greater in 1977 than in 1976, despite similar rainfall in each year.

Poole and Mooralup coupes had less regular run-off response than Iffley or Crowea coupes. It is possible that in both coupes, especially Mooralup, either there is significant sub-surface outflow of water with the surface streams only flowing during and immediately following periods of intense rainfall or, as observed in the Yerraminnup catchments (Project 2), both stream and groundwater flow are minimal, the major output being due to evapotranspiration. Unfortunately, there is, as yet, insufficient data for Mooralup coupe to assess the effects of forest removal on the levels of evapotranspiration output.

Salinity

Three aspects of salinity must be considered; first, the salinity of groundwater measured in the boreholes, second, the concentration of salts in streamwater, and finally the "salt flow" or total amount of salts exported by a stream per unit time.

As with analysis of groundwater levels, the interpretation of groundwater salinity data is complicated considerably by the variations observed between boreholes and even within the same borehole on different sampling occasions (Figure 18).

However, several boreholes (for example bores 4 and 22 in Figure 18), have had almost constant groundwater salinity since they have been under observation. Based on these, there is no apparent sign that changes in groundwater salinities have occurred in any coupe as a whole in 1977 as compared with 1975 or 1976.

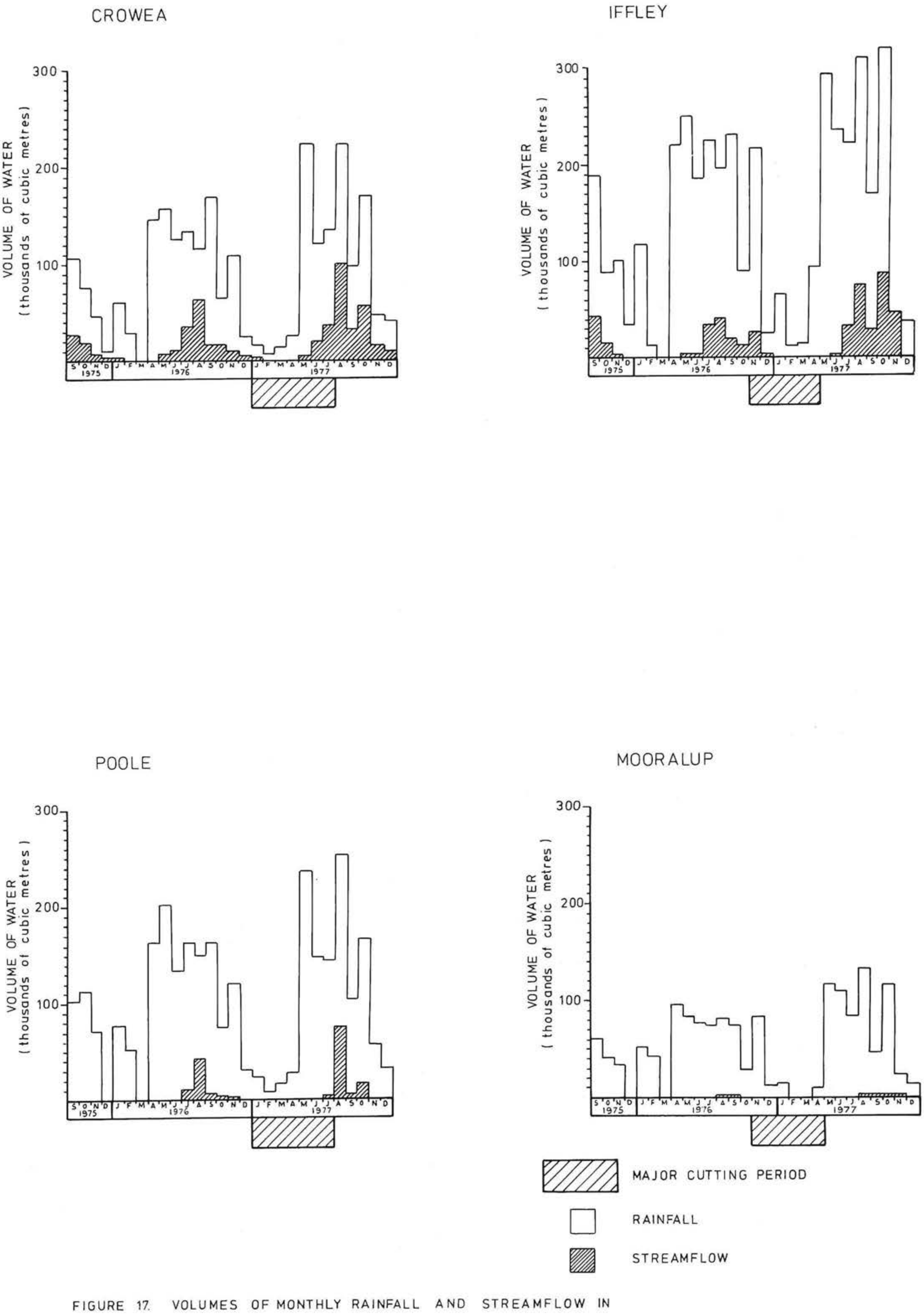


FIGURE 17. VOLUMES OF MONTHLY RAINFALL AND STREAMFLOW IN PROJECT 4 COUPES, 1975–1977.

Stream water salinities and total saltflows are presented in Figure 19.

At Iffley coupe, stream water salinity (expressed in terms of total dissolved solids) at the weir was about 500-600 mg/l, when the stream started to flow at the end of autumn 1976, fell to 300 mg/l in periods of greatest flow and then rose steadily to reach 500-600 mg/l before the stream dried up in summer. The streamwater salinity was much the same in each of the three years of observation. In 1976 water samples were also taken at points downstream from the weir, three of which were on the main stream and two on side streams. The salinity at all these points was found to be lower than the salinity at the weir. These sampling points will allow checks to be made in future as to whether any changes in salt flow take place downstream from the weir, possibly due to groundwater seepage.

At Crowea coupe stream salinity at the weir was about 100 mg/l in July 1976 and rose steadily to reach 250 mg/l before the stream dried up. It was only in 1977 that measurements were made at the very beginning of winter when it was found that the salinity when the stream started to flow was about 330 mg/l. No samples were taken downstream from the weir as the stream joined one arising from cleared private property.

At Poole there was little variation in salinity (100-120 mg/l) during the period of streamflow. The salinity in 1977 appears to be slightly higher than in 1976. In 1976 water samples were taken at some points further downstream from the weir and these showed slightly higher salinity levels than the weir.

No stream flow samples were taken at Mooralup in 1976 because streamflow was intermittent and was insufficient for sampling purposes at the time of monitoring visits. In 1977 the stream flowed for only about four months and during this time the salinity was found to be about 140 mg/l.

Reviewing the data presented above, it is clear that Iffley coupe shows anomalously high levels of salinity of stream flow for the rainfall zone in which it occurs. This is not unexpected, since Johnston *et al* have previously identified an anomalously high level of storage of soluble salts in this catchment. Similarly, the low level of 140 mg/l reported for Mooralup in the low rainfall zone also appears anomalous, but due to the paucity of records it can hardly be considered as highly meaningful. The data from Iffley in particular emphasizes that stream salinity is not related simply to rainfall, but also depends on other factors, such as the amount of salt stored in the catchment and position in the landscape. Thus, although the generally accepted trends of decreasing salinity of stream flow with increase in rainfall, and of increases in salt stored with decrease in rainfall, identified in the Licence Area by Johnston *et al (loc. cit.)* still hold, it is to be noted that departures from this trend can be expected when smaller catchments are investigated in detail.

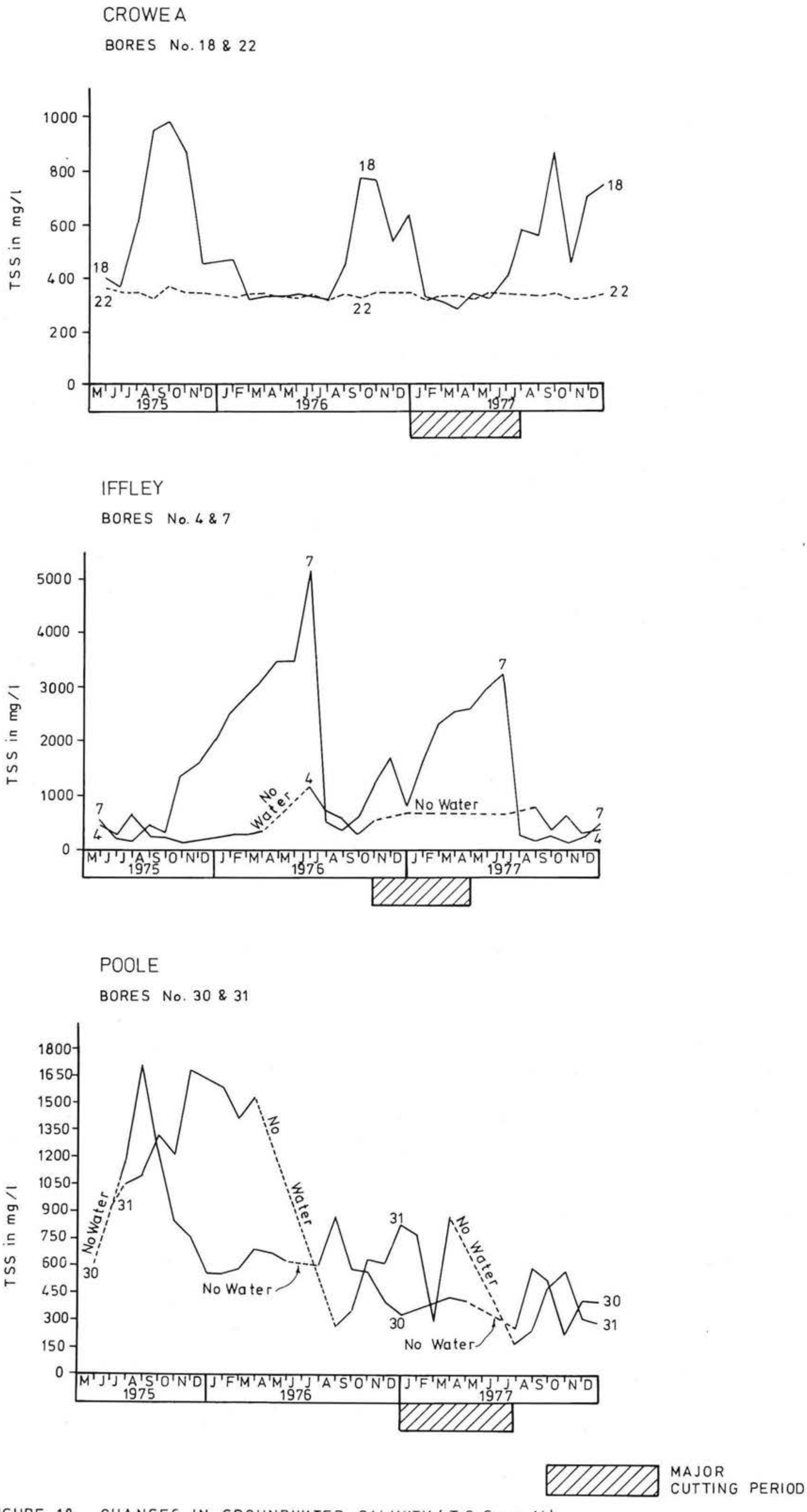


FIGURE 18. CHANGES IN GROUNDWATER SALINITY (T.S.S. mg/l) FOR SELECTED PROJECT 4 BORES, 1975–1977.

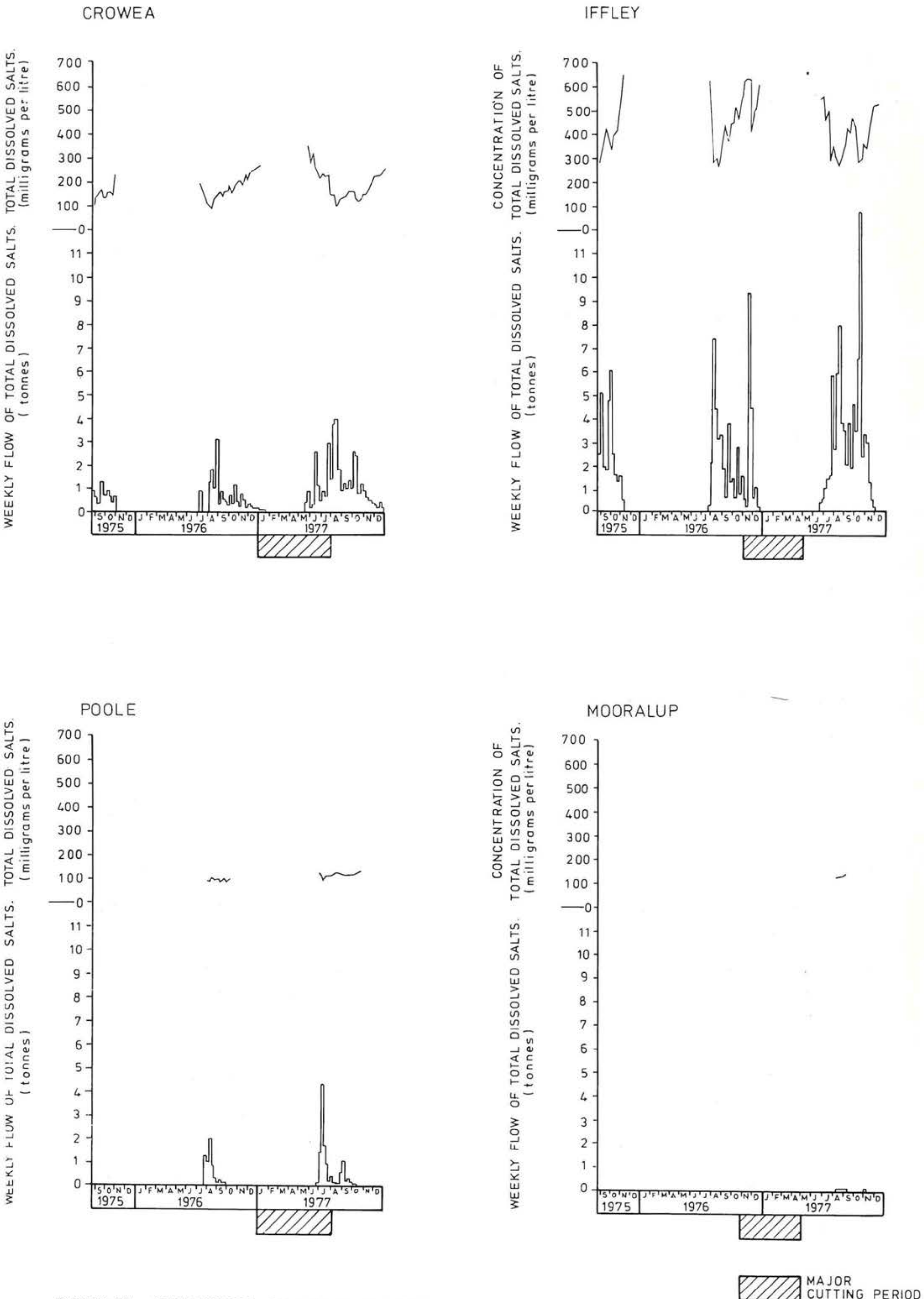


FIGURE 19. STREAMWATER SALINITIES AND TOTAL SALTFLOWS FOR PROJECT 4 COUPES, 1975–1977.

The total salt flow in all four coupes was slightly greater in 1977 than in 1976 or 1975. However, this effect is due to the increased volumes of streamflow in 1977 which have already been described.

Stream sediment levels

Measurements of sediment levels in the stream water were made weekly for Iffley, Crowea and Poole coupes during 1976 and 1977. At Mooralup coupe the first measurements were taken in 1977. The data are presented in Figure 20.

At both Iffley and Crowea coupes the total sediment levels were slightly higher for 1977 than for 1976. In the case of Crowea coupe the sediment levels in the initial stream flow at the beginning of winter were much higher than for Iffley coupe.

At Poole coupe the sediment level was lower in 1977 than in 1976. However, the weir in this coupe was only constructed in 1976 and thus it is probable that the sediment loads recorded for that year were anomalously high due to sediment run-off from earth works during weir construction.

Regeneration

By April, 1978, regeneration burns had been carried out on the Poole and Crowea coupes, both of which had been clear cut. Planting of karri seedlings was scheduled to commence shortly. Mooralup and Iffley coupes, which were selectively cut, had not yet received regeneration burns. Nevertheless, some re-growth from coppice and lignotubers was already well established.

Summary

The results to date which are based purely on a part season (1975) and one full winter season prior to cutting (1976) and one full winter season following cutting (1977) may be summarised as follows:

1. The total rainfall throughout the study area has been below the long term average for all three years of measurement (1975, 1976, 1977). After cutting it appears that more rainfall reaches the soil surface.

2. Preliminary evidence suggests that there has been a slight rise in the water table towards the surface since cutting. This is the reverse trend from that observed in the uncleared Project 2 catchments discussed earlier.

3. Streamflow has increased since cutting in all four coupes studied. There is also some indication of a more rapid response to rainfall fluctuations.

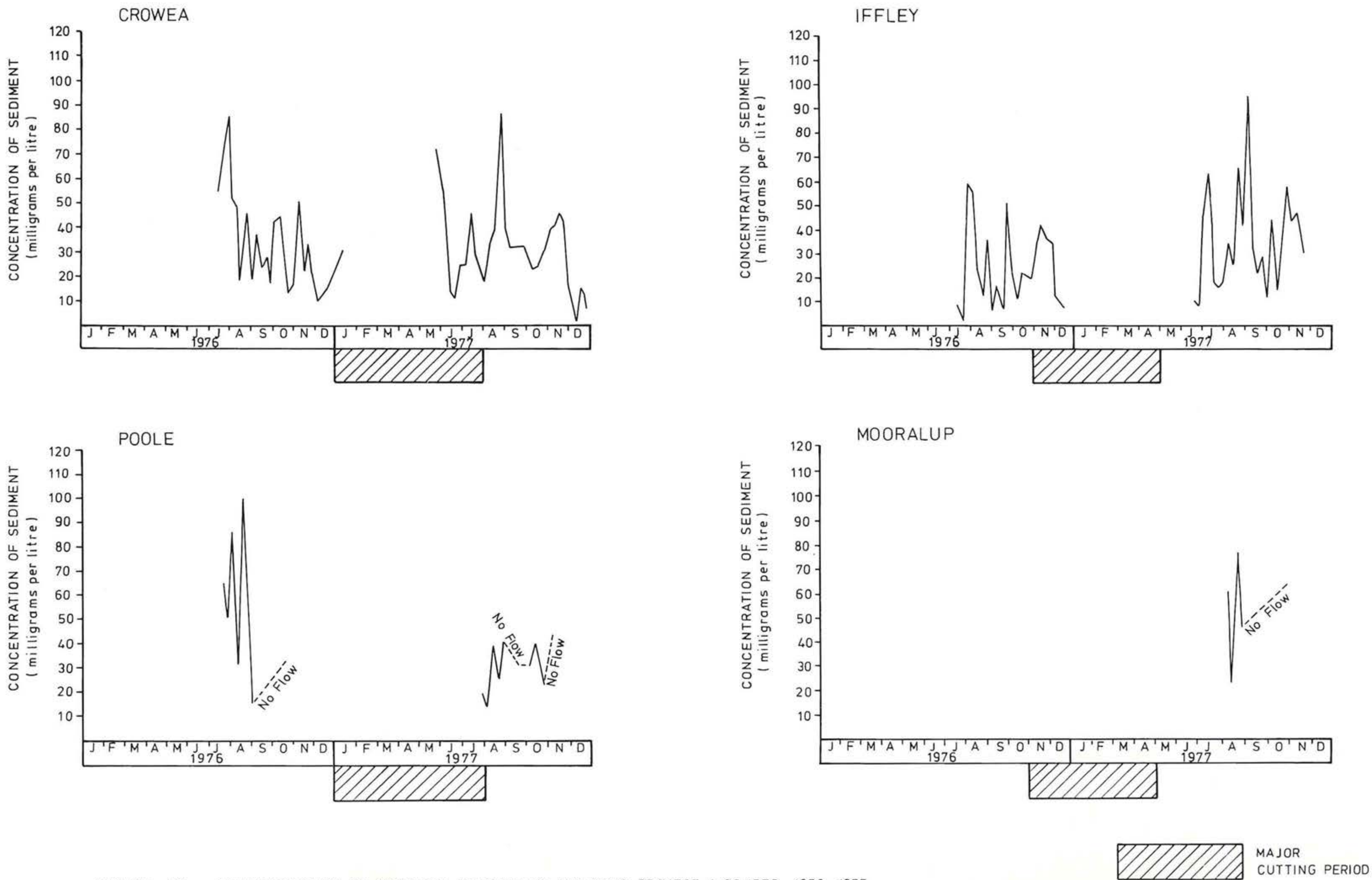


FIGURE 20. CONCENTRATION OF SEDIMENT IN STREAMS DRAINING PROJECT 4 COUPES, 1976—1977.

4. There have been no observable changes in groundwater salinity since cutting. The total saltflow from all four coupes has increased. This is mainly attributable to increased streamflow as the concentration of salts in the streamwaters has remained almost unchanged.

5. In the two coupes where comparative data for 1976 and 1977 are available a slight increase has been observed in the sediment levels of streamwaters.

5. RELATED INVESTIGATIONS

There are a number of other investigations, not under the direction of the Kelsall Steering Committee, which are being undertaken by the CSIRO Division of Land Resources Management, and which will provide additional information.

Nutrient element distribution in the karri forest

In order to ensure future water quality it is important to maintain the biological productivity of the forest. Concern has been expressed that one of the more subtle effects of cutting and regeneration burns may be a net migration of nutrient elements out of the harvested area through extraction of timber and into the atmosphere, soil or water draining the area. It has also been suggested that adsorption of these elements on ash or on soil particles might be a significant factor in the transport of nutrients in stream flow. However, before detailed analysis of the possible total nutrient losses can be made, it is necessary first to have a sound understanding of natural nutrient cycle operation in the unharvested forest. While we have some information on levels of nutrient elements in forest soils (McArthur and Clifton, 1975; Hatch, 1960; Loneragan and Loneragan, 1964; Valentine, 1976) little is available on their distribution in the total forest ecosystems, particularly in the components of the vegetation.

Consequently, a team from the CSIRO Division of Land Resources Management was engaged by the Department of Conservation and Environment to provide estimates of the nutrient capital of the forest with particular reference to the tree biomass for karri and marri. The analytical methods and full data observed are reported elsewhere (Hingston, Turton and Dimmock, 1977).

The nutrient contents of the biomass were, in broad terms, similar to those observed overseas and in eastern Australia. Compared with the total element contents of soils and extractable nutrients, the quantities of nutrients that would be removed from the forest in harvesting boles are small. The data also suggested that after clear-felling, a considerable proportion of elements removed in harvest would be replenished during regeneration of the forest by natural inputs in rainfall, nitrogen fixation by leguminous understorey species and the weathering of soils and rocks. The possible exception was potassium, for which a considerable proportion (31% in karri forest and 60% in mixed karri-marri forest) of the amounts of potassium in exchangeable forms in the soils was present in tree boles.

Fertiliser applications, especially phosphate at a rate at least sufficient to replace nutrients in the harvest are probably desirable. On site stripping of bark before removal of wood, would decrease removal of potassium and calcium considerably.

Whereas this project has gone a considerable way towards estimation of nutrient losses through the harvesting of timber, attention should now be turned to the equally complex problems of possible depletion through ash losses and water transport.

Leaf Area Index Measurements

A major factor in controlling soil water recharge is the evapotranspiration effect of the overlying vegetation, in particular the total leaf area. As a conservative estimate the evaporation from forest regrowth after cutting will approximate that of the original forest when it has attained a similar leaf area.

Measurements of leaf area index (the ratio of the area of leaves to the projected ground area which they cover) have been undertaken at a number of sites in the Licence Area (CSIRO, 1975). In the case of jarrah-marri forest the original leaf area was reached in a period of less than five years where the regrowth occurred principally from coppices and lignotubers. In the karri-marri forest the leaf area index of the regenerating forest exceeded that of the original within six years where the main regeneration was from karri seedlings.

Thus, on the basis of leaf area index measurements it seems that the period of risk of increase in salt levels in the soil surface and in streams will be restricted to something less than five to six years after successful regeneration is achieved. It is not yet possible to predict the rate at which any increased stream salinity could fall once the water balance is restored to its original state.

Mathematical Modelling

The problem of increasing salinity of streams and rivers following removal of native forest vegetation is a common occurrence in south-western Australia. This has led to the development of predictive models which enable forecasts to be made of the effects of forest removal on stream salinity. The early approaches of Peck (1976) neglected dynamic aspects of the problem such as evapotranspiration time lags and the effects of revegetation. Recently, however, a more sophisticated approach has been developed to simulate the effects of bauxite mining and jarrah dieback disease on river salinity in the South Dandalup catchment within the Darling Range (Peck, Hewer and Slessar, 1977).

With the availability now of extensive data from research in the Woodchip Licence Area and with experience gained in predictive modelling elsewhere it should now be possible to use similar techniques in order to develop predictions on the effects of woodchipping activities on water resources.

* * *

ACKNOWLEDGEMENT

The members of the Steering Committee extend their sincere thanks for the efforts of the members of the supervisory panels and the working groups of the research projects and to all other persons who have contributed to the Committee's research programmes.

REFERENCES

Butcher, T.B., 1977. Impact of moisture relationships on the management of *Pinus pinester* Ait. plantations in Western Australia, *Forest Ecology and Management*, 1, 97-107.

Christensen, P., 1975. *Jarrah dieback - soil temperature and moisture regimes of some southern forest types*, Forests Department, Western Australia, Bulletin No.88

Collett, D.B., 1976. *Research into the effects of the woodchip industry.* In "Land Management and Water Quality, A Seminar on Current Research into the effects of Land Use on Stream Salinity and Turbidity in South Western Australia", Department of Conservation and Environment, Western Australia, September, 1976.

CSIRO, 1975. *Report on some aspects of the environmental effects of woodchip fellings in south western Australia.* Division of Land Resources Management, Perth.

Department of Agriculture, Western Australia, Study Group 1974. *The influence of Land Use on stream salinity in the Manjimup area, Western Australia.* Technical Bulletin, No.27., December, 1974.

Furness, L.J., 1977a. *Aquifer tests on bores in the Yerraminnup Creek catchments, Project 2, Manjimup Woodchip Industry research,* Mines Department, Western Australia, Hydrology Report No. 1498.

Furness, L.J., 1977b. *Water and salt balances, Yerraminnup Creek catchments, Project 2, Manjimup Woodchip Industry research,* Mines Department, Western Australia, Hydrology Report No. 1499.

Hatch, A.B., 1960. *Ash bed effects in Western Australian forest soils.* Bull. No. 64 Forests Department of Western Australia, 1960.

Herbert, E.J. and Ritson, P., 1976. *Small streamflow measurements in the Northern jarrah forest, Western Australia,* Forests Department, Western Australia, Research Paper No. 28.

Hingston, F.J. and Gailitis, V., 1977. *Salts in rainfall in Western Australia (1973-1974).* CSIRO Division of Land Resources Management, Technical Memorandum 77/1.

Hingston, F.J., Turton, A.G. and Dimmock, G.M., 1977. Nutrient elements in *Eucalyptus diversicolor and Eucalyptus calophylla* from the Karri Forest, southwest Western Australia. Rep. to Department of Conservation and Environment, CSIRO Division of Land Resources Management, September, 1977.

Hunt Steering Committee, 1976. *Research into the effects of bauxite mining in the Darling Range,* Review, May 1976.

Johnston, C.D., McArthur, W.M. and Peck, A.J., 1978. *Distribution of soluble salts in water in soils of the Manjimup Woodchip Licence Area, Western Australia,* (in preparation).

Kelsall Steering Committee, 1976. *Research into the effects of woodchipping in the Manjimup Area, Review,* Department of Conservation and Environment, Western Australia, November, 1976.

Loh, I.C. and King, B., 1978. *Annual rainfall characteristics of the Warren, Shannon and Donnelly River Basins,* Water Resources Technical Report, No. 78, May, 1978.

Loneragan, O.W. and Loneragan, J.F., 1964. Ashbed and nutrients in the growth of seedlings of Karri *(Eucalyptus diversicolor F and M).* *J. Roy. Soc. W.A.* 47, 75-80.

McArthur W.M. and Clifton A.L., 1975. *Forestry and agriculture in relation to soils in the Pemberton area of Western Australia.* CSIRO Soils and Land Use Series No. 54, 1975.

Peck, A.H., 1976. *Estimating the effect of a land use change on stream salinity in southwestern Australia.* In "System Simulation in Water Resources", ED. G.C. Vansteenkiste, North Holland, Amsterdam.

Peck, A.J. Hewer, R.A. and Slessar, G.C. 1977. *Simulation of the effects of bauxite mining and dieback disease on river salinity,* CSIRO Division of Land Resources Management, Technical Paper, No.3.

Peck, A.J. and Hurle, D.H., 1973. Chloride balance of some farmed and forested catchments in southwestern Australia, *Water Resources Research, 9,* 648-657.

Smith, M.K., 1974. Throughfall, stemflow and interception in pine and eucalypt forest, *Australian Forestry, 36,* 190-197.

Vallentine, P.S., 1976. *A preliminary investigation into the effects of clear cutting and burning on selected soil properties in the Pemberton area of Western Australia.* Geowest, No.8, Department of Geography, University of W.A., 1976.

Watkins, D., 1973. *Focus on the marri woodchip project,* Forest Focus, No.12, Forests Department of W.A., December, 1973.

White, B.J. and Underwood, R.J., 1974. *Regeneration in the Karri forest community,* Forests Department of W.A., 1974.

* * *