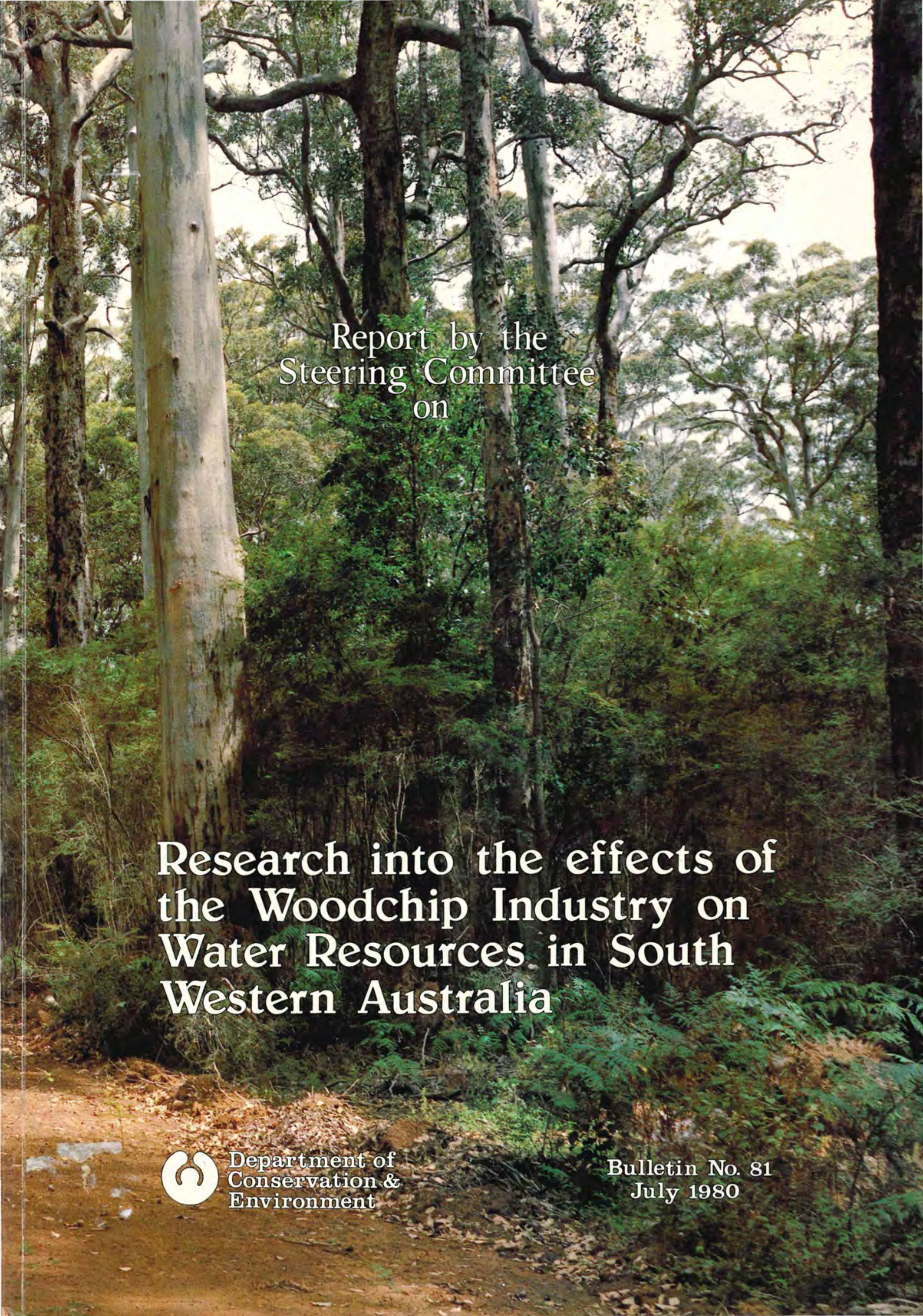


Report by the Steering Committee on

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

Department of Conservation & Environment

Bulletin No. 81
July 1980

REPORT BY THE

STEERING COMMITTEE

ON

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

Cover: Mixed marri and karri forest near Manjimup. Photography by Forest Department.

JULY

1980

CONTENTS

LIST OF FIGURES

FIGURE

FOREWORD

This Report presents the major findings of the technical Steering Committee, since it was set up in 1973, and updates to December 1979 the information published in April 1978 in Bulletin No 31.

The terms of reference of the Steering Committee cover only one of the environmental aspects of the woodchip industry, namely, the possible effects on the quality of water resources in the Licence Area, which is centred on Manjimup.

The studies initiated by the Steering Committee have extended basic hydrological research and have improved general water resource monitoring in the very important lower South West area of Western Australia. The work complements that which is being undertaken further north in respect of the Wellington Dam catchment and bauxite mining in the Darling Range. Furthermore, the results of the studies will enable the effects of the woodchip industry on the water resources of the region to be realistically assessed before the existing Licence becomes due for renewal in 1991.

The report contains an overall summary (Chapter 1) and a discussion (Chapter 7). Projects 2, 3 and 4 have generated a large amount of technical data which has been summarised and interpreted in Chapters 4, 5 and 6 of the Report. The various Study Groups are prepared to make available more detailed data and discuss any aspect of their projects with interested members of the public.

The period since 1975, when field work was initiated by the Steering Committee, has been abnormally dry and no year of above average stream flow has occurred. Consequently, it is important that the studies should be continued.

The Steering Committee is due to report again in 1983.

Colin Porter

COLIN PORTER
CHAIRMAN
ENVIRONMENTAL PROTECTION AUTHORITY

LIST OF TABLES

SUMMARY

Chapter 1

CHAPTER 1

SUMMARY

Background

The Woodchipping Industry Agreement Act came into force in September 1969 defining the Woodchip Licence Area (see Figure 1), hereinafter referred to as the Licence Area. However it was not until four years later, when the Commonwealth Government granted an export licence to the W.A. Chip and Pulp Co. Pty. Ltd., that the woodchip industry was actually launched in Western Australia. Very little detailed hydrological work had been undertaken in the Manjimup District up to that time. Nevertheless on the basis of past experience from earlier forestry activities, and also from hydrological studies elsewhere, it had been confidently predicted that the cutting operations could be controlled without placing the region's valuable water resources at risk. The importance of the need to protect the water resources was recognised in the Environmental Impact Statement. In particular it pointed out a possible salt problem in the north-east sector (i.e. Coonan, Yardup, and Warrup Blocks), which necessitated the restriction of cutting during the first decade to experimental stages to determine the impact of further logging on stream salinity.

In October 1973, the then Minister for Environmental Protection arranged for the formation of a technical Steering Committee under the chairmanship of the Deputy Director of Engineering, Public Works Department (Mr. K.J. Kelsall). The terms of reference of the Committee were to monitor the quality (i.e. salinity and turbidity) of the water resources, initiate research to identify salt sensitive areas, and provide the Conservator of Forests with technical data on which to base his management plan.

This Report reviews progress to the end of 1979, and thereby updates the information published by the Steering Committee in April 1978.

Administration and Costs

The Steering Committee has utilized the staff and facilities of appropriate government departments, and has worked through study groups to establish four research and monitoring projects relating to water resources in the Licence Area. This type of research is costly to establish and to operate. Also, hydrology is considerably influenced by a number of seasonal factors, the effects of which cannot be fully isolated. Consequently there is a need to monitor through a whole range of situations, and the research is therefore essentially of a long term nature. Direct expenditure incurred in the five financial years up to 30 June 1979 has totalled $631 615. Although this research was initiated in respect of the woodchip industry, it is extending very considerably the general knowledge of hydrology in the lower South West. This has already provided valuable information for water resource studies and land use management in Western Australia.

The Steering Committee has co-ordinated its activities with the Hunt Steering Committee (which is researching the effects on

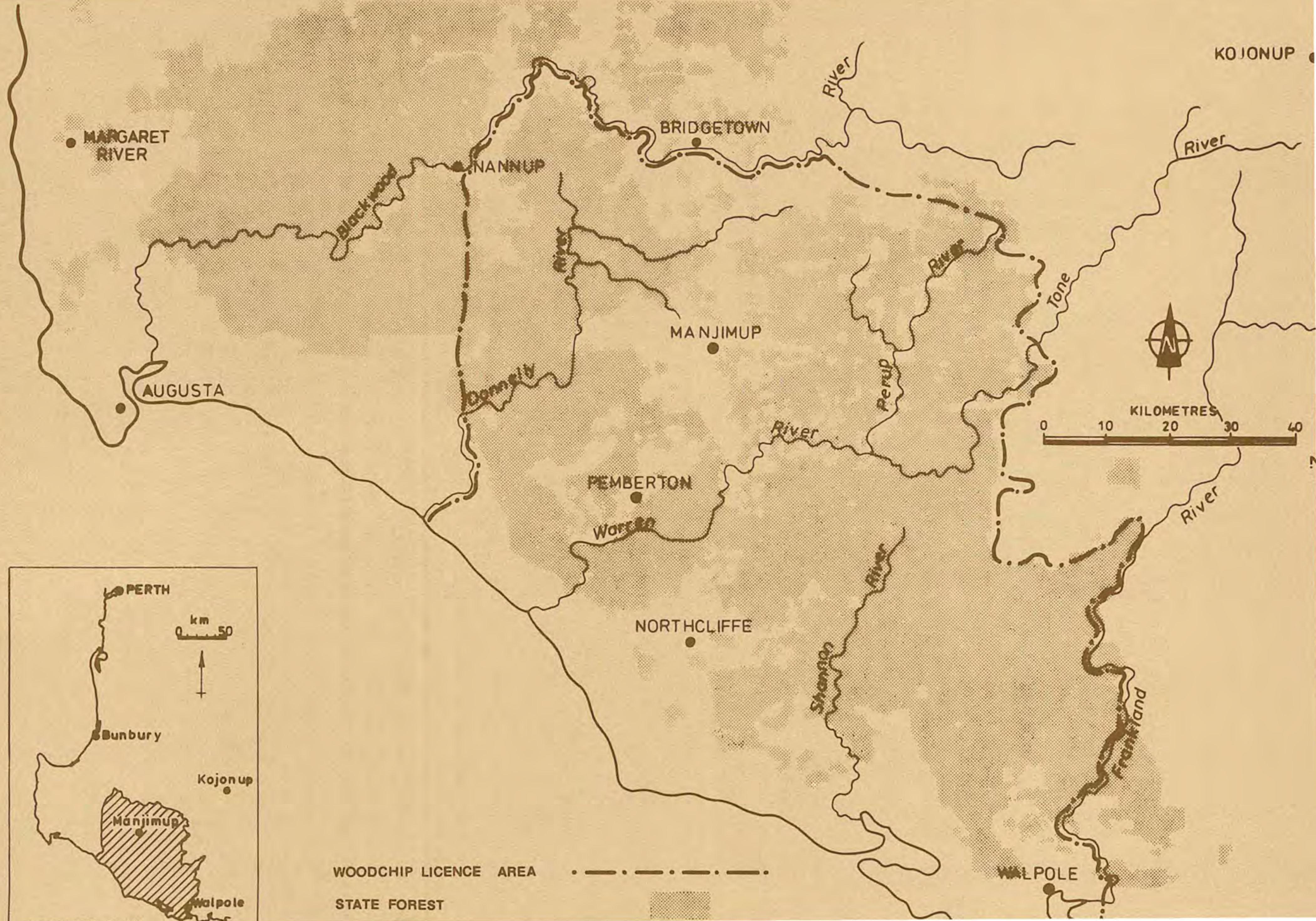


FIGURE 1

MANJIMUP WOODCHIP PROJECT LICENCE AREA

water resources of bauxite mining) and also with the groups controlling research on the Wellington Dam and other catchment areas. This has been facilitated by the largely common membership which was intentionally arranged, not only on the Steering Committee, but also at the work level.

Research Projects

The research projects initiated within the Licence Area have involved a variety of approaches, including an 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 (Project 1) and the long term monitoring of rivers in the Licence Area (Project 3).

The other two projects involve studying the effects of logging operations on water quality within carefully selected experimental catchments. One is directed towards long term objectives (Project 2), while the other (Project 4) is less sophisticated, and has been planned to provide a means of identifying in the shorter term the effects that heavy cutting might have on either groundwater or streamflow.

As previously reported in 1978, the historical surveys conducted by the Steering Committee under Project 1 have shown that where any salinity increase has been reported within the Manjimup district, it has been associated with permanent clearing, generally for agriculture, as distinct from normal forestry operations which provide for early regeneration of the deep rooted vegetation.

With more detailed data now becoming available from the three other projects, there is no purpose in continuing with either the historical reviews or the stream sampling programmes of the type carried out in Project 1. Consequently the Steering Committee has terminated this project.

The existing network of stream gauging stations already being operated by the Public Works Department on a State-wide basis provided the framework for Project 3. However the equipment has been upgraded within the Licence Area to provide more accurate flow measurements and improved monitoring of water quality, particularly sediment assessment. A new gauging station was constructed in 1978 on the Tone River (a tributary of the Warren River) near the boundary of the Licence Area, and monitoring was upgraded on the station at Wheatley Farm on the Warren River in 1979. This was to enable a better assessment to be made of the quality of water flowing into the Licence Area from the upstream salt-susceptible farmlands, to which reference had been made in the Steering Committee's 1978 Report, and to better delineate existing sources of stream salinity within the Licence Area. On information available to date, the Tone River, which rises in the Kojonup Shire, contributes 53% of the total salt load of the Warren River from upstream of the Licence Area. Another 27% of the total salt load is contributed from sectors within the Licence Area where no woodchip activities have so far taken place.

Unfortunately, the period since 1975, when field activities were initiated by the Steering Committee, has been abnormally dry and no year of above average flow has occurred. For this reason, the calibration phase of the experimental catchments in Project 2 has had to be extended. In addition, the data collected from all projects have to be interpreted in the light of those abnormal seasons.

Nevertheless, as detailed in Chapters 3 to 6 of this Report, some valuable observations concerning the hydrology of the region can already be made, particularly when the data collected from the Licence Area are co-ordinated with data from related studies in other areas.

Salinity

The logging activities associated with the woodchip industry can have a deleterious effect on stream salinity only in areas where sufficiently large quantities of salt are stored in the landscape.

Evidence from these and other studies in similar areas of the Darling Range, have substantiated that the most hazardous conditions relating to stream salinity occur in the lateritic soils of the low rainfall zone (i.e. less than 900 mm per annum).

Experience with Projects 1 and 3 indicates that over extended periods in the intermediate rainfall zone (i.e. 900 - 1200 mm per annum), there has been some introduction of salt to the river systems from areas of permanent clearing. However on the basis of historical data supported by recent studies, it is reasonable to expect that with the well proven rapid regeneration techniques employed in this woodchip industry, the salinity increases will be minimal within the intermediate rainfall zone. In the high rainfall zone (i.e. above 1200 mm per annum) wood-chipping poses no salinity risks to the region's water resources.

Groundwater in the salt-sensitive low rainfall zone is generally characterised by high salinity and great depth below the surface in the uncleared state. Except in very dissected landscapes, this saline groundwater requires to be raised a considerable distance by water infiltrating from the surface before it is able to enter the streams. This generally takes a considerable period of time. On the other hand, in the higher rainfall zones, the groundwater is considerably fresher but is more extensive and shallower, so that it often discharges direct to streams under natural forest conditions.

Results to date from Project 4 show that rises in groundwater level have occurred in the three high rainfall experimental catchments which were clear felled, and that the flow of ground-water to the streams has increased. However because of the freshness of the groundwater there has been no appreciable change in quality of average stream flow. On the experimental catchment within the low rainfall zone, the rise in saline groundwater following logging has been very small (a fact no doubt influenced by the dry seasons), and the groundwater is still well below creek level. It is expected that the re-establish-ment of the vegetation cover will prevent any major continuation of the rise in groundwater on this catchment. This aspect will continue to be monitored.

As would be expected, Project 4 has shown that a higher proportion of the rainfall has been converted to stream flow, since clear felling of the experimental catchments in the high and intermediate rainfall zones. In the low rainfall zone, stream flows have been very small, which reflect the poor rainfall over the study period.

Project 4 has identified some increase in salinity of stream flow in the experimental catchments following logging operations. This will need to be monitored for longer periods in order to determine its significance and to eliminate any masking effects from seasonal conditions. An increase in stream flow salinity during periods of low rainfall,with decreases during years of high rainfall, are natural responses which have been regularly observed on all south-west catchments. The condition has also been noted on the Project 2 experimental catchments, which are still fully forested.

In December 1978, an amendment to the Country Water Supply Act extended to four important rivers, which were exposed to a serious salinity threat, the same catchment clearing controls that had been imposed on Wellington Dam catchment in 1976. One of the areas now subject to clearing controls is the Warren River catchment. The legislation was primarily directed against permanent clearing. However, it has acted as a constraint on the management of the woodchip industry, because clear felling activities have been avoided in a substantial section of the Warren River catchment, which is additional to the area originally identified in the Environmental Impact Statement as being salt sensitive.

Sediment Loads

It has been noted in the Project 4 studies that, in the winter season following logging, the intermediate and high rainfall catchments yielded annual sediment loads of between 8 and 13 tonnes per square kilometre (tonnes/km^2), while similar areas in Project 2, which are still untouched, have yielded less than one tonne/km^2. However, the disturbance in the Project 4 catchments was only temporary, and the condition was corrected within 12 months, as the vegetation cover was re-established.

Sediment loads in a river system vary according to soil type, topography, vegetation, rainfall intensity and land use. The sediment loads of the river systems in the Manjimup area have always been low. According to both Australian and world standards, annual sediment loads less than 100 tonnes/km^2 are seldom continuously monitored in detail. Therefore, regular sediment measurements were not undertaken in the Manjimup area until Project 3 was initiated by the Steering Committee. The equipment which has now been installed can detect very small sediment loads.

The highest short period sediment load or "slug" on the major streams occurred in 1977 on Dombakup Brook where the value was 528 milligrams per litre (mg/L). The total sediment load of Dombakup Brook during 1977 was 3.76 tonnes/km^2. However, the sediment load on this stream the following year was very low, being 1.19 tonnes/km^2. A slug of smaller concentration, but associated with a greater volume of flow, was detected on the Weld River in 1978 when the annual sediment load was 7.09 tonnes/km^2.

During 1979 (the driest year of the study period), no significant slugs were detected within the Licence Area, and the sediment loads were generally lower than in the previous 3 years.

Activities associated with logging have provided virtually the only forms of disturbance on the catchments of both Dombakup Brook and Weld River. On other rivers, turbidity can be attributed to several activities including agriculture and road construction.

The Steering Committee drew the attention of the Conservator of Forests to the detection of sediment slugs, and this simply confirmed assessments already made by his own field staff during the winters of 1976 and 1977 (Whitely 1978) on which action had already been taken. Specifications for logging operations and erosion control are now being issued by the Forests Department for each production coupe; and since 1977 the industry has increased its commitment to stockpile logs to avoid working in very wet weather.

Conclusions

In conclusion therefore, the Steering Committee has detected no indication that the operations to date of the woodchip industry have affected the quality of the region's water resources to a level which provides a basis for any concern.

Nevertheless the Steering Committee points out that there is a risk of increased sediment load being transported by the rivers, if logging operations are not rigidly controlled (and preferably avoided) when soils are too wet. In particular the layout of roads and snigging tracks must be carefully planned. However the Steering Committee does not wish the seriousness of the minor changes which have occurred to date to be overstated.

In respect of salinity, the Steering Committee confirms as an area of high salt risk that part of the north-east sector of the Licence Area which is generally bounded by the 900 mm isohyet. Within the Warren River atchment, this area is more particularly identified as Zone A in the Catchment Clearing Control Guidelines issued by the Public Works Department in March 1979. The Steering Committee will continue to supervise activities under Projects 2, 3 and 4. It will report further at appropriate intervals. No clear felling activity should take place in areas within potential water supply catchments where the rainfall is less than 900 mm, until Project 2 studies provide more definite data on which to base the forest management practice.

INTRODUCTION

Chapter 2

CHAPTER 2

INTRODUCTION

The Licence Area under the Wood Chipping Industry Agreement Act, 1969, covers 9000 km^2 of the lower south-west of Western Australia and is centred on the town of Manjimup. It extends from the south coast northwards to the Blackwood River, being bounded on the west by an extension of the Darling Scarp and on the east by the Frankland River (Figure 1). Most of the Licence Area is within State Forest. However, some of the land is in private ownership and much of this has not been cleared.

The Licence Area contains the catchment areas of some of the State's major "freshwater" rivers, including the Donnelly, Shannon and Deep Rivers, all of which have mean annual salinity levels below 500 mg/L of total soluble salts (TSS), as well as the Warren River, a major water resource which has a current salinity level of 725 mg/L.

The Environmental Impact Statement for the woodchip project recognised that, under certain conditions, cutting of timber might adversely affect the quality of surface water resources, particularly by increased salinity and turbidity.
The Statement proposed action which is very important for the control of water quality and also provided for the restriction of cutting for the first decade on areas suspected of being salt sensitive.

Although very little hydrological research work had been attempted up to that time in the Manjimup area, the State Government had gained considerable experience throughout the south-west, and particularly in the wheatbelt, covering the problems of increasing salinity following the clearing for agriculture of the deep rooted perennial vegetation. In addition, extensive studies had been undertaken by State government departments and the CSIRO in similar country within the Darling Range which includes the catchment of the Wellington Dam as well as areas to be mined for bauxite.

On the basis of this experience, and from a knowledge of the land forms, rainfall patterns, soils, etc., it had been assessed that the effects of logging activities on water resources would be minimal within the Licence Area, particularly in the south-west sector which is in the high rainfall zone (more than 1200 mm per annum) and is more effectively drained. However, it was also recognised that salinity problems could occur, particularly in the dry north-east sector, which had been specially identified in the Environmental Impact Statement. Provision was made to avoid this salt-sensitive area from logging operations for the first decade pending research.

In August 1973, the Environmental Protection Council (now the Conservation and Environment Council) was concerned that an increase in the intensity of forestry operations brought about by the introduction of a woodchip industry could result in an increase in salinity of surface water resources. This led to a report from the Public Works Department which stressed the need to prepare strategies for determining sensitive areas and for effectively monitoring any changes in water quality.

In October 1973, the Deputy Director of Engineering, Public Works Department (Mr. K.J. Kelsall), was requested to convene a technical committee to advise the Conservator of Forests on salinity aspects in relation to forestry management of the area. That technical committee was established as the Steering Committee on Research into the Effects of the Woodchip Industry on Water Resources in South Western Australia , which for brevity is referred to as the Kelsall Steering Committee . The Committee had much in common with another Steering Committee set up some months earlier,under the chairmanship of the Chief Engineer of the Metropolitan Water Board (Mr. H.E. Hunt), to investigate the effects of bauxite mining on water supplies. Because of this, the membership of the two Committees was made up of the same officers where practicable. The first meeting of the Steering Committee was held in January 1974.

This report reviews the progress up to the end of 1979 in research projects instigated by the Kelsall Steering Committee and other related projects, including those 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 (1976; 1978). Similar reviews of progress in the bauxite research projects have been published by the Hunt Steering Committee (1976; 1978).

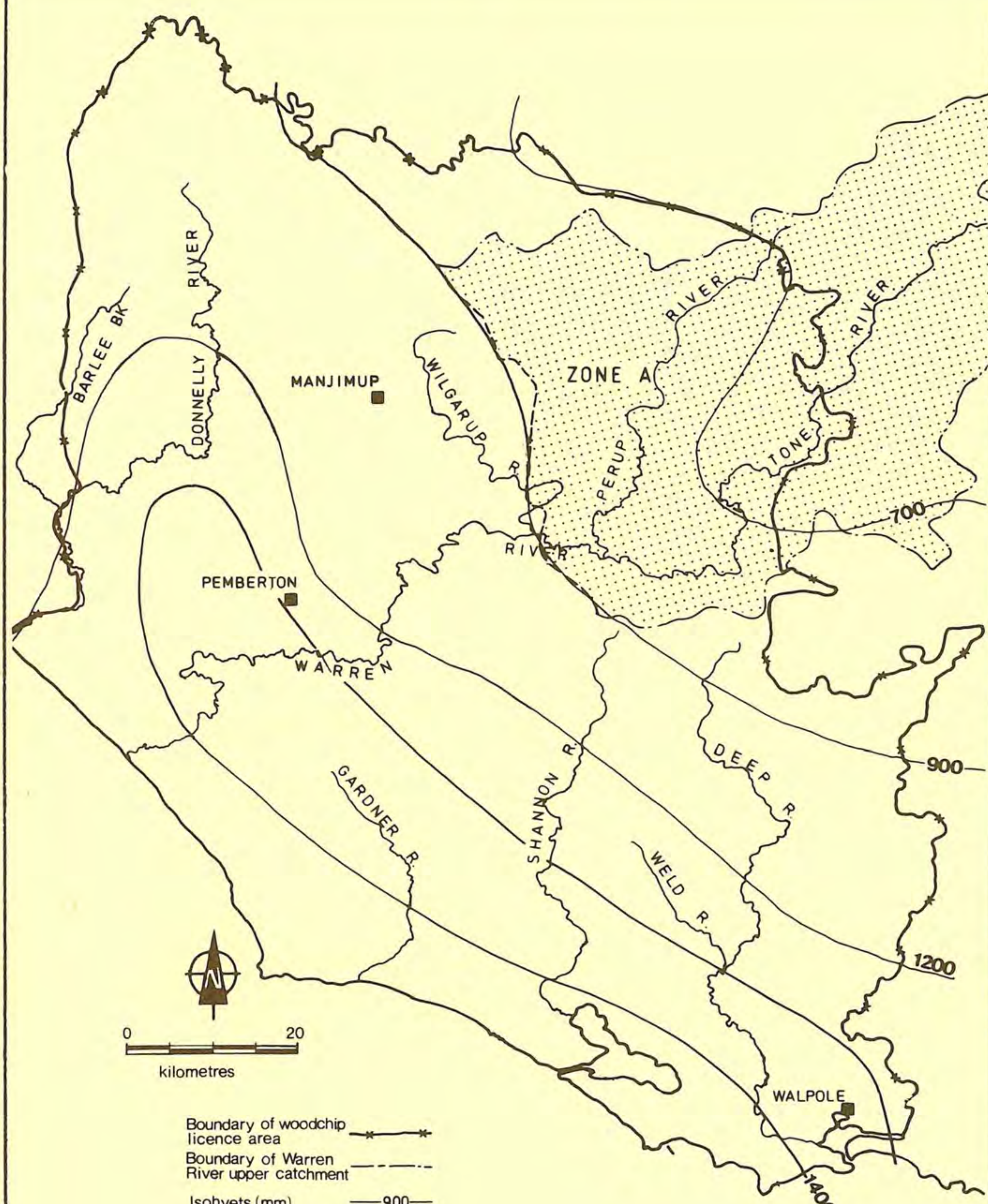
THE WOODCHIP LICENCE AREA

Distribution of rainfall, soil types and major vegetation zones

Precipitation in the Woodchip Licence Area is dominated by winter rainfall. Over 75% of annual rainfall occurs between May and October inclusive, emphasising the seasonal nature of the rainfall and consequently the streamflow response in the region. There is a band of high rainfall (1200 - 1450 mm per annum) some 10-20 km inland from the coast, along the edge of the dissected plateau. Further inland rainfall decreases rapidly and near the north-eastern boundary of the area some 80 km from the coast is only 700 mm per annum (see Figure 2). The variability of annual rainfall is low relative to other regions of Australia, but it gradually increases with decreasing rainfall over the Licence Area, standard deviations varying from around 15% to 20% of the mean (Loh and King 1978).

McArthur and Clifton (1975) have described the soils and forest types of part of the Licence Area, and a very broad scale soil map of the whole is available (CSIRO 1975). Podzolic soils and red earths develop on acidic and basic gneiss respectively. Gravelly lateritic soils predominate in the drier inland plateau area with sluggish drainage lines. These soils are underlain by "pallid zone" clays and deep zones of weathering in which considerable amounts of soluble salts have accumulated.

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 an associate in either karri or jarrah forest.



ANNUAL RAINFALL DISTRIBUTION AND CATCHMENT CLEARING CONTROL ZONE A

FIGURE 2

Soil water and salinity

The quantity of soil water tends to increase with annual rainfall, although there is considerable variability over localised areas.

The amount of stored salts in the soils of the Licence Area tends to show a strong inverse relationship to average annual rainfall. This has important implications for the management of the woodchip industry and has influenced operations and research in the Licence Area, as detailed in this Report.

Forestry operations in the Licence Area

The Agreement Act allows for the supply of 680 000 tonnes green weight of logs from State Forest for chipping per annum, and it was expected to come from an average area of 11 000 ha (i.e. 2.7% of the Licence Area) to be logged annually. The export licence permits the annual export of 750 000 tonnes green weight of woodchips, the additional 70 000 tonnes resulting from residues (i.e. off-cuts) from sawmilling operations. Table 1 shows the quantities of woodchips produced and the areas logged since the first full year of operation (i.e. the year ended 30 June 1977). It will be observed that the production figures are significantly less than those permitted under the Agreement, and the areas logged are also less than expected.

TABLE 1 APPROXIMATE WOODCHIP PRODUCTION AND AREA CUT OVER IN THE THREE YEARS TO 30 JUNE 1979

Year	Logs from Licence Area (tonnes)*	Sawmill Residues (tonnes)	Area Logged (ha)
1976-77	445 508	31 150	2 458
1977-78	512 130	89 390	3 250
1978-79	535 379	114 766	3 642

* Note: Weight is green weight of chips calculated from volume m^3 x 1.179. Source: Annual Reports, Forests Department.

The removal of woodchips has so far been concentrated in the more productive karri-marri forest. This meant that a much greater quantity of woodchips was obtained from a unit area of forest, and a markedly smaller area of forest was cut for woodchips. With the resurgence of woodchip markets a greater area of jarrah-marri forest must be logged, which will mean that a greater overall area is to be covered by the woodchip operations.

After cutting operations, regeneration of the forest is carried out as quickly as possible using techniques developed by the Forests Department. These 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 Forests Department nursery near Manjimup, or by broadcasting karri seed by hand or from aircraft.

Since the inception of the woodchip operation there has been progressively closer control over forest operations. Field control systems have been developed and adapted to different situations. Specifications for logging operations and erosion control are issued for each production coupe. Since 1977 the industry has increased its commitment to stockpiling logs to avoid snigging in very wet weather. Stockpiling prior to the 1980 winter reached a level of approximately 100 000 tonnes.

The quarantine regulations introduced in December 1977 to minimise the spread of jarrah dieback disease caused by the fungus *Phytophthora cinnamomi* are still in operation in parts of the Licence Area. Thus, vehicular access has been restricted in the north-eastern sector, in the western sector adjacent to the Darling Escarpment, and in parts of the eastern sector. The areas of forest to be cut for sawlogs and subsequent woodchip production have been programmed to avoid these sectors. Some of the experimental catchments described later in this report are, of necessity, located within quarantine areas. However, the strict hygiene requirements relating to vehicles are observed and much of the monitoring work is undertaken on foot.

The risk of dieback being spread is potentially less serious in the Licence Area than in jarrah forests further north because:

(i) much of the central part of the Licence Area is dominated by karri and marri which are non-susceptible to dieback;

(ii) the climate, soils and biological environments in these areas generate 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 poorly drained sites and lateritic soils.

In December 1978, Parliament amended the Country Areas Water Supply Act to extend to four major south west river catchments (including the Warren River and its tributaries) the same clearing controls which had been imposed on the Wellington Dam catchment in 1976. In the clearing control guidelines, which were published by the Public Works Department in March 1979, the various catchments were divided into four zones (namely A to D) in decreasing order of salt susceptibility. Approximately 123 000 ha of State Forest in the Licence Area fall within the one A of the Warren River catchment (see Figure 2) in which clear felling is currently prohibited. This action represents a constraint on woodchipping in the drier section of the Licence Area. Some of the area affected by the catchment clearing controls is additional to that provided for in the Environmental Impact Statement.

By the utilisation of departmental staff for the administration and supervision of the various projects, as well as for much of the field work associated with them, the cost of the work has been kept to a minimum. Nevertheless research and monitoring studies of the type that have been initiated and co-ordinated by the Steering Committee, require appreciable funds and staff for their implementation.

TABLE 2 COSTS DIRECTLY INCURRED ON RESEARCH PROJECTS

Year	Agri-culture	Forests	Mines	P.W.D.	Annual Totals
1974-75	-	39 385	86 000	19 210	144 595
1975-76	-	29 955	84 205	79 380	193 540
1976-77	4 794	44 073	-	39 532	88 399
1977-78	6 116	15 185	33 091	45 415	99 807
1978-79	-	19 598	21 525	64 151	105 274
Departmental Totals	$10 910	148 196	224 821	247 688	631 615

The cost of the various projects was carefully estimated by the Steering Committee, and the financial commitment involved in the programme was recognised before it was submitted for approval in 1974. However, any lesser programme would not have realistically covered all the investigations considered necessary in order to assess the impact of the woodchip industry on water resources of the region.

It was also recognised that a full range of systematically collected hydrological data would be of great value in the future planning of other land uses such as agriculture, agro-forestry, mining, construction of water storages, etc.

SCIENTIFIC RESEARCH IN THE LICENCE AREA

The Steering Committee's terms of reference are:

> *"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 Steering Committee recognised the need not only to identify short term effects of clearing for woodchip but also to assess long term changes through the complete forest regeneration cycle. Four special research projects were therefore initiated, and detailed progress reports on the four research projects are given in Chapters 3 to 6.

Project 1 - Identification of areas vulnerable to salinity increases.

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

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

Project 4 - Monitoring of underground and stream water using selected operational coupes as experimental catchments.

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.

The Steering Committee arranged for each project to be undertaken by field staff under the guidance of its own particular study groups. Progress on all projects is reviewed regularly by the study groups and the Steering Committee itself. The members of the Steering Committee and Project Study Groups are shown in Appendices 1 and 2.

PROJECT 1 – Identification of Areas Vulnerable to Salinity Increases

Chapter 3

CHAPTER 3

PROJECT 1 - IDENTIFICATION OF AREAS VULNERABLE TO SALINITY INCREASES

In this project two approaches have been used in an attempt to identify areas vulnerable to stream salinity increases as a result of woodchipping operations. The first involved an historical assessment of land clearing and its effects on salinity, while the second concerned a stream sampling project in two major part-cleared catchments near Manjimup.

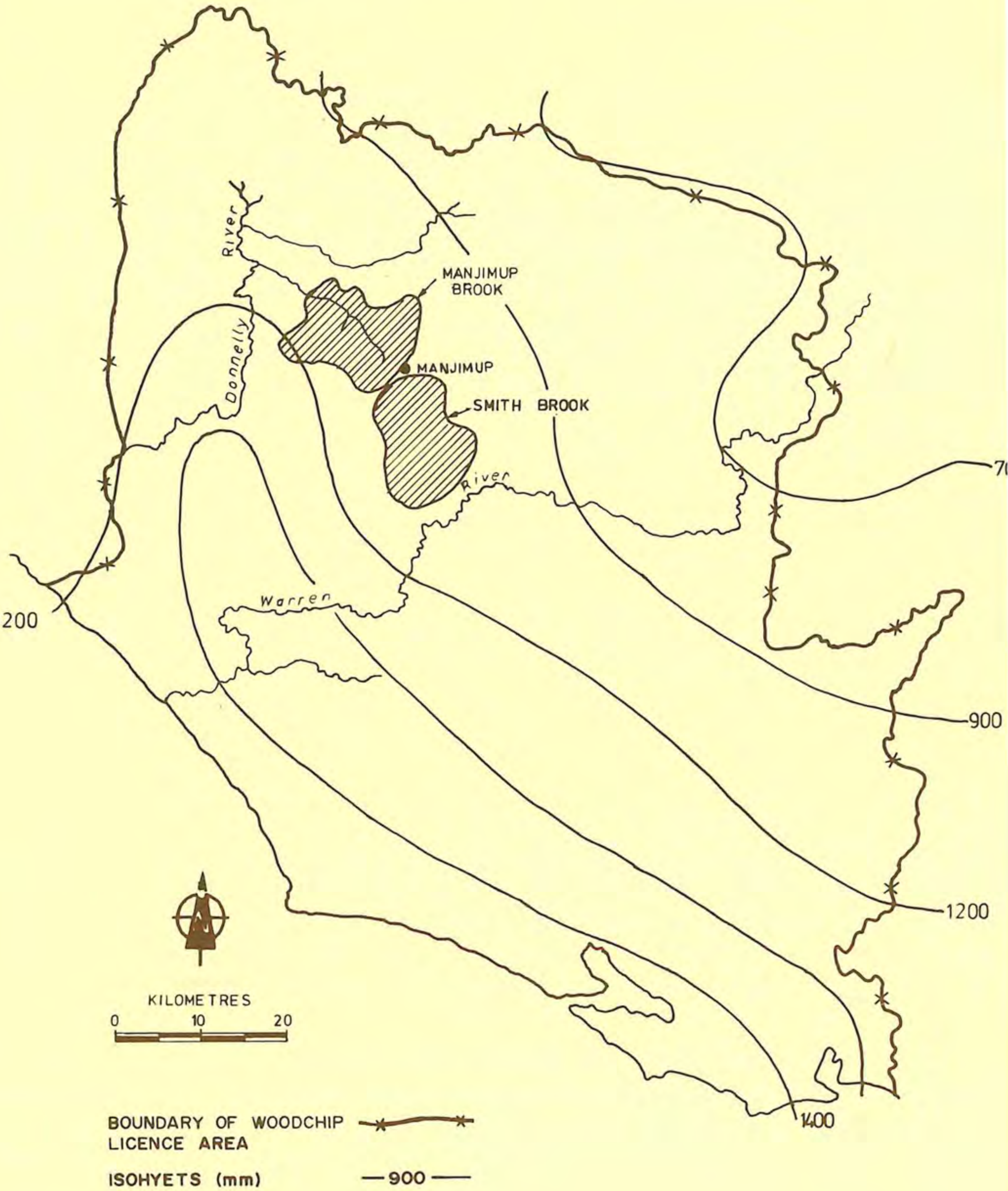
The historical evidence has been reviewed by the Department of Agriculture in a Technical Bulletin (1974). Permanent clearing for agriculture was recognised as being likely to produce a greater increase in salinity than the same area involving logging followed by regeneration. Nevertheless, the two effects may be cumulative within any given area, and if the effect of clear felling for woodchips is to increase an already high level of stream salinity, then this is a legitimate cause for concern.

Using this historical approach, parts of catchments of the Donnelly and Warren Rivers with a mean annual rainfall of between 1000 and 1200 mm per annum (i.e. within the intermediate rainfall zone), were indicated as areas in which adverse salinity changes might possibly occur. Those sections of the Licence Area with mean annual rainfall less than 1000 mm had been identified in the 1974 studies as possibly being prone to salinity increase following permanent clearing, while areas with more than 1200 mm (i.e. high rainfall zone) were generally considered to be not vulnerable to significant salinity increases.

Consequently, during 1977 a stream sampling programme was implemented for Smith Brook, which drains into the Warren River, and for Manjimup Brook, a tributary of the Donnelly River (see Figure 3). The catchments of these two brooks are approximately the same size with similar areas of permanent clearing and both lie almost completely between the 1000 mm and 1200 mm per annum isohyets.

The programme involved fortnightly sampling of the two brooks and their side streams at a total of 60 points. Each water sample collected was analysed in the laboratory for electrical conductivity, total dissolved solids (by evaporation), and chloride ion (by titration with silver nitrate). The resulting measures of salinity levels, together with estimated flow rates, allowed the total salt load of each individual stream over the 1977 season's flow to be estimated. Other information was obtained from aerial photographs and maps in respect of catchment boundaries, dissection, rainfall and clearing. In all, 21 different catchment parameters were derived.

Annual flow weighted chloride concentrations for both Smith Brook and Manjimup Brook at their lowest point of measurement were 287 mg/L chloride and 159 mg/L chloride respectively. The equivalent total soluble salts concentration were approximately 550 mg/L and 320 mg/L respectively.



LOCATION OF ISOHYETS AND PROJECT 1 STREAM SAMPLING STUDY AREA IN 1977

FIGURE 3

The data collected in 1977 were analysed, using the Statistical Package for Social Sciences produced by the Vogelbach Computing Centre, Northwestern University, U.S.A. This produced a correlation matrix for all the parameters measured within the catchments. A Principal Component Analysis (P.C.A.) was performed on the same data set, which ranked the inter-relationships between groups of variables in an order of importance. The results of the P.C.A. were then used to derive regression equations in which attempts were made to eliminate colinearity between variables.

The correlation matrix of the whole data set showed that there were high correlations between streamflow and the areal parameters measured in the catchments. The salinity of the streams was not highly correlated with any of the parameters measured, the highest correlation being between salt flow from the catchment and the easterly position of the sampling point. The correlation coefficient was 0.42 (ρ <0.001).

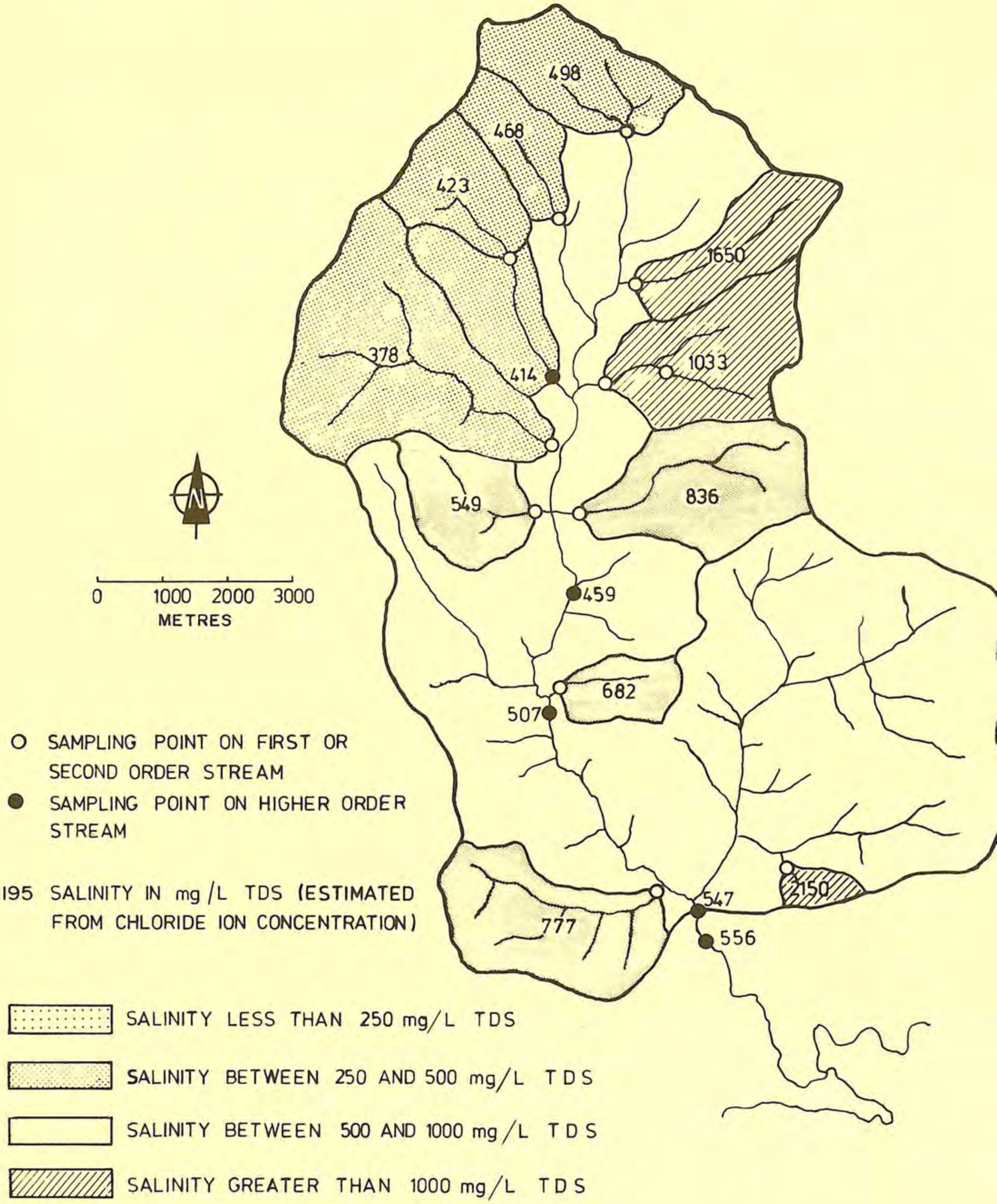
Figures 4 and 5 show the easterly positions of the higher salinity areas within Smith Brook and Manjimup Brook. Rainfall was negatively related to the salinity of the streams with a correlation coefficient of -0.39, thus showing the important influence of rainfall even over the small rainfall interval of 200 mm which was used in this study.

The results from the P.C.A. produced five rankings (factors) of groups of correlation coefficients which accounted for 88% of the variation in stream salinity, with factor 1 accounting for 46% of the total variation. This factor contained a strong relationship between the spatial variables such as total flow and catchment area. The salinity variable appeared in factor 2, which accounted for 19% of the variation. Salinity was negatively correlated with rainfall and height of catchment boundary, but positively correlated with the more easterly position in the catchment.

The regression analyses, derived from 38 primary sampling sites and by using information from the P.C.A. to obviate the problems of colinearity, produced equations which at best accounted for only 39% of the variance in salt flow. With stream salinity as the dependent variable, which has more direct application to water resource management, the regressions produced accounted for less of the variance.

Thus the use of these equations as quantative models in the prediction of land use charges affecting stream salinity is of limited value.

The mix of data on land systems, rainfall and patterns of clearing made the interpretation of the statistical analyses difficult. The low level of significance in relating the salinity levels to the measured parameters was due largely to this complexity. The most notable example was the clearing patterns occurring around Manjimup. Most of the fertile valley systems were cleared early in the century while the laterite ridges and swampy areas remained under native vegetation. As a result the major areas of native forests correspond with these infertile areas and their future land use appears to be with the forest industries.



FLOW WEIGHTED SALINITY AREAS IN SMITH BROOK CATCHMENT IN 1977

FIGURE 4

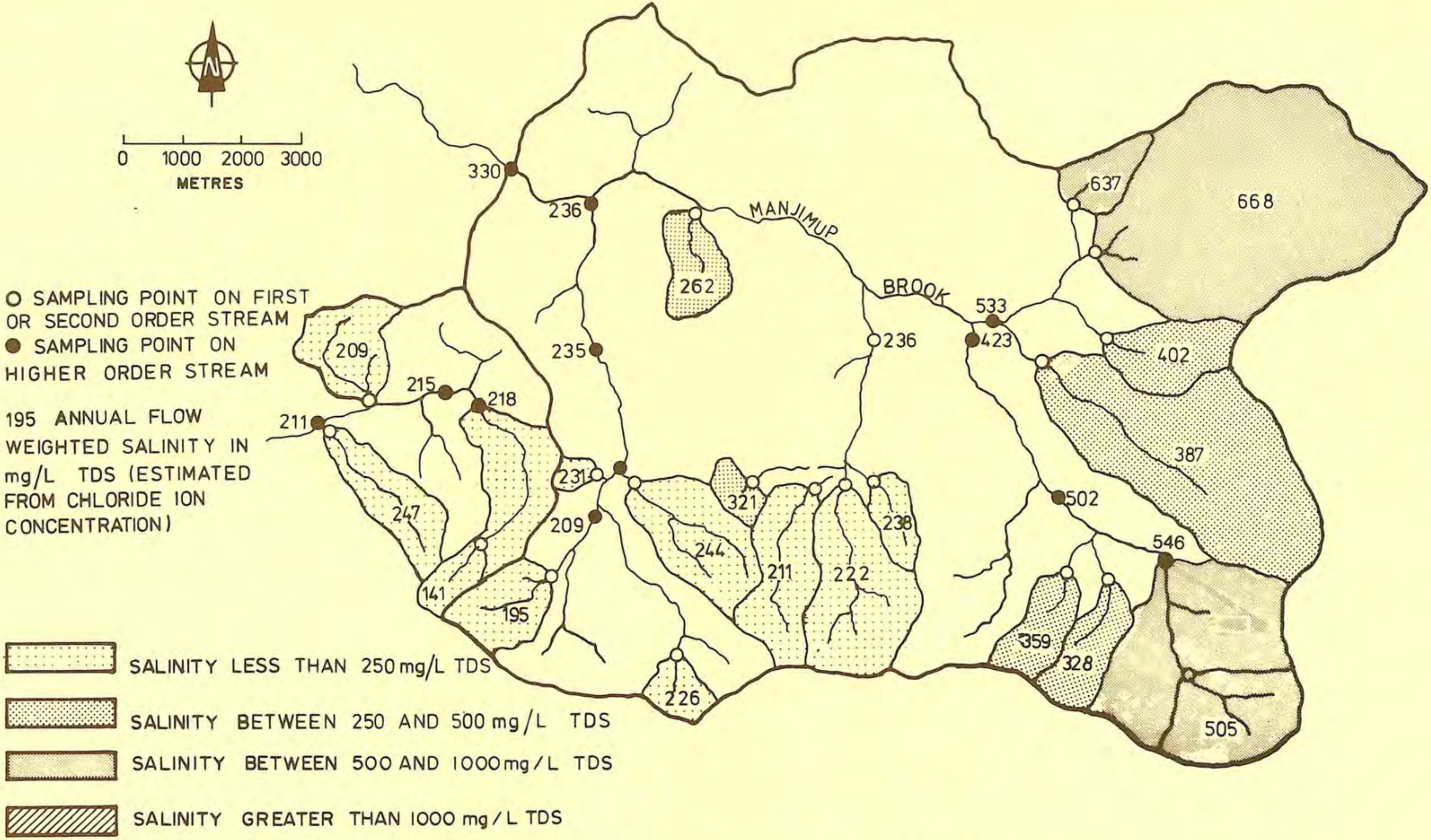


FIGURE 5

FLOW WEIGHTED SALINITY AREAS IN MANJIMUP BROOK CATCHMENT IN 1977

In the early stages of its programme, the Steering Committee had to rely heavily on information either gathered from an examination of historical records or else readily obtainable in the field. Therefore Project 1 was set up to rapidly identify salt-prone areas in the Licence Area.

However, as more detailed data from its own research activities have become available, the need for the earlier approach has lessened and the Committee now considers that Project 1 is no longer justified. Project 1 activities will therefore be discontinued.

PROJECT 2 – Monitoring of Surface and Underground Water Changes in 'Paired Catchments'

Chapter 4

CHAPTER 4

PROJECT 2 - MONITORING OF SURFACE AND UNDERGROUND WATER CHANGES IN "PAIRED CATCHMENTS"

Introduction

Project 2 is essentially a long term project. The aim is to gain detailed knowledge of water and salt balances in representative areas so that changes can be demonstrated and predictions made about the effects of forest operations associated with the woodchip industry on hydrology throughout the Licence Area. Both surface and groundwater hydrologies are being intensively monitored on seven catchments comprising three groups (two pairs and one group of three) throughout the region for a calibration period of 4 to 5 years. After this time a single catchment from each group (two in the case of the group of three) will be cut and regenerated using the normal operational procedure. The similar adjacent catchment in each group 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 findings it should be possible to make reliable predictions of hydrologic changes induced by the woodchip industry.

Location and Characteristics of Catchments

The catchments, each 100-300 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 6). Characteristics of the catchments are presented in Table 3.

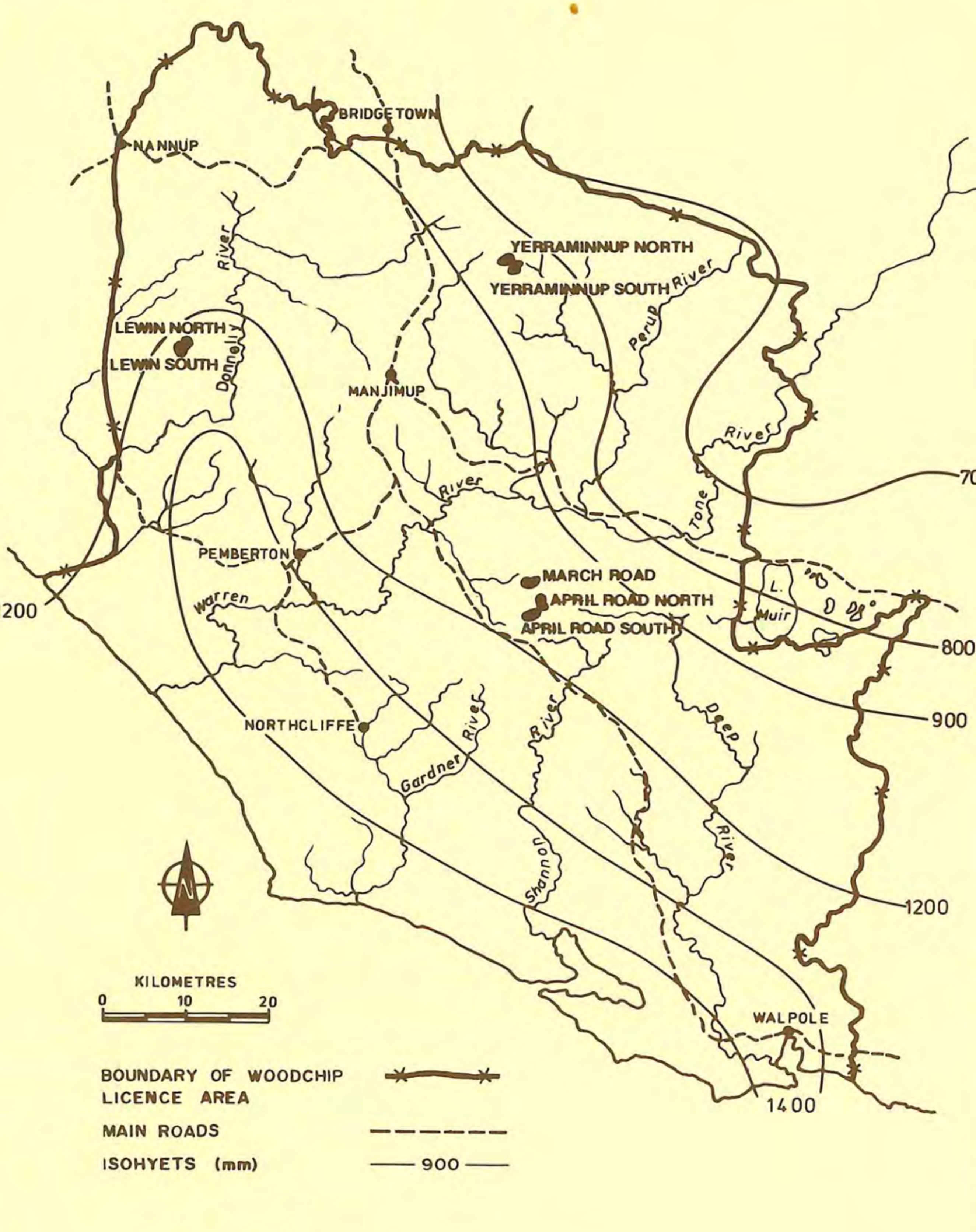
Groundwater occurs in the catchments as a perched water table within the shallow soils and gravels and as a saturated zone of the subsoils and weathering profile above fresh bedrock. The perched groundwater is ephemeral in nature while the subsoil groundwater is present throughout the year.

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 river 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. Additional samples are collected during periods of rapidly varying flow on Lewin North and South catchments. The amount of sediment deposited in the stilling basins is measured at the end of each winter, when the basins are emptied.

Rainfall is continuously measured by a pluviometer located at the top of each catchment and a pluviometer adjacent to each gauging station. Rainfall intensities occurring over 15 minute periods can be recorded accurately.



LOCATION OF THE PROJECT 2 EXPERIMENTAL CATCHMENTS

FIGURE 6

TABLE 3 CHARACTERISTICS OF THE PROJECT 2 "PAIRED CATCHMENTS"

Catchment Name	Forest Block	Soil Type	Forest Type	Mean Rainfall (mm) Long Term	Mean Rainfall (mm) Four Years 1976-79
Yerraminnup North Yerraminnup South	Warrup	laterites and yellow podzolics	jarrah-marri	850	748
March Road East	Sutton	laterites yellow podzolics red earths	marri-karri and karri	1070	994
April Road North		laterites upland swamps yellow podzolics	jarrah-marri some karri on slopes		
April Road South		laterites yellow podzolics	jarrah marri-karri		
Lewin North Lewin South	Lewin	laterites yellow podzolics red earths	jarrah-marri and karri	1220	1055

RESULTS

Rainfall

Table 3 includes the 1976-79 annual rainfall means and the estimated long term mean for each of the three groups of catchments. The recorded mean rainfall over the 4 year sequence has been approximately 100 mm less than the long term mean. The chance of this condition recurring is about 1 in 10 and indicates the severity of the dry conditions during the period of study.

Catchment Water Balances

Table 4 lists the annual quantities of rainfall input, streamflow output and subsoil groundwater outflow. Groundwater flows have been estimated from the soil and bedrock profiles as determined by seismic survey, groundwater observation and pump testing of overburden and weathered bedrock (Mines Department Hydrology Internal Reports Nos 1498, 1499, 1904, 1905).

The figures quoted are based on average estimates of the groundwater cross-sectional area and typical groundwater gradients at each site. Therefore variations from year to year are not included but these are known to be small. As can be seen from the table, underflow is not a significant variable in the catchment water balances, being less than 0.1% of rainfall in all but two cases. Table 4 also lists the difference between the rainfall input and the streamflow and groundwater outputs, termed the nett water loss.

As noted above the recorded rainfall means are well below the long term mean. Although rainfalls for 1978 were close to the long term mean, streamflows in 1978 would be below average because of the preceeding two dry years. Therefore the bias towards low flows in the recorded streamflow is likely to be higher than the bias in the rainfall.

Despite the considerable bias to low streamflow over the period of record the water balances of the catchments reflect a number of important general characteristics. Streamflow increases as a percentage of the rainfall from the low rainfall to high rainfall catchments. For example, 1978 flows on Yerraminnup South (mean rainfall 850 mm) represented only 7.4% of rainfall while Lewin North catchment (mean rainfall 1220 mm) represented 22.8% of rainfall. Considerable variation occurs between years and within catchment groups.

Variations from year to year are greatest on March Road catchment where streamflow varied between 3.8% and 15.7% of rainfall in 1976 and 1978 respectively. The greatest variation between catchment pairs occurs between Lewin North and South. Lewin South yielded only 14.9% of rainfall in 1978 compared with 22.8% for Lewin North in the same year. Such variable behaviour is characteristic of the rainfall-streamflow system generally but is particularly marked on small catchments. Small differences in topography, soils and hydrogeology can significantly affect the processes of streamflow generation and thereby the annual streamflow quantities.

Catchment Name Gauging Station	Year	Rainfall Input (mm)	Rainfall Input (10^3m^3)	Stream Outflow (10^3m^3)	Stream Outflow % of Rainfall	Maximum** Groundwater Outflow (10^3m^3)	Maximum** Groundwater Outflow % of Rainfall	Net Water Loss (10^3m^3)	Net Water Loss (mm)	Net Water Loss % of Average Pan Evaporation
Yerraminnup North 607005	1975	703	1700	54.9	3.2	0.19	.01	1650	682	51
	1976	780	1890	6.75	3.2	0.19	.01	1650	682	58
	1977	706	1700	6.57	0.4	0.19	.01	1700	702	52
	1978	869	2100	155	7.4	0.19	.01	1950	806	60
	1979	648	1570	*6.3	*0.4	0.19	.01	1560	646	48
Yerraminnup South 607006	1975	699	1370	38.0	2.8	0.35	.03	1330	679	50
	1976	786	1540	8.91	0.6	0.35	.02	1530	781	58
	1977	701	1370	3.46	0.3	0.35	.03	1370	699	52
	1978	851	1670	98.9	5.9	0.35	.02	1570	801	59
	1979	643	1260	*3.8	*0.3	0.35	.03	*1260	640	47
March Road East 607010	1976	988	2700	103	3.8	1.7	.06	2590	949	76
	1977	956	2610	256	9.8	1.7	.07	2350	861	69
	1978	1057	2890	453	15.7	1.7	.06	2440	894	72
	1979	896	2450	*148	*6.0	1.7	.07	*2300	842	67
April Road North 607011	1976	1010	2380	92.2	3.9	0.19	.01	2290	970	78
	1977	990	2340	167	7.2	0.19	.01	2170	919	74
	1978	1094	2580	358	13.9	0.19	.01	2220	941	75
	1979	904	2130	*88.6	*4.2	0.19	.01	*2040	864	69
April Road South 607012	1976	1040	2180	111	5.1	0.28	.01	2070	995	80
	1977	988	2060	171	8.3	0.28	.01	1880	904	72
	1978	1103	2300	329	14.3	0.28	.01	1970	947	76
	1979	894	1860	*116	*6.2	0.28	.02	*1740	837	67
Lewin North 608004	1976	1130	1390	147	10.6	1.3	.09	1240	1010	83
	1977	1066	1310	203	15.5	1.3	.10	1110	902	74
	1978	1120	1380	314	22.8	1.3	.09	1060	862	71
	1979	904	1110	*160	*14.4	1.3	.12	*160	772	63
Lewin South 608005	1976	1131	1190	72.8	6.1	0.83	.07	1120	1070	88
	1977	1043	1100	108	9.9	0.83	.08	987	940	77
	1978	1138	1200	179	14.9	0.83	.07	1020	972	80
	1979	909	957	*86	*9.0	0.83	.09	*871	830	68

* flows from September 1979 to December 1979 have been estimated. ** upper estimate of groundwater flow based on the largest cross sectional area determined from siesmic traverse.

However, similarity of the seasonal responses to rainfall is reflected in Figures 7 and 8 where the daily pattern of flows in 1977 from the three Sutton Block catchments is shown. Differences only occur in the wetting up behaviour of catchments. April Road North catchment requires more rainfall before its streamflow response approaches that of March Road and April Road South. This slow wetting up behaviour can be related to the greater depth to the saturated zone in the subsoils of the April Road North catchment as shown in Table 4. Methods of accounting for these differences are discussed in later sections on catchment calibration and modelling.

The water balance figures also indicate that the nett water loss increases from the low rainfall Yerraminnup catchments to the higher rainfall Sutton and Lewin catchments. The nett water loss is a combination of water loss to evapotranspiration, deep drainage and changes in the saturated and unsaturated groundwater storages each year. Because of the underlying hard bedrock and relatively small variations in groundwater level, both deep drainage and changes in the saturated groundwater are considered small components of the annual water balances. Although soil moisture has not been measured, neutron moisture meter work at forested sites on experimental catchments near Collie and on the Coastal Plain near Perth has indicated that soil moisture levels approach a similar minimum water content each year. Consequently the annual change in the unsaturated soil moisture storage is also likely to be a small component. Therefore, the nett water loss at least during the current calibration phase is considered a good estimate of the actual evapotranspiration each year. The fact that there is a higher evapotranspiration in the higher rainfall catchments is a reflection of their having a greater availability of moisture and greater forest densities. This occurs despite the lower potential for evaporation in the higher rainfall areas. As indicated in the last column of Table 4 the nett water loss (or evapotranspiration) from the Yerraminnup catchments represents only around 53% of the estimated annual average Australian Class A pan evaporation, while the Sutton and Lewin catchments represent around 73% to 75%. The same tendency occurs between wet and dry years in these catchments. Nett water loss is generally higher the higher the rainfall. This indicates that to date, water availability has been the limiting factor in evapotranspiration.

Catchment Salt Balances

Small quantities of salts are deposited on catchments each year in rain and dust and are discharged from catchments in streamflow and groundwater underflow through the soils and weathering profile. A relatively large store of salts exists in the soils of catchments in the Licence Area and depending on the hydrologic conditions, soil types and catchment land use, these salts may be either accumulating or leaching from the catchment. Such catchment salt balances can be studied by monitoring chloride ion concentrations. Chloride ions represent over 50% of the total soluble ions in rainwater and streamflow, and because they do not readily react with soils, form an ideal tracer to identify hydrologic changes following a change in land use.

Table 5 represents the input, output and nett accumulation of chloride on each catchment for each year of record. For consistency chloride concentrations in rainfall have been determined from the distance of each catchment from the coast (Hingston and Gailitis 1977). Comparisons between specific sites where concentrations have been determined are made below.

The stream output of chloride is determined from the combined integration of continuous flow measurements and frequent (at least daily) chloride ion concentration measurement. Groundwater output has been assessed from the product of groundwater chloride ion concentration and the groundwater outflow.

Table 5 shows that the quantities of chloride discharged by groundwater underflow on the Yerraminnup catchments are a significant proportion of the total output and in dry years can exceed the surface stream output. This chloride export is only significant because of the large difference between the concentration of the surface water and subsoil groundwater passing the gauging station on the Yerraminnup catchments (see Table 6). On other catchments chloride underflows are insignificant to the total catchment balances.

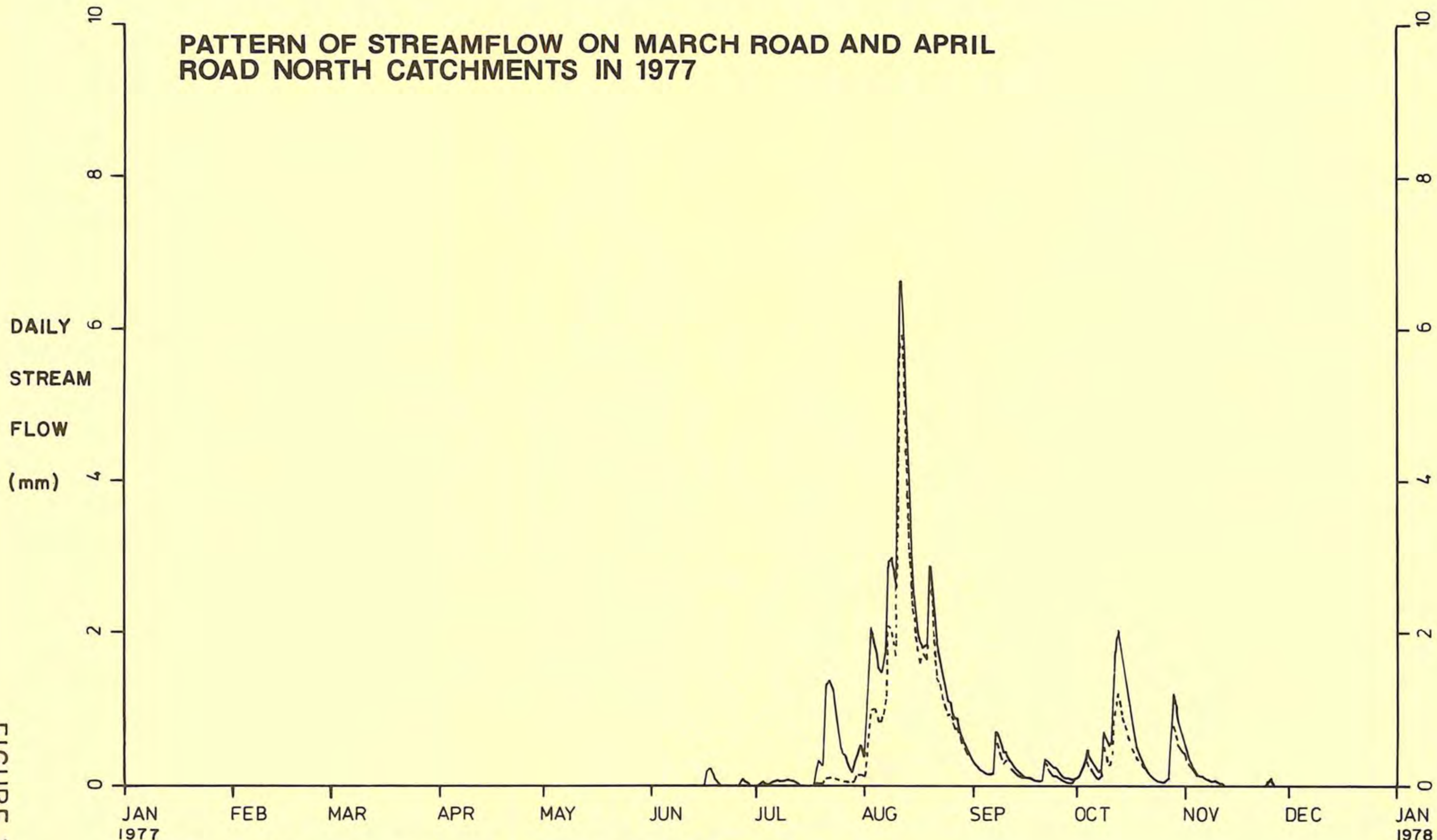
All catchments accumulated chloride over the period of record. This phenomenon was, in part, related to the sequence of dry years causing a significant bias towards below average streamflow rather than any inherent chloride imbalance. However, the following comments can be made.

The highest rates of accumulation tend to occur on the catchments which have the greatest depth to the saturated zone.

Catchments where subsoil groundwater is in excess of 3 metres from the surface have accumulated chloride at mean rates in excess of 55% of their yearly input. The two catchments, Lewin North and March Road, with subsoil groundwater within about 1 metre of the surface have accumulated chloride at mean rates of less than 20% of yearly input and have shown a nett export of chloride in some years. Given a period of record closer to the long term mean there is little doubt that the Lewin North and March Road catchments would have a nett export of chloride.

Chloride Ion Concentrations

Table 6 lists the chloride ion concentrations associated with the water and chloride balances of Tables 4 and 5. As stated above, chloride concentrations used in Table 5 were based on average figures obtained from a correlation with distance from the coast. Included in brackets are measured concentrations at one site on each of the three groups of catchments during 1978 and 1979. Significant variations occur throughout the year with the highest concentrations occurring in summer months where dry fall can be significant. On an annual basis the adopted and measured concentrations for the Yerraminnup and Lewin catchments are very similar. However measured concentrations for the Sutton catchments are higher. If these were used in Table 5 greater accumulations of chloride would have been calculated.



MARCH ROAD ——— GAUGING STATION No. 607010

APRIL ROAD NORTH - - - - GAUGING STATION No. 607011

FIGURE 7

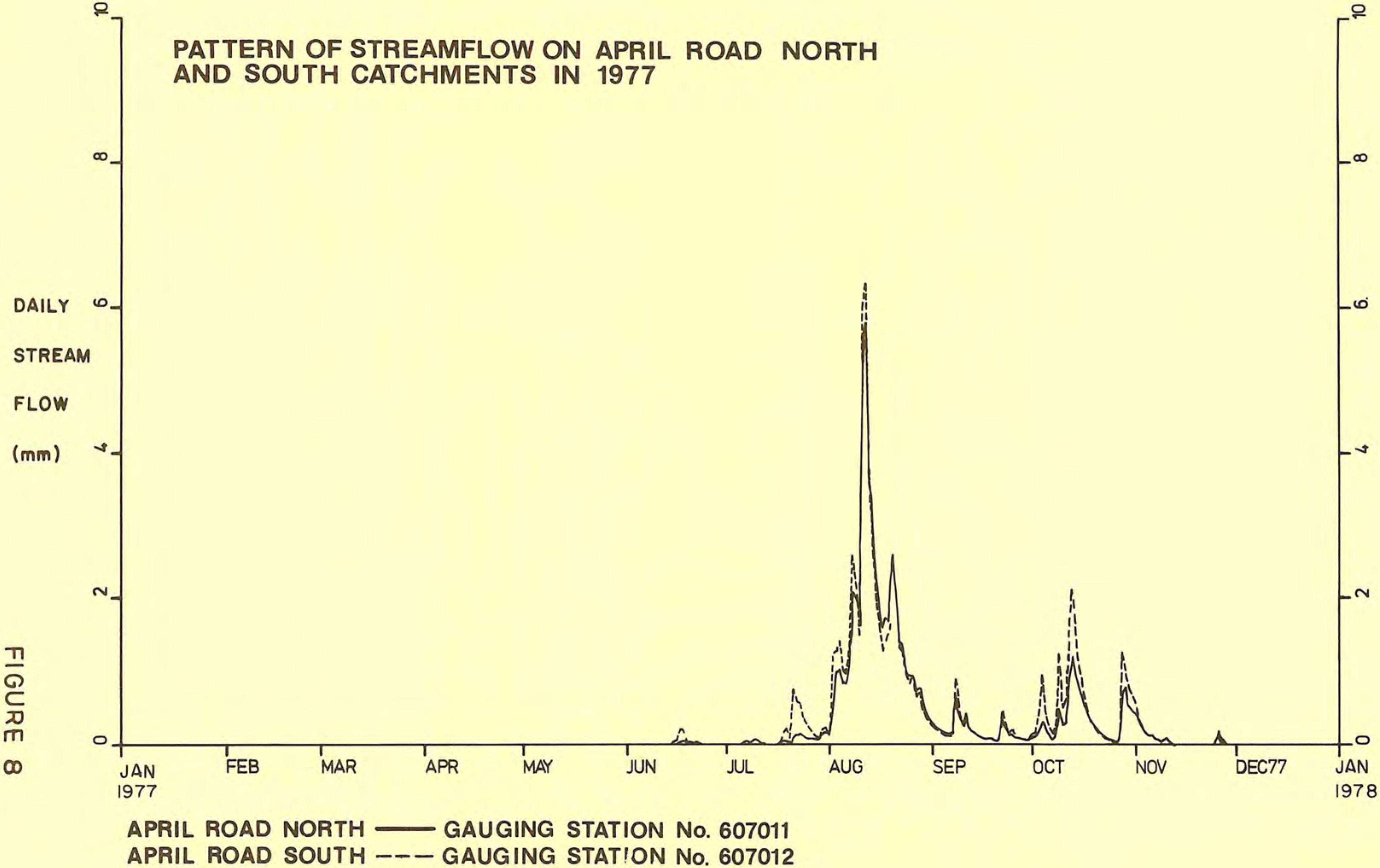

PATTERN OF STREAMFLOW ON APRIL ROAD NORTH AND SOUTH CATCHMENTS IN 1977
DAILY STREAM FLOW (mm)
0
2
4
6
8
10
JAN 1977
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC77
JAN 1978
APRIL ROAD NORTH —— GAUGING STATION No. 607011
APRIL ROAD SOUTH - - - GAUGING STATION No. 607012

FIGURE 8

TABLE 5 ANNUAL CHLORIDE BALANCES FOR THE PROJECT 2 CATCHMENTS

Catchment Name Gauging Station	Year	Rainfall Input (10^3kg)	Stream Output (10^3kg)	Groundwater Output (10^3kg)	Nett Accumulation (10^3kg)	(10^{-3}kg/m^2)	As percentage of Input	Current Storgage (Kg/m^2)
	1975	10.1	3.16	1.3	5.54	2.29	55%	
Yerraminnup	1976	11.1	1.17	1.3	8.68	3.59	78	
North	1977	10.1	0.80	1.3	8.00	3.31	79	12.3
607005	1978	12.4	5.36	1.3	8.04	3.32	65	
	1979	9.2	0.77	1.3	7.13	2.96	78	
Yerramminnup	1975	8.08	1.78	2.5	3.80	1.94	47	
South	1976	9.09	0.66	2.5	5.93	3.33	65	
607006	1977	8.11	0.36	2.5	5.25	2.68	65	20.7
	1978	9.82	2.90	2.5	7.80	3.98	79	
	1979	7.41	0.30	2.5	4.61	2.35	62	
March Road	1976	18.9	12.2	.33	6.37	2.33	34	7.0
East	1977	18.3	18.6	.33	-0.63	-0.23	-3	
607010	1978	20.2	19.5	.33	0.37	0.14	2	
	1979	17.1	11.5	.33	5.27	1.93	31	
April Road	1976	16.7	4.17	.09	12.44	5.27	74	
North	1977	16.4	8.29	.09	8.02	3.40	49	5.8
607011	1978	18.0	12.5	.09	5.41	2.29	30	
	1979	14.9	3.9	.09	10.9	4.60	73	
April Road	1976	15.4	7.67	.19	7.54	3.63	49	
South	1977	14.4	11.4	.19	2.81	1.35	20	4.1
607012	1978	16.1	13.5	.19	2.41	1.16	15	
	1979	13.0	6.36	.19	6.45	3.10	50	
Lewin	1976	11.1	9.10	.16	1.84	1.50	17	
North	1977	10.5	7.61	.16	2.73	2.20	26	
608004	1978	11.0	12.7	.16	-1.86	-1.51	-17	7.3
	1979	8.89	8.16	.16	0.56	0.46	6	
Lewin	1976	9.50	4.05	.10	5.35	5.10	56	
South	1977	8.76	5.97	.10	2.69	2.56	31	7.3
608005	1978	9.55	6.96	.10	2.49	2.37	26	
	1979	7.63	3.83	.10	3.70	3.52	48	

TABLE 6 CHLORIDE ION CHARACTERISTICS OF THE PROJECT 2 CATCHMENTS

Catchment Name Gauging Station	Year	Chloride Ion Concentrations mg/L				Depth to Permanent Groundwater (Metres)
		Rainfall Annual Concentration	Streamflow Annual Flow Weighted Mean	Annual Maximum	Typical of Deep Groundwater at Catchment Outlet	
Yerraminnup	1975	6	57	315		
North	1976	6	174	558	7000	3.1
607005	1977	6	121	251		
	1978	6.4	35	142		
	1979	5.9	132	250		
Yerraminnup	1975	6	47	103		
South	1976	6	74	182		
607006	1977	6	105	129	7100	4.0
	1978	6.4	29	47		
	1979	5.9	80	96		
March Road	1976	7	118	412		
East	1977	7	73	264		
607010	1978	8.9	43	162	280	0.6
	1979	8.8	77	99		
April Road	1976	7	45	65		
North	1977	7	49	64		
607011	1978	8.9	35	51	740	6.3
	1979	8.8	44	49		
April Road	1976	7	69	139		
South	1977	7	66	163		
607012	1978	8.9	41	90	890	2.2
	1979	8.8	55	100		
Lewin	1976	8	62	120		
North	1977	8	37	85		
608004	1978	8	40	87	130	1.3
	1979	7.9	51	70		
Lewin	1976	8	56	106		
South	1977	8	55	82		
608005	1978	8	39	53	310	1.5
	1979	7.9	44	53		

The flow weighted and maximum annual chloride concentrations of streamflow are compared with the typical chloride concentrations and depths of permanent groundwater at the gauging station outlets (Table 6).

Chloride ion variability in streamflow, both between years and within years, is lowest on April Road North catchment where the saturated zone is 6 metres below the surface. Maximum streamflow concentrations are only 65 mg/L compared with 740 mg/L for the subsoil groundwater. Clearly then, the streamflow is a consequence of water passing over and through the shallow soils and has no connection with the subsoil groundwater. In contrast on March Road, where subsoil groundwater is within 0.6 metres of the surface, maximum streamflow concentrations are of the same order as the groundwater concentrations (260 to 310 mg/L). As a consequence, greater variation occurs in the annual weighted streamflow concentration depending on the degree of dilution of groundwater by the seasonal streamflow.

Figures 9 and 10 reflect these characteristics during 1978. Streamflow from the March Road catchment showed concentrations of 40 to 50 mg/L chloride during the winter months, but these concentrations rise sharply and reach in excess of 150 mg/L by December, when the very low flow is dominated by the subsoil groundwater (Figure 9). Similar high concentrations occur at the start of streamflow each winter. In contrast, April Road North catchment's winter chloride concentrations range between 20 and 50 mg/L, show no marked increase at the end of November and do not approach the subsoil groundwater concentrations of 740 mg/L chloride (Figure 10). Chloride ion concentrations of between 20 and 40 mg/L appear characteristic of the perched groundwater.

Variations in chloride concentrations, both within years and between years on the Lewin and April Road South catchments fall between these extremes. Some interaction between perched and subsoil groundwater appears to occur. Either the subsoil groundwater is at some intermediate depth where some salts may be transported to the shallow soils by capillary action, or the subsoil groundwater is sufficiently shallow to cause interaction. On these catchments the concentrations of subsoil groundwater and perched groundwater are similar, and therefore the effect of the subsoil groundwater contribution to streamflow is less obvious.

The surface water salinity levels of the Yerraminnup catchments vary significantly from year to year, but do not approach the highly saline concentrations of the subsoil groundwater. For example, annual maximum concentration never exceeds 560 mg/L chloride despite the fact that subsoil groundwater salinity levels were around 7000 mg/L chloride. In the very low flow years of 1976 and 1977, some concentration of perched groundwater by evapotranspiration appears to be occurring. However during 1978, both Yerraminnup North and South catchments displayed a relationship between chloride concentration and streamflow rate characteristic of perched groundwater being diluted by varying amounts of fresher water generated following intense rainfall. Figure 11 indicates that groundwater with chloride concentrations of 110 mg/L and 40 mg/L was diluted to levels approaching 20 mg/L on Yerraminnup North and South catchments respectively.

Groundwater Observations

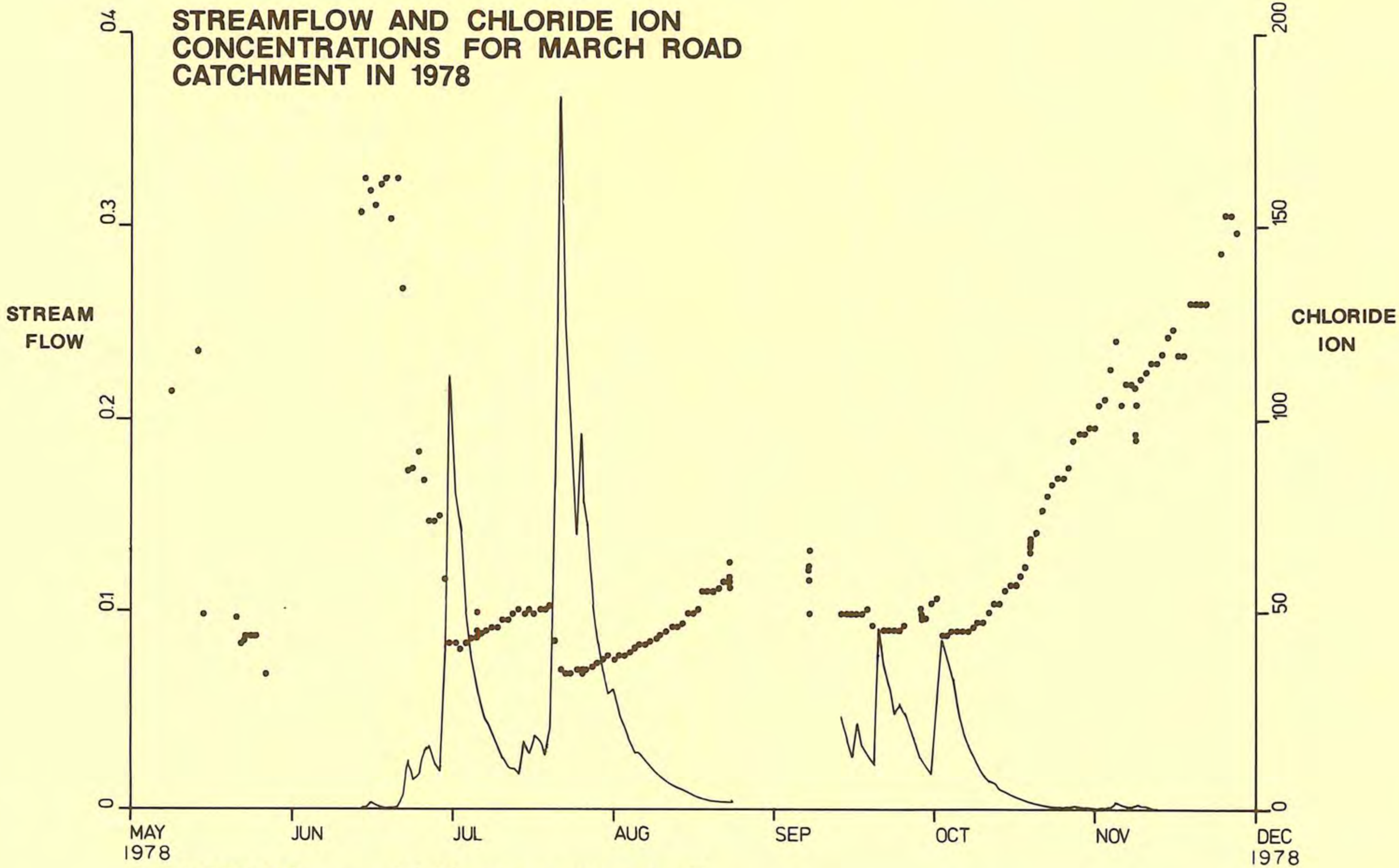
The groundwater drilling programme was carried out to determine general characteristics of the groundwater systems in the subsoils of the catchments prior to the logging operation and thereby to provide a data base from which changes following treatment could be identified. The drilling revealed a profile consisting of surficial soil, laterite gravel, sand and clay underlain by clays, gritty clays and clayey grits of the subsoil and weathering profile. Bores were completed to the top of weathered bedrock as defined by the limit of auger penetration. Holes established during winter confirmed the existence of a perched water table within the surficial profile. While the subsoil and weathering profile is hetrogeneous, a saturated zone or subsoil groundwater body was found to exist along the lower reaches of the valley systems of all catchments. Many dry holes were drilled near catchment ridge lines, but this does not preclude the existence of groundwater in the area as a saturated zone may be associated with shear and joint systems within the weathered and fresh bedrock which was not penetrated during drilling.

As noted above, the Yerraminnup and April Road North catchments had subsoil groundwater which did not discharge to the surface stream. Groundwater from the remaining catchments, particularly Lewin North and March Road, is sufficiently close to the surface to affect the water quality and quantity of streamflow draining the catchment. Figure 12 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 bore from the lower, middle and upper valley positions as many higher elevation holes were dry. These responses are considered to reflect typical groundwater responses over the catchment but do not represent either average behaviour or the complete range of responses observed. The monthly rainfall data for each catchment are plotted on the same time scale.

Water level fluctuations generally decrease with decreasing rainfall and with increasing depth to water. For example, fluctuations on the Yerraminnup catchments are considerably less than those shown for the Lewin North and April Road South catchments. It is also evident that recharge to the groundwater in 1978 was larger than in other years, although there has been a general decline in the minimum yearly level of most bores over the period of record. An increased lag between rainfall input and groundwater response is also apparent with increasing depth to water.

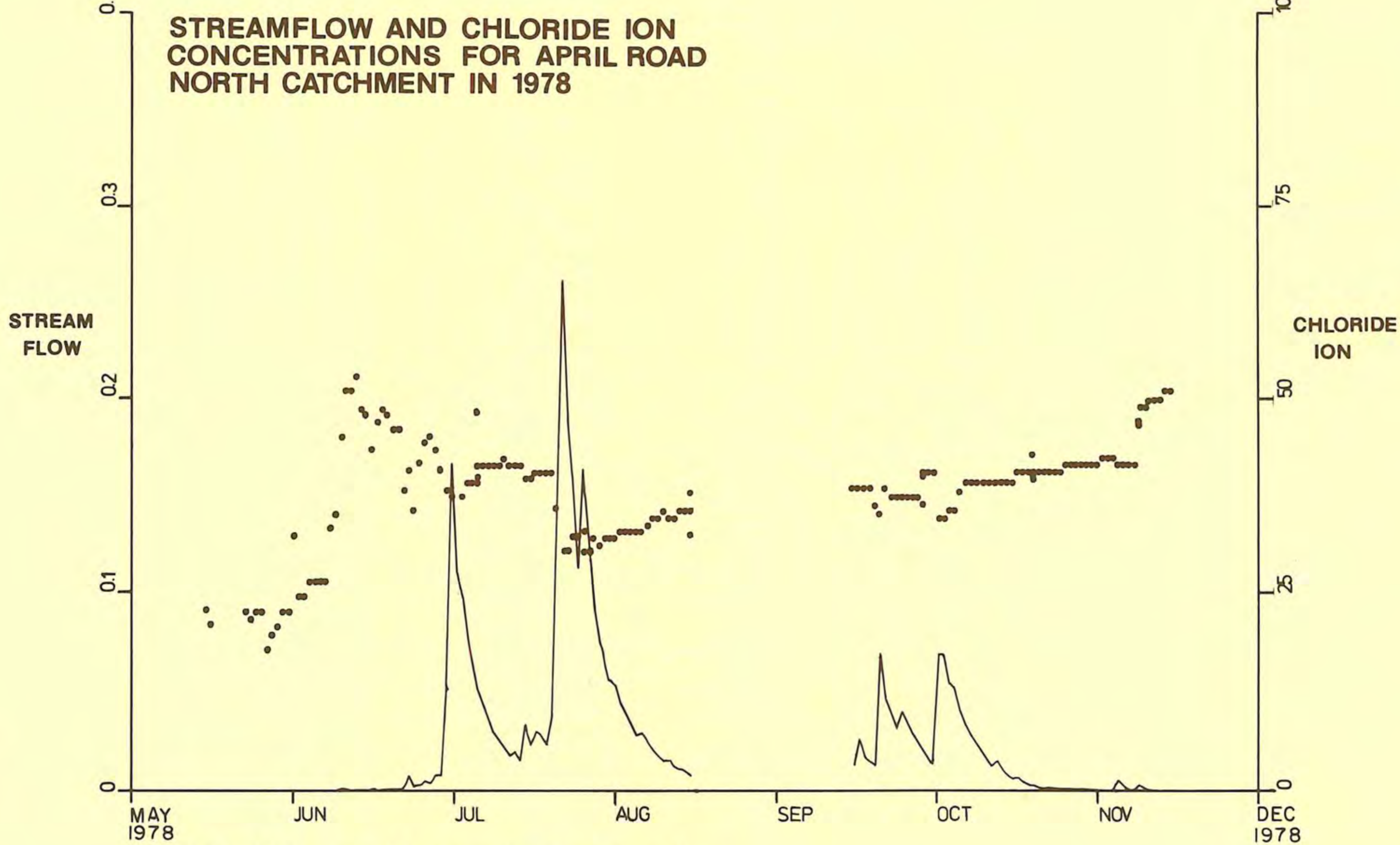
The subsoil groundwater systems are formed by a complex of local geological, topographic, soil and climatic characteristics. Although these local variations affect both specific catchments and individual bore responses, the results indicate that groundwaters are more active in the higher rainfall areas, where recharge is greater and where discharge to streams of greater incision is more likely.

Some bore holes show a rapid rise in water level following rainfall and an associated reduction in salinity which do not conform to the above generalisations. Artificial mixing between



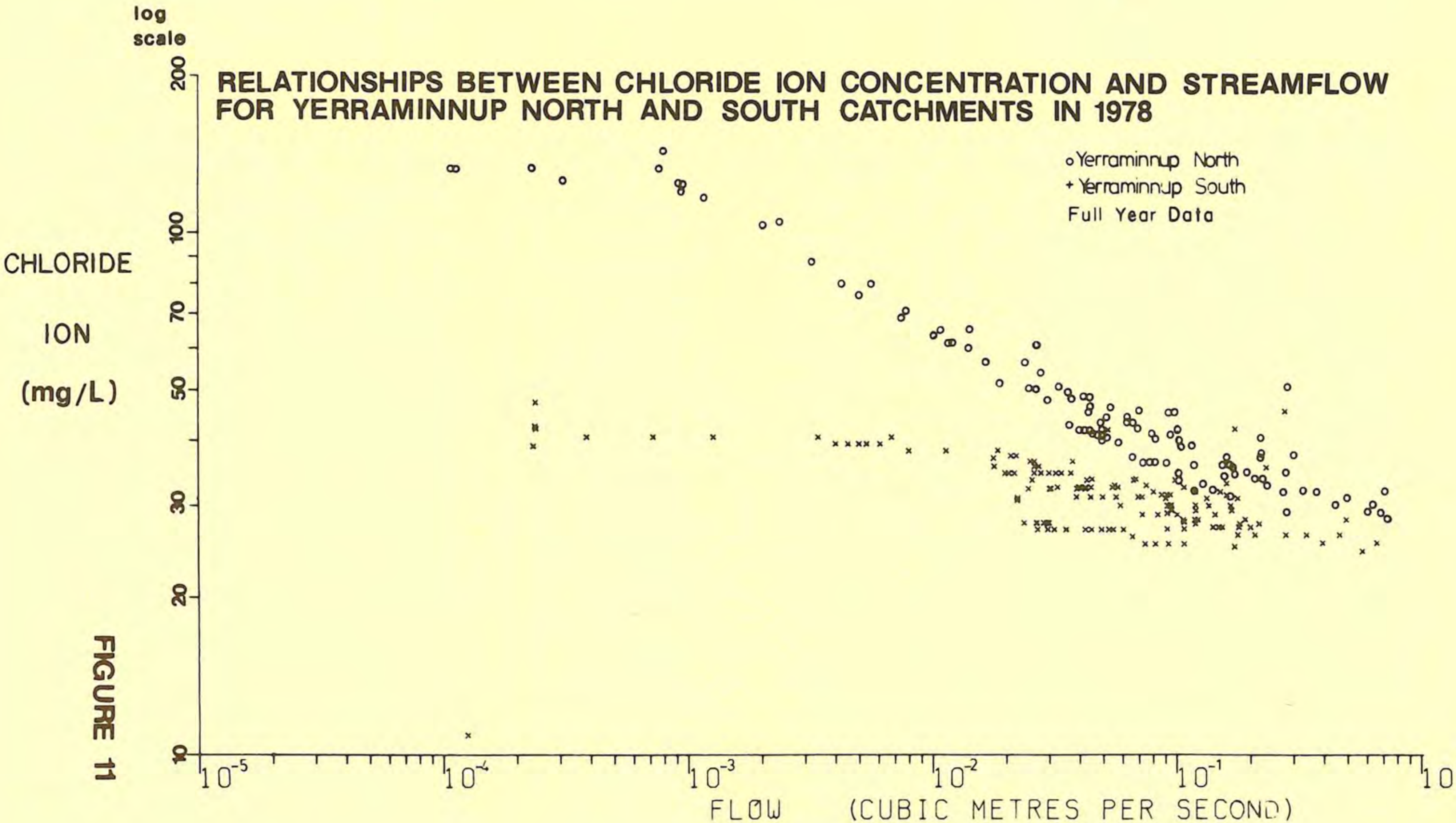
STREAMFLOW —— (Cubic metres per second)
CHLORIDE ION CONCENTRATIONS .... (mg/L)

FIGURE 9



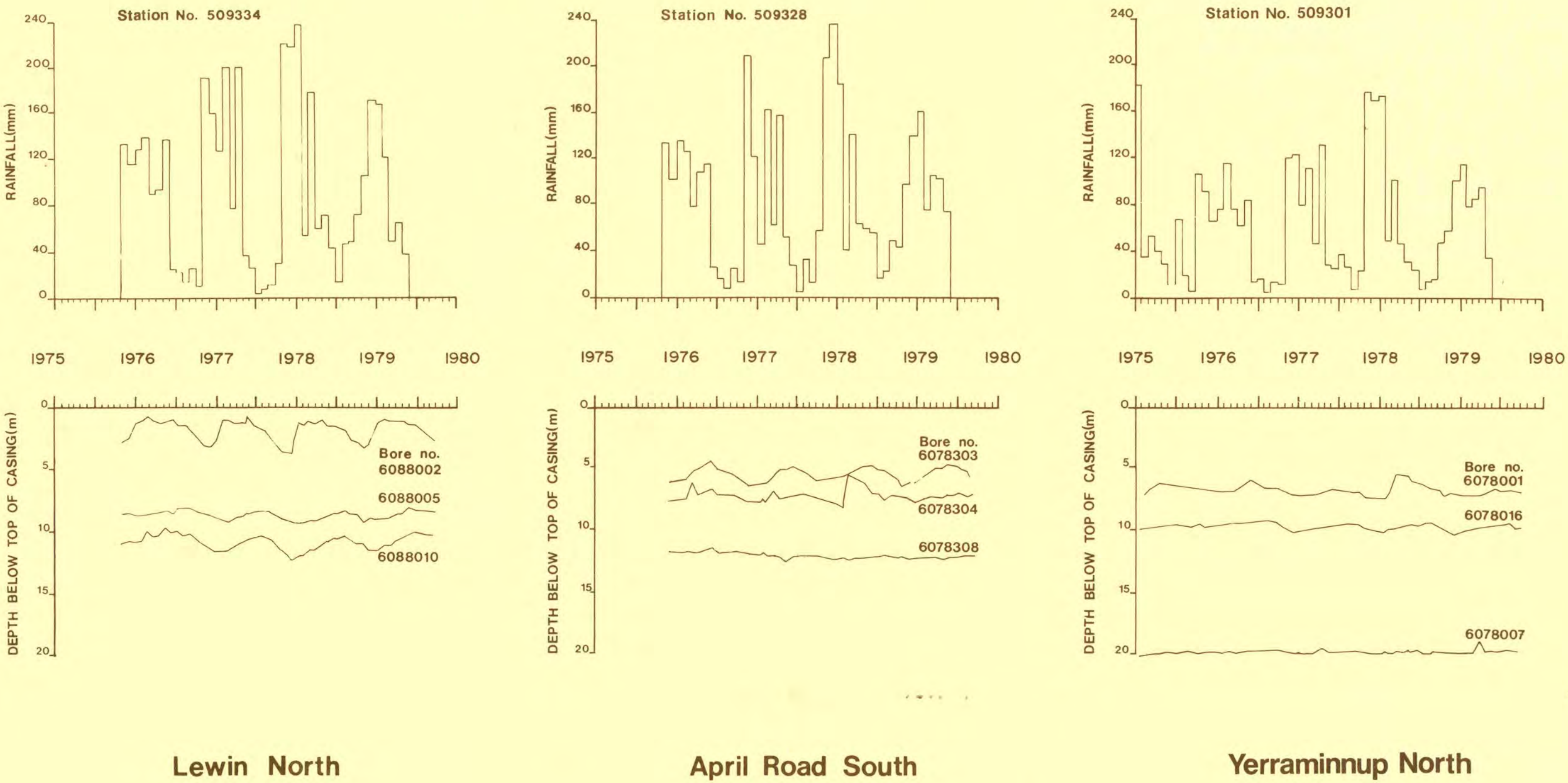
STREAMFLOW —— (Cubic metres per second)
CHLORIDE ION CONCENTRATIONS ••••• (mg/L)

FIGURE 10



RELATIONSHIPS BETWEEN CHLORIDE ION CONCENTRATION AND STREAMFLOW
FOR YERRAMINNUP NORTH AND SOUTH CATCHMENTS IN 1978
o Yerraminnup North
+ Yerraminnup South
Full Year Data
log scale
CHLORIDE ION (mg/L)
200
100
70
50
30
20
10
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
FLOW (CUBIC METRES PER SECOND)

FIGURE 11



MONTHLY RAINFALL AND WATER TABLE FLUCTUATIONS

IN REPRESENTATIVE BORES FROM THREE PROJECT 2 CATCHMENTS

FIGURE 12

the perched and subsoil groundwaters induced by the bore hole construction is known to cause this behaviour in some locations and is the likely cause in others.

Sediment

The total quantity of fine suspended material discharged from the catchments each year was determined from daily sampling of material filtered through a 63 micron filter, expressed as a daily concentration and integrated with the daily flow volume. An assessment of bed load deposited in the stilling pond between periodic cleanings was also made.

Table 7 summarises the measurements of fine sediment loads by the automatic pumping sampler.

A range of sediment loads per year is presented in the table as most concentrations were at the limit of detection. Sediment analysis was not accurate below 5 mg/L. The maximum of the sediment load range quoted has been calculated by setting all samples with concentrations below 5 mg/L equal to 5 mg/L, while the minimum estimate is based on setting all such samples equal to zero. The annual flow weighted mean and sediment load per unit area are based on the upper estimate of sediment loads.

The maximum estimates of sediment load and flow weighted concentrations clearly shows how little sediment is carried by these streams naturally. Annual flow weighted concentrations have never exceeded 9 mg/L on any catchment and maximum loads are less than one tonne per square kilometre.

The catchments with the highest daily concentrations were the Sutton Block catchments. Relatively high daily maximum concentrations have been recorded (320 mg/L) but these have always occurred at low flows at the start of the year and have been related to local soil disturbance around the gauging station. The highest daily concentrations and sediment loads occurred during 1978, the wettest year recorded to date. Higher concentrations could be expected if more intense rains occurred early in the winter on these locally disturbed areas. It should be stressed that peak sediment concentrations have not occurred at peak flow rates. This indicates that little or no sediment is in the streamlines and the stream channels are relatively stable to erosion at high flows. Two measurements of the total quantity of sediment deposited in the stilling ponds over two periods, the 1977 and 1978 winters and the 1979 winter, indicate that the maximum volume deposited on any stilling pool was less than $0.3m^3$. Clearly bed loads, similar to the suspended sediment, are very low.

FUTURE WORK

Catchment Calibration

It was originally intended to carry out the calibration phase of the project over a period of 4 to 5 years. Five years of data are now available on the Yerraminnup catchments and 4 years on the remaining five catchments. Unfortunately no year of above average flow has yet occurred and for this reason commence-

TABLE 7 FINE SEDIMENT (LESS THAN 63 MICRONS) LOADS AND CONCENTRATIONS

Catchment Name Gauging Station	Year	Annual Flow Weighted Concentrations (mg/L)	Estimated* Load (Kg)	Estimated** Load per Unit area (Kg/km^2)	Annual Arithmetic Mean (mg/L)	Daily Maximum Concentrations (mg/L)
Yerraminnup	1976	2.1	1 to 13	5	2.7	18
North	1977	8.6	41 to 59	24	5.2	88
607005	1978	3.8	85 to 585	242	4.3	70
Yerraminnup	1976	2.8	7 to 25	13	9.4	192
South	1977	3.6	0 to 13	7	9.4	5
607006	1978	4.4	4 to 431	220	5.2	80
March Road	1976	7.0	552 to 726	266	5.8	167
East	1977	3.2	30 to 883	323	16.3	535
607010	1978	3.8	52 to 1720	630	17.1	320
	1979	4.4	23 to 439	160	5.3	77
April Road	1976	2.6	106 to 241	102	4.1	71
North	1977	3.6	23 to 606	257	7.0	300
607011	1978	3.3	9 to 1170	496	12.9	206
	1979	4.5	3 to 247	104	11.1	65
April Road	1976	3.6	190 to 401	193	3.4	22
South	1977	6.4	514 to 1090	525	6.1	95
607012	1978	3.7	38 to 1170	562	16.4	215
	1979	5.1	37 to 339	163	25.0	126
Lewin	1976	1.5	38 to 230	187	1.1	14
North	1977	2.8	55 to 578	470	2.6	9
608004	1978	3.0	4 to 957	778	3.1	17
Lewin	1976	1.2	0 to 98	93	0.9	5
South	1977	2.7	2 to 287	274	2.7	7
608005	1978	3.4	6 to 602	573	3.8	28

* Two estimated loads have been calculated. The lower estimate was based on setting concentrations assessed as less than 5 mg/L to 0 mg/L and the upper estimate based on setting them to 5 mg/L.

** The estimated load per unit area and sediment concentrations are based on the upper estimate.

ment of timber removal from the catchments has been delayed. It is now planned to cut the catchments during 1982, and burn and regenerate in the autumn of 1983. Detailed calibration studies between catchments have not been carried out as yet, because no high flow years are available to define relationships in above average years. Preliminary analysis shows that good annual correlations of flow and salt load exist between all catchment groups despite significant differences in total water and salt discharges of catchments. The daily patterns of streamflow (Figures 7 and 8) show considerable similarity even on the Sutton catchments where annual correlations are poorest.

Modelling

A number of techniques for modelling the rainfall-streamflow system will be employed to account for different wetting up characteristics of catchment pairs and to improve on the simple annual correlations. These techniques include computer simulation models which use daily rainfall and potential evaporation figures as inputs to moisture accounting schemes and thereby enable the prediction of daily streamflow response.

Techniques based on modelling the daily time series characteristics of streamflow and salt load, using both catchment rainfall and the streamflow and salt load sequence of the adjacent control catchment, will also be applied. The primary aim of these modelling exercises will be to determine improved predictions of the monthly flows and salt loads of the catchments to be treated so that estimates of the changes caused by the treatment can be accurately identified.

To improve understanding of the processes causing changes in the observed response at a catchment outlet, it will be necessary to model flow and solute movement within typical hillslopes and monitor areas of surface soil saturation throughout catchments. The complexity of catchment processes has been highlighted in recent years by Pilgrim and others (1978) and Kirkby (1979). The need for major field investigations within catchments to identify them successfully has been emphasised. Particularly important in this context is the behaviour of the groundwater regime in the shallow soils, how it affects the generation of streamflow and how it influences soil compaction and erosion. As a first step to improve shallow groundwater monitoring, nests of piezometers will be drilled at selected locations to clearly differentiate shallow and deep groundwater behaviour.

Detailed monitoring and modelling studies of the shallow groundwater regimes on adjacent cleared and forested catchments near Collie have been commenced. Additional detailed work within Project 2 catchments will depend on the results and experience gained from this work.

PROJECT 2 SUMMARY

Bearing in mind the fact that the period of record to date has been dry, the following characteristics have been observed :

1. Streamflow generally increases as a percentage of the rainfall from the low to high rainfall catchments. However annual variations in streamflow are high.

2. Water balance calculations indicate that evapotranspiration increases from the low to the high rainfall catchments. This is a reflection of the higher forest densities in the higher rainfall catchments, and suggests that water availability is the limiting factor in evapotranspiration.

3. During the period of record, all catchments accumulated chloride. The rate of accumulation is higher than would be expected if average climatic conditions had applied during the period of record and in fact two catchments (March Road and Lewin North) could, under average conditions, be discharging chloride from their landscape.

4. Drilling identified the presence of subsoil groundwater along the valleys of all catchments, but this was not generally encountered along ridge lines. In the low rainfall catchment (i.e. Yerraminnup) subsoil groundwaters were sufficiently deep not to influence the surface stream response. However they did have an effect in the high rainfall catchments (e.g. Lewin). On the three Sutton block catchments (intermediate rainfall), one catchment does not influence the surface stream response (April Road North) while the remaining two do have an effect to varying degrees. Local hydrogeological soils and topographic characteristics are considered important in contributing to these differences.

5. Those catchments which had no connection between the subsoil groundwater and the surface stream system, produced low volumes of streamflow and high rates of chloride accumulation.

6. Differences in the characteristics of chloride ion concentrations, both within years and between years as well as between catchments, can be related to differences in the interaction of perched aquifers in shallow soils and the deeper subsoil groundwaters.

7. Except for the effect of local disturbance around the gauging stations, sediment concentrations from the uncleared experimental catchments have been extremely low even at high flow rates. Sediment yields have been less than 1 tonne per square kilometre.

8. Despite differences in short term catchment responses, the yearly distributions of daily streamflow and salt loads are similar. Preliminary analysis shows that good annual correlations can be obtained within catchment groups and these will be improved by further modelling studies.

9. Because of the dry years the cutting of the catchments has been delayed until 1982.

PROJECT 3 – Monitoring of Major Catchments of Rivers Draining the Woodchip Licence Area for Changes in Water Quality

Chapter 5

CHAPTER 5

PROJECT 3 - MONITORING OF MAJOR CATCHMENTS OF RIVERS DRAINING THE WOODCHIP LICENCE AREA FOR CHANGES IN WATER QUALITY

Introduction

Project 3 is designed to detect on a regional scale, any significant long term changes in the quality and quantity of water in the major rivers flowing through the Licence Area.

The first gauging stations included in Project 3 were on the Barlee and Dombakup Brooks, and the Donnelly, Deep, Gardner, Shannon, Warren, Weld and Wilgarup Rivers. These nine stream systems drain over 80% of the Licence Area. To better assess the quality of water flowing from regions upstream of the Licence Area,a new gauging station was constructed on the Tone River, close to the boundary of the Licence Area in 1978. Monitoring was upgraded on the Warren River at Wheatley Farm in 1979. The locations of all gauging stations in relation to areas of forest cut during 1976 to 1979 are shown in Figure 13. Figure 14 shows the pattern of agricultural clearing in the region.

As can be seen by comparing Figures 13 and 14, agricultural clearing and woodchipping activities combine to form a complex pattern of land use over large catchment areas. Table 8 summarises the catchment areas and dominant land uses on the catchments monitored since 1976.

Data from Project 3 provides broad scale water quality and streamflow characteristics,which reflect the overall effect of land use practices in the region. The Warren, Donnelly and Gardner River systems reflect the combined effect of agricultural clearing and forest operations. The Shannon, Weld and Deep Rivers and Barlee Brook systems have catchments that are dominated by State Forest. Forestry operations are therefore the primary factors affecting catchment land use,and it is these catchments which provide the best opportunity for assessing the long term effects of clear felling and regeneration,associated with the woodchip industry.

Measurements and Instrumentation

The gauging stations were established originally as part of the State's stream gauging network,but have been upgraded to provide both accurate flow measurements and much improved water quality monitoring. Automatic pumping samplers have been installed on all sites to collect samples at least daily. To improve the definition of stream water quality variations, the Warren River mainstream and Barlee Brook gauging stations have been equipped with a device, which initiates the taking of additional samples when the river level changes rapidly. Samples are collected from the site by field staff at four to six week intervals, and are analysed for chloride ion, conductivity, sediment and colour. Selected samples have been analysed for major ion concentrations, to identify chemical changes in streamflow, and to provide accurate data to develop conductivity versus total soluble salts relationships throughout the region.

FORESTRY ACTIVITIES IN PROJECT 3 CATCHMENTS

LOGGING FOR WOODCHIPS 1976–1979

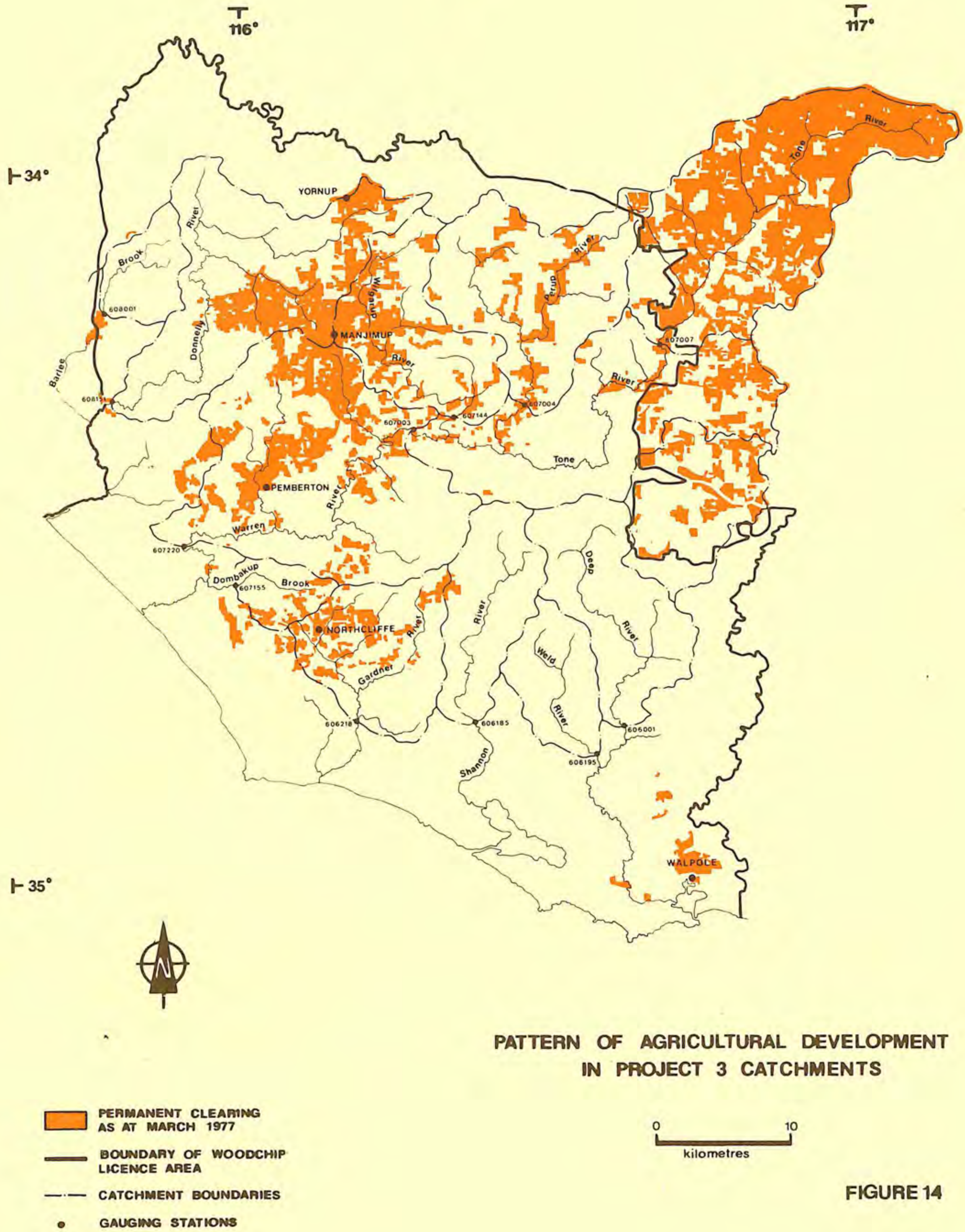
BOUNDARY OF WOODCHIP LICENCE AREA

CATCHMENT BOUNDARIES

GAUGING STATION

0 10
kilometres

FIGURE 13



PATTERN OF AGRICULTURAL DEVELOPMENT IN PROJECT 3 CATCHMENTS

PERMANENT CLEARING AS AT MARCH 1977

BOUNDARY OF WOODCHIP LICENCE AREA

CATCHMENT BOUNDARIES

GAUGING STATIONS

FIGURE 14

TABLE 8 CATCHMENT AREAS AND DOMINANT LAND USES FOR THE CATCHMENTS MONITORED UNDER PROJECT 3

Catchment Name	Gauging Station	Catchment Area (km^2)	Average Isohyetal Rainfall (mm)	Permanent Clearing as at March 1977 (% of Area)	Clear Felling Between 1976 and 1979	Major Land Uses
Deep	606001	457	900	-	Yes	Forestry
Shannon	606185	350	1190	2.5	Yes	"
Weld	606195	240	1250	-	Yes	"
Barlee	608001	165	1170	-	No	"
Gardner	606218	420	1390	16.5	Yes	Forestry
Dombakup	607155	115	1425	15.7	Yes	and
Donnelly	608151	817	1150	21.7	Yes	Agriculture
Warren	607220	4035	865	32.2	Yes	Combined
Wilgarup	607144	450	915	32.2	No	Agriculture
Perup	607004	645	765	18.6	No	with some
Tone	607007	1035	630	65.2	No	minor
						Forestry

Streamflow Characteristics

Table 9 summarises the streamflow characteristics from the long term stations in the region. Points to note are the range of responses from the high to the low rainfall areas of the region. Much higher mean annual streamflows per unit area occur in the high rainfall Dombakup Brook and Gardner River catchments, compared with the lower rainfall Wilgarup and Perup River catchments.

The figures in Table 9 accord with the regional patterns of water yield throughout the South West and reflect a number of inter-related climatic, landforms and vegetation characteristics, which cause areas with annual rainfall in excess of 900 mm (i.e. intermediate and high rainfall zones) to yield much greater streamflow than lower rainfall areas. Variations in mean rainfall can explain 98% of the variation in the mean streamflows of the nine catchments.

Landform studies were also carried out to correlate landform indices with streamflow. The proportion of different landform units such as dissected lateritic slopes, lateritic plateaux and deeply incised valley forms was calculated for each catchment. A landform index was then determined by weighting these proportions relative to their potential to produce streamflow. The resulting correlation between landform indices and streamflow explained approximately 75% of the variation in streamflow. Clearly landform, together with rainfall, affects the water yield from streams in the Licence Area. For example, the higher the proportion of karri loam soils on steep slopes and the smaller the proportion of undissected lateritic soils, the higher the water yield. Because rainfall is strongly correlated with different landform types, it is not possible to isolate the different effects of landform from rainfall in any quantitative sense at this broad scale.

Seasonal accumulation of average monthly streamflow and rainfall data into winter and summer seasons, from May to October and November to April respectively, showed that between 77% and 80% of rainfall and 91% to 95% of streamflow occurs during the winter.

Mean monthly rainfall minus mean monthly streamflow values were calculated for the seven smallest of the catchments, data for the Warren and Donnelly River catchments being excluded. By summation of these values over the year and assuming other components of the catchment water balance were zero over the 1966-1977 period of record, estimates of actual evapotranspiration were made in a similar fashion to the Project 2 study. Results are presented in Figure 15, where the actual evapotranspiration has been expressed as a percentage of estimated pan evaporation.

The results show that evapotranspiration in the low rainfall areas represents a significantly smaller percentage of the evapotranspiration potential than in the high rainfall areas. Available moisture is seen as the limiting factor in evapotranspiration. This is in agreement with the Project 2 results.

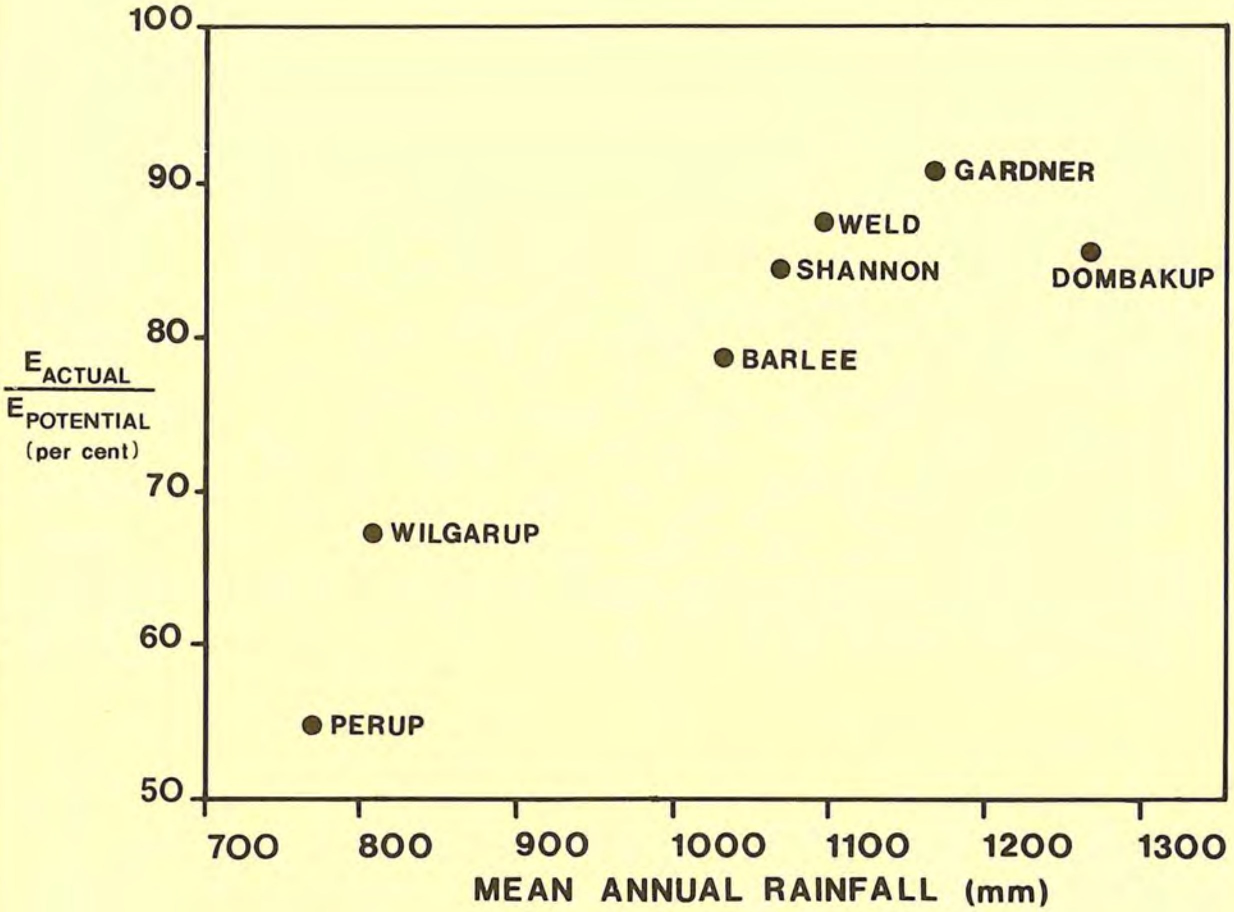
Such water balance calculations on large scale catchments have provided general characteristics of the regional hydrology, but changes in water balance characteristics as a result of land

TABLE 9

RAINFALL AND STREAMFLOW CHARACTERISTICS OF THE MAJOR STREAMS IN THE LICENCE AREA

Stream			Mean*			Coefficient* of Variation		Range of Recorded Streamflow Expressed as a Ratio of Mean Flow	
Name	Gauging Station	Catchment Area (km^2)	Rainfall (mm)	Streamflow (mm)	Streamflow ($10^6 m^3$)	Rainfall	Streamflow		
Dombakup Brook	607155	114	1264	366	42	.133	.293	0.60	1.64
Gardner River	606218	419	1168	308	129	.142	.315	0.44	1.46
Weld River	606195	240	1102	230	55	.147	.365	0.29	1.49
Shannon River	606185	350	1073	232	81	.141	.360	0.32	1.68
Barlee Brook	608001	164	1043	198	33	.148	.345	0.38	2.28
Donnelly River	608151	808	992	160	129	.149	.349	0.38	1.95
Warren River	697220	4080	820	81	331	.133	.366	0.25	1.91
Wilgarup River	607144	455	811	71	32	.140	.415	0.33	2.17
Perup River	607004	627	765	22	14	.182	.571	0.40	3.25

*Statistics are based on the period 1966 to 1977 except for Perup River figures which are based on the period 1968 to 1977.



E_{ACTUAL} - ACTUAL EVAPOTRANSPIRATION (mm) ESTIMATED FROM THE DIFFERENCE BETWEEN RAINFALL AND STREAM FLOW

$E_{POTENTIAL}$ - POTENTIAL EVAPORATION, ESTIMATED FROM CLASS A PAN EVAPORATION

ANNUAL CATCHMENT EVAPOTRANSPIRATION COMPARED WITH ANNUAL RAINFALL FOR MAJOR STREAMS IN THE LICENCE AREA

FIGURE 15

use change cannot be identified at this scale. This is principally because differences in evapotranspiration between mature forest, young regenerating forest and pasture are small, relative to variations in annual rainfall and streamflow from year to year. Differences in rainfall, topography, geology and vegetation on large scale catchments also compound the problem. It is for this reason that detailed studies are being undertaken in Project 2.

An appreciation of the magnitude of streamflow variability is particularly important when studying water quality variables. Streamflow volumes can vary dramatically from year to year and have a much higher variability than annual rainfall. Table 9 lists the coefficients of variation from annual streamflow for long term stations in the Licence Area. Also presented are the maximum and minimum annual flows recorded to date,expressed as a percentage of the mean annual flow. Greater variability occurs in the lower rainfall areas notably the Perup River. Again this characteristic is typical of the South West as a whole, although annual variations in the Licence Area tend to be lower than in the Northern Jarrah Forest catchments.

Salinity Characteristics

Figure 16 shows the pattern of yearly fluctuations in flow and total soluble salts concentrations on the Warren River since 1955. Also shown is a 5 year moving average which demonstrates the long term trend of increasing salinity of the Warren River. Superimposed on this time trend are relatively large variations in salinity from year to year. Salinity levels tend to be higher in dry years than in wet years. However, the relationship between flow and salinity on large catchments such as the Warren River is by no means simple. Much depends on the distribution and intensity of rainfall and resultant portions of the catchment, which contribute both salt and water to the catchment outlet.

Variations of Warren River water quality within years indicate that salinity can increase with increasing flow, a phenomenon contrary to the usual dilution effects of high flows following rainfall, as indicated by Project 2 and shown in Figure 16. Relatively fresh flows occur on the Lower Warren River before saline flows from the inland agricultural areas contribute to the catchment outlet. Salinity tends to increase as the first flood waters from the inland areas wash the salts accumulated over the previous summer from the surface and shallow soils, down the river system. If the winter is sufficiently wet, most of the accumulated surface salts are removed and subsequent high flows can be much less saline. Salinity of the Warren River during the winter months can vary by more than 300 mg/L total soluble salts (TSS) in a matter of days. In contrast streams, such as the Shannon River, which drain forested catchments rarely vary more than 30 mg/L TSS.

The annual yields of water and salts from three regions of the Warren River catchments for 1978 and 1979 are shown in Figure 17. Based on figures for 1978, which approximated an average year, the region of the catchment in which clear felling operations are currently taking place (downstream of gauging station 607003), currently produced about 66% of the Warren River's streamflow but only 20% of its salt. Some 53% of the Warren River's total salt load, but only 10% of its streamflow comes from the Tone

WARREN RIVER FLOWS AND SALINITY

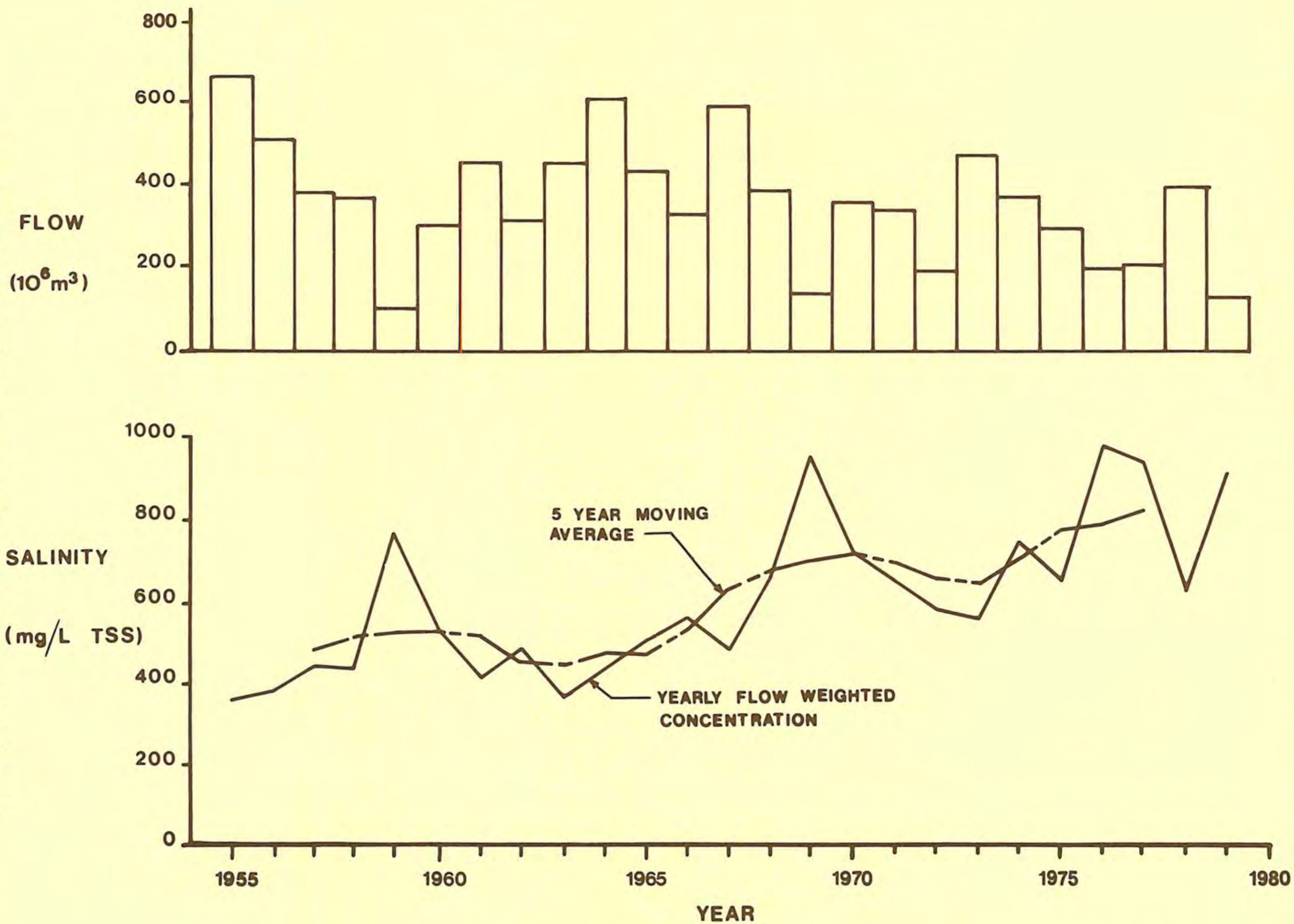
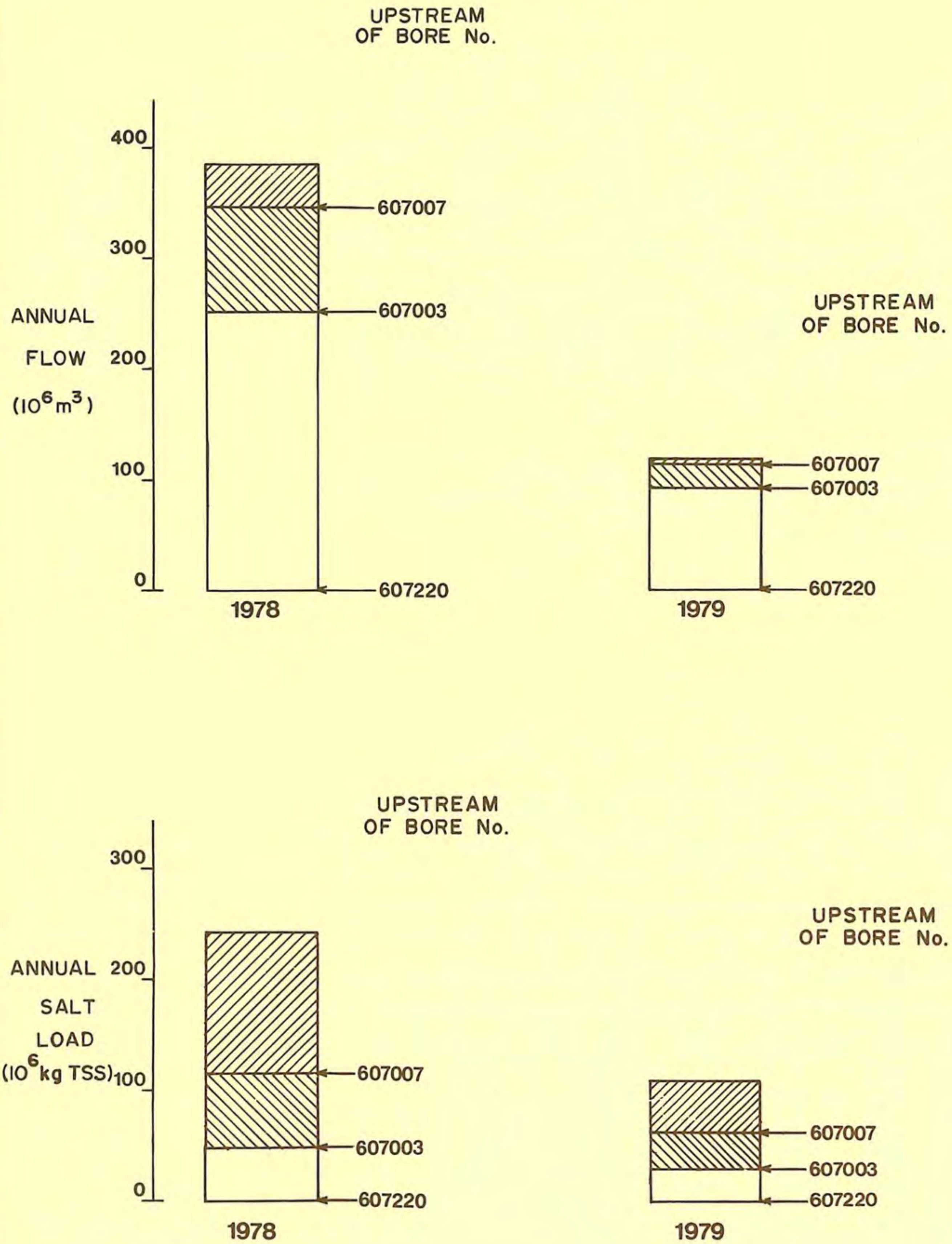


FIGURE 16



WARREN RIVER CATCHMENT FLOWS AND SALT LOADS

FIGURE 17

River which rises outside the Licence Area. As can be seen from Figure 14, there has been considerable permanent clearing for agriculture in the Tone River catchment. The full effect of agricultural clearing already undertaken on the catchment will increase the proportion of salts coming from the Tone River. Figure 17 shows that greater proportions of water and salts come from the high rainfall areas during drought years.

Figure 18 and Table 10 summarise the annual salinity levels of the major streams in the Licence Area. Figures for the Wilgarup, Tone, Perup and Warren Rivers clearly indicate the major effect that agriculture has had on their salinity. Calculations of salt balances for the Wilgarup and Warren River catchments over the period 1966 to 1977, indicate that some 5 times the yearly input of chloride is being discharged from the catchments by streamflow each year. Much higher ratios of output to input occur on the Perup and Tone River catchments.

Although the remaining catchments are less saline, the calculated salt balances for the period 1966 to 1977 suggest that a slight excess of salts is being discharged in streamflow.

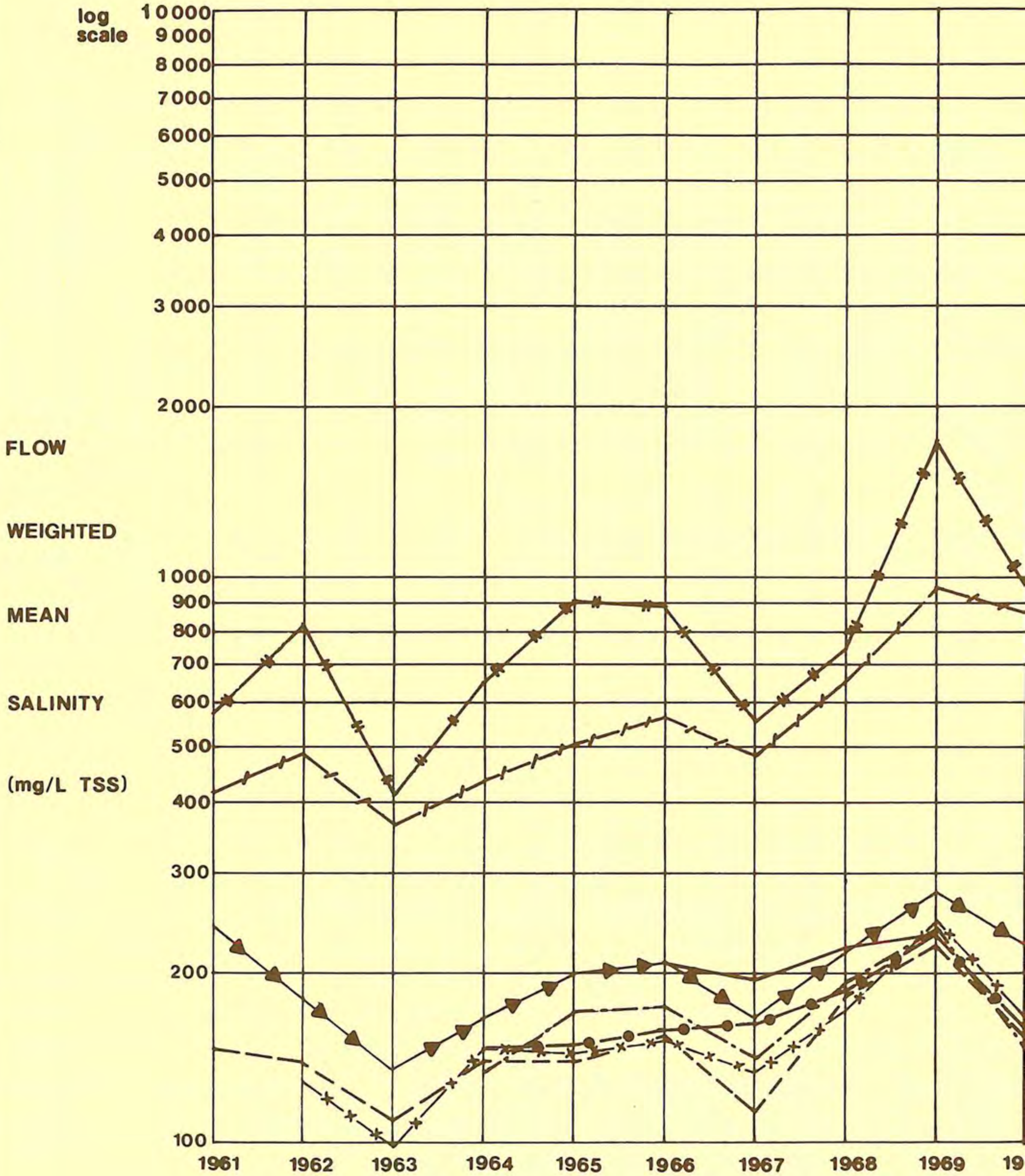
Figure 18 shows that salinity levels were generally high in the dry years of 1969, 1972 and 1979 but low in the wet years of 1962 and 1967. Levels in 1978 were also relatively low despite the fact that 1978 was only an average year. Since 1975, daily sampling has provided better definition of salinity at higher flow rates, and would therefore tend to result in lower annual flow weighted concentrations than those derived from the previous less frequent sampling. For this reason, annual figures prior to 1975 probably slightly overestimate the true levels.

Table 10 also shows that the variability of annual stream salinity is much less for forested catchments than for catchments that have been seriously affected by agricultural clearing.

An assessment based on these statistical characteristics and annual flow versus salinity relationships has been carried out to determine the magnitude of changes in mean salinity that could be detected from the current monitoring programme.

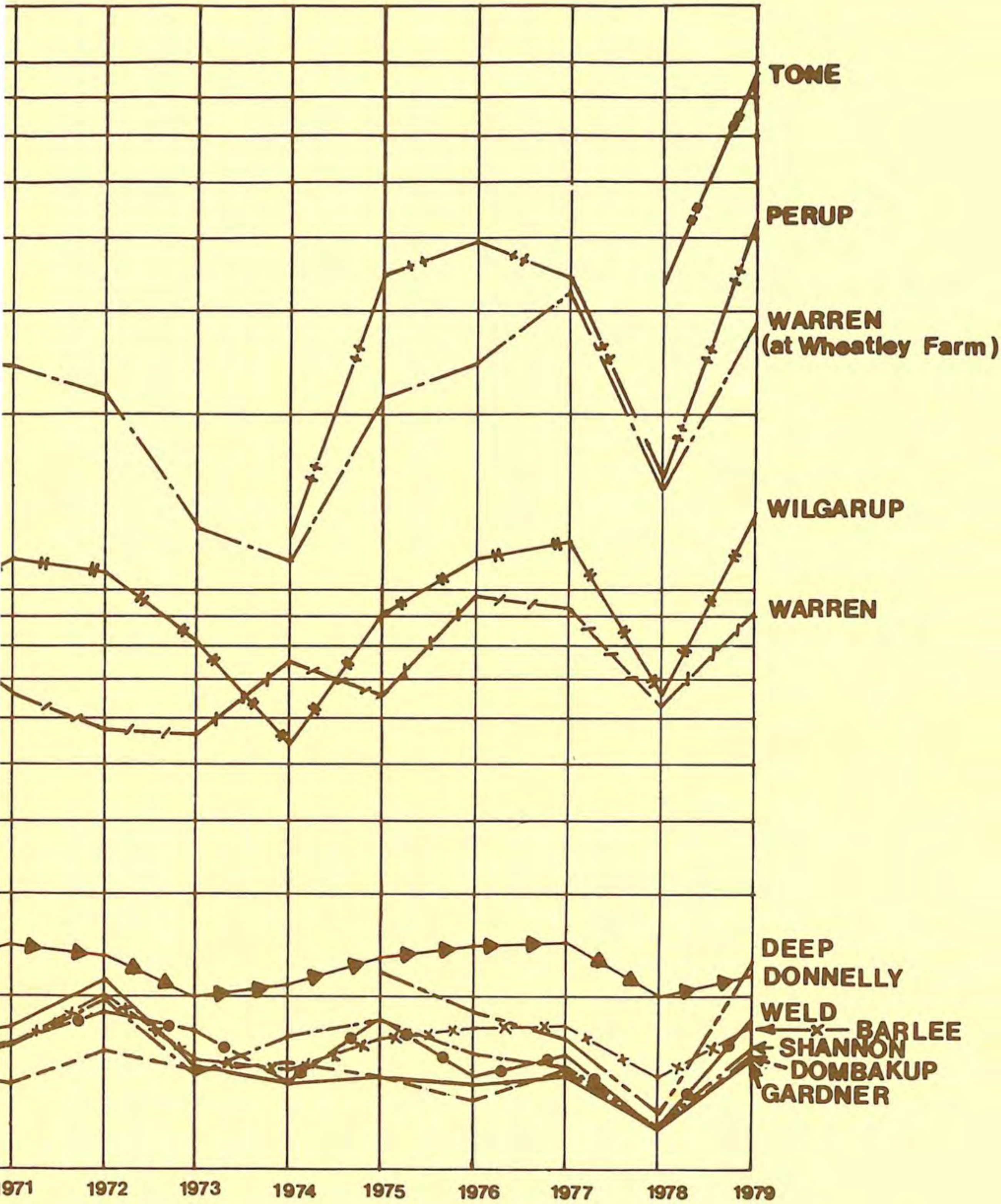
Studies have been made of selected forested catchments in the Darling Range, including the Shannon River and Barlee Brook catchments, for which more than 12 years of combined flow and salinity information have been collected. The studies have shown that between 50% and 80% of the variation in annual salinity can be explained by variations in annual flow. Average unexplained variations in salinity represent between 10% and 15% of mean values. Long term monitoring should therefore be able to readily detect changes in mean salinity of between 20% and 30% of current values. These represent between 40 and 55 mg/L TSS for the forested catchments being studied in Project 3.

It is more difficult to identify changes on catchments which have already been disturbed by agricultural clearing. This is because natural salinity variations are much higher (Table 10) and there is poorer correlation with annual streamflow. Statistically significant increases in the salinity can only be identified using long term water quality data. A statistically significant



VARIATIONS IN ANNUAL

MAJOR STREAMS IN THE



REAM SALINITY OF
DDCHIP LICENCE AREA

FIGURE 18

TABLE 10 STATISTICS OF ANNUAL SALINITY LEVELS OF THE MAJOR STREAMS IN THE LICENCE AREA

Stream Name	Gauging Station	Mean (mg/L TSS)	Standard Deviation (mg/L TSS)	Maximum (mg/L TSS)	Minimum (mg/L TSS)	Coefficient of Variation	Years of Record
Deep River	606001	187	42	230	126	0.22	1975-1979
Shannon River	606185	165	28	238	120	0.17	1964-1979
Weld River	606195	165	25	231	118	0.15	1964-1979
Barlee Brook	608601	161	31	246	99	0.19	1962-1979
Gardner River	606218	173	36	234	119	0.21	1966-1979
Dombakup Brook	607155	147	25	223	109	0.17	1961-1979
Donnelly River	608151	213	35	279	136	0.16	1961-1979
Warren River	607220	650	194	971	364	0.30	1961-1979
Wilgarup River	607144	898	323	1730	420	0.36	1961-1979
Perup River	607004	2980	1280	4290	1238	0.43	1974-1979
Warren River (at Wheatley Farm)	607003	2160	695	3270	1120	0.32	1970-1979
Tone River	607007	5340	-	-	-	-	1978-1979

trend was identified on the Warren River only after data from three gauging stations had been used to complete an annual flow and salinity series of 24 years (Figure 16). No statistically significant trends were identified on the Wilgarup, Donnelly or Gardner Rivers. Even if changes are identified in the long term, it will not be possible to attribute the changes to either agricultural clearing or forest operations. The isolation of the independent effects of agriculture and forest activities will be attempted using catchment modelling techniques designed to be appropriate to regional scale prediction but developed from results of the detailed small catchment salt and water balance studies carried out under Project 2.

Sediment Characteristics

Table 11 lists the annual daily flow weighted mean and maximum daily concentrations of fine suspended sediment (less than 63 microns), determined from automatic sampling of major streams draining the Licence Area. Also included is a calculated range of the total fine sediment transported from each catchment and the maximum associated upper estimate of sediment discharge per unit area, calculated in the same manner as for Project 2.

Sediment concentrations are generally low and approach the limit of accurate determination. Daily concentrations are usually less than 5 mg/L with only sporadic higher concentrations. For example, Weld River in 1978 only had 10 days in which the concentrations exceeded 5 mg/L, the highest of any catchment. On other catchments the number of days with sediment concentrations greater than 5 mg/L was less than 20.

The associated total quantities of fine sediment (Table 11) were also very low. In all but two cases the total fine sediment load represents the removal of less than 3 tonnes of silts and clays per square kilometre per year. Some 50 full sediment meterings carried out during 1979 indicated that the proportion of silts and clays (material with particle sizes less than 63 microns) represented some 80% of the total suspended sediment load. Measurement of the fine suspended sediment therefore provides a good indication of the total suspended sediment load.

Comparison between the concentrations obtained from the automatically collected samples (Table 11) and the fine fractions of the full sediment meterings, indicated that the automatic sampler underestimated the fine sediment concentration. In general, this underestimation has been similar to the average concentrations listed in Table 11. Although only a limited number of full meterings have been carried out at sediment concentrations in excess of 20 mg/L, better correlation exists between the automatic sampler and the sediment meterings at these higher concentrations. True sediment loads are unlikely to be in excess of twice those values listed in Table 11. Total annual suspended sediment transported by the Deep, Donnelly, Warren and Wilgarup Rivers and Barlee Brook are therefore likely to be less than 2 tonnes per square kilometre, the Shannon and Gardner Rivers less than 4 tonnes per square kilometre, and the Weld River and Dombakup Brook less than 8 tonnes per square kilometre.

TABLE 11 CHARACTERISTICS OF FINE SUSPENDED SEDIMENT IN THE MAJOR STREAMS IN THE LICENCE AREA

Stream Gauging Station	Year	Flow Weighted Sediment Concentrations (mg/L of Sediment Less than 63 microns)		Estimated Annual Sediment Loads (Less than 63 microns)	
		Annual Mean	Maximum Daily	Range (10^3 kg)	Upper Estimate per unit area (10^3 kg/km^2)
Dombakup Brook					
607155	1976	10.0	50	230 to 290	2.6
	1977	14.5	528	400 to 430	3.8
	1978	5.9	29	5 to 140	1.2
Weld River					
606195	1976	7.1	49	130 to 250	1.1
	1977	5.5	152	44 to 250	1.0
	1978	24.4	170	1530 to 1700	7.1
Gardner River					
606218	1976	6.7	42	250 to 540	1.3
	1977	6.3	27	215 to 560	1.3
	1978	6.7	166	300 to 840	2.0
Shannon River					
606185	1976	5.2	13	42 to 720	0.6
	1977	5.1	13	92 to 290	0.8
	1978	5.0	82	24 to 510	1.5
Donnelly River					
608151	1976	7.4	78	280 to 490	0.6
	1977	6.7	37	320 to 510	0.6
	1978	6.8	61	400 to 950	1.2
Warren River					
607220	1976	6.4	15	766 to 1280	0.3
	1977	8.6	35	125 to 1690	0.4
	1978	9.4	84	2460 to 3620	0.9
Wilgarup Brook					
607144	1976	6.7	68	117 to 159	0.4
	1977	7.3	30	86 to 131	0.3
	1978	6.3	23	100 to 300	0.7
Barlee Brook					
608001	1976	5.6	10	15 to 63	0.4
	1977	7.7	79	62 to 122	0.7
	1978	4.9	8	5 to 135	0.8
Deep River					
606001	1976	5.1	31	133 to 148	0.3
	1977	5.0	7	7 to 192	0.4
	1978	4.5	20	8 to 345	0.6

The factors contributing to differences in sediment loads between catchments include differences in rainfall, streamflow, soil and landform, the extent of areas developed for agriculture, the amount of recent forest saw-logging activity and the quantity and distribution of road systems within the catchment, as well as forest clear felling activities.

A rigorous quantitative analysis of the effect of clear felling as distinct from the effect of other variables is not possible. This is because no long term base data on sediment characteristics of streams in the region were available prior to the current clear felling activities, and because of the difficulty of controlling land use activities over such large catchments. Detailed changes in sediment loads following clear felling will eventually be determined from studies of the Project 2 catchments.

Sufficient differences in the magnitude and distribution of sediment loads, however, have occurred at the large catchment scale to support the following qualitative discussion.

While sediment loads are very low when compared with other areas where sediment is known to be an engineering problem in reservoirs, the two highest loads per unit area occurred on the two streams which have the highest percentage of clear felling on their catchments, namely the Weld River and Dombakup Brook with 4% and 5% of their catchment clear felled and regenerated to August 1978 respectively.

These two streams also had the highest peak sediment concentrations and characteristic periods of three to four days when substantial portions of the total yearly sediment load were transported. Between 28 and 31 August 1977 on Dombakup Brook, some 40% of the yearly sediment load was transported past the gauging station, with the maximum daily concentration of 528 mg/L occurring in this period. The Weld River's peak concentration in 1978 of 170 mg/L, occurred on the day of the highest flow and was the only catchment on which peak concentration and peak flow coincided. Some 82% of the annual sediment load was transported over the associated four-day flood period (20 to 23 July 1978). Clear felling operations were occurring less than 1 kilometre upstream of the Dombakup Brook's gauging station at the time its major concentration occurred. High sediment loads did not persist for long periods and similar high concentrations were not recorded in 1978 following regeneration, despite the larger streamflows of that year. Extensive clear felling occurred in the Weld River catchment during 1977 and 1978, although activities were further from the gauging station (Figure 13).

Sediment concentrations in excess of 150 mg/L also occurred on the Gardner River in 1978 where clear felling was also being carried out.

Catchments with significant agricultural clearing tended to have a greater number of days with concentrations over 5 mg/L, but lower peak sediment concentrations and lower unit area sediment loads than catchments more affected by clear felling activities. The Warren, Donnelly and Wilgarup Rivers have relatively large catchment areas which drain the less dissected landscape in lower rainfall areas of the Licence Area and are characterised by relatively low streamflows. It is therefore not surprising that, despite the major disturbance of agriculture together with some clear felling on the Warren and Donnelly River catchments, sediment loads and peak concentrations are lower than for smaller catchments in higher rainfall zones.

Data from Barlee Brook and Deep River catchments provide a first estimate of stream sediment characteristics not influenced by clear felling activities. Barlee Brook catchment has had no clear felling activity to date, although saw-logging operations have occurred during the period of record, while the first coupe clear felling only took place on the Deep River in 1978.

The lowest sediment loads and peak concentrations have occurred on the Deep River catchment. This is presumably a reflection of the low relief and rainfall combined with the low level of activity on this predominantly forested catchment.

Although sediment loads are slightly lower for Barlee Brook than the other high rainfall forested catchments with clear felling, sporadic days with concentrations well in excess of 5 mg/L did occur with the commencement of significant flows at the start of winter and during the peak flows of 1977. Local disturbance around the gauging station in 1977 is not considered a problem, although a major road crosses the stream approximately 500 metres from the station and is a possible source of sediment. Considerable logging activity, although no clear felling, has occurred on the Barlee Brook catchment since the early 1970s. No reliable record was obtained from 1978 because following cyclone Alby a fallen tree modified the sediment deposits in the stilling pond at the gauging station. Sediment deposited around the tree was high in organic material, indicating that significant vegetative matter is naturally transported by rivers draining the wetter parts of the Licence Area. Peak concentrations (less than 100 mg/L) were, however, lower than occurred on catchments with clear felling activity.

The above discussion has been based on analysis of data to the end of 1978. Data from automatically collected samples during 1979 have only been analysed to September, and no detailed analysis has been carried out to date. Inspection of the data, however, indicates that both sediment yields and maximum concentrations have been lower than previous years. No concentrations in excess of 50 mg/L were recorded during the winter months of 1979 on any of the streams.

PROJECT 3 SUMMARY

1. Much higher mean annual streamflows per unit area occur in the high rainfall Dombakup Brook and Gardner River catchments compared with the lower rainfall Wilgarup and Perup River catchments.

2. Inter-related climatic, landform and vegetation characteristics of the region contribute to the higher rainfall areas producing the largest quantities of streamflow per unit area.

3. Over 50% of the Warren River salt load drains into the Licence Area via its Tone River tributary. A further 27% of the salt load is contributed from low rainfall regions within the Licence Area, where some permanent clearing exists but no clear felling for woodchips has yet taken place.

4. Long term water balances show that evapotranspiration in the low rainfall areas represents a smaller percentage of evapotranspiration potential than in the high rainfall areas. This indicates that the availability of moisture is limiting evapotranspiration.

5. Streamflow and salinity can vary dramatically from year to year. The largest variations in both flow and salinity occur on the partly cleared catchments in the low rainfall zone of the Licence Area.

6. Between 50% and 80% of the variation in annual salinity can be explained by variations in annual flow from forested catchments. Poorer correlations exist for partly cleared catchments.

7. Long term monitoring should readily detect changes in mean salinity of between 40 and 55 mg/L TSS on forested catchments.

8. Because of the highly variable data from partially cleared catchments, it is necessary to maintain records over more than 20 years in order to reliably identify trends in increasing salinity.

9. Annual sediment loads recorded to date have been very low by world standards, all being less than 8 tonnes per square kilometre.

10. The highest annual sediment loads occurred on the catchments where the highest proportion of clear felling had taken place (Dombakup Brook and the Weld and Gardner Rivers). These catchments also had the highest annual peak concentrations of sediment, being in excess of 150 mg/L.

11. The major portions of the annual sediment loads on Dombakup Brook and the Weld River tended to occur over 3 or 4 days of high flow in 1977 and 1978 respectively. High peak concentrations, however, did not occur in 1978 and 1979 after regeneration had been established. The daily concentrations outside these short periods of high sediment load were very low and were generally below 5 mg/L (the lower limit for accurate determination).

12. Catchments with significant agricultural clearing tended to have lower peak concentrations but a greater number of days with concentrations in excess of 5 mg/L.

13. The lowest sediment loads (less than 2 tonnes per square kilometre) and lowest frequency of samples with sediment loads greater than 5 mg/L occurred on catchments which had little or no clear felling activities or permanent clearing. There is some evidence, however, that natural sediment loads from these relatively undisturbed catchments are higher in the higher rainfall steeply dissected country than the lower rainfall regions where the relief is lower.

PROJECT 4 – Monitoring of Underground and Stream Water Using Selected Operational Coupes as Experimental Catchments

Chapter 6

CHAPTER 6

PROJECT 4 - MONITORING OF UNDERGROUND AND STREAM WATER USING SELECTED OPERATIONAL COUPES AS EXPERIMENTAL CATCHMENTS

The Project 4 studies began in 1975, their objective being to provide an early warning system of any effects that the heavy cutting practices used in the Licence Area might have on ground or stream waters. Four experimental catchments (coupes) were chosen so as to represent different conditions of rainfall, soils, and forest types (Figure 19 and Table 12). In each case the coupe covers between 100 and 200 hectares 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 streamflow, and boreholes to enable the measurement of groundwater changes.

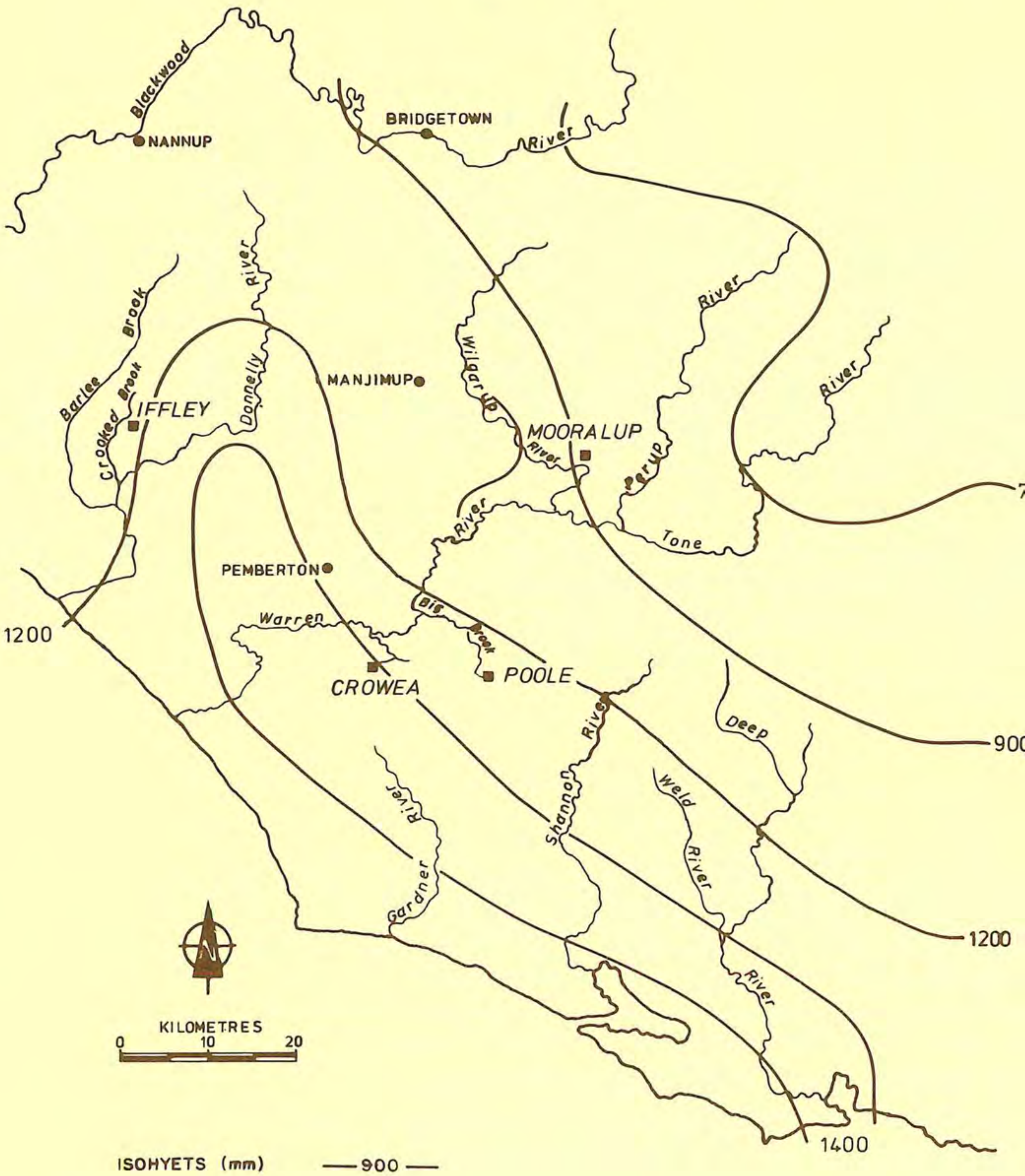
TABLE 12 SOIL AND FOREST TYPES AND RAINFALL DATA FOR THE PROJECT 4 COUPES

Coupe	Soil Types	Forest Types	Mean Annual Rainfall (mm)
Crowea	podzolics on upper slopes red earths in valleys	jarrah-marri karri	1380
Poole	podzolics red earths	jarrah-marri karri	1290
Iffley	laterites (extensive) red earths	jarrah-marri	1220
Mooralup	podzolics	jarrah-marri	900

Logging and Regeneration

All four coupes were cut during the 1976-77 summer, that is after at least one year of monitoring in each case. Crowea and Poole coupes, where karri had been the dominant species, were burnt in April 1978 and planted with karri seedlings in June 1978. Iffley and Mooralup coupes, where jarrah had been the dominant species, were burnt in November 1979 and are being allowed to regenerate from coppice shoots and lignotuberous advance growth.

The return of the vegetation in Crowea and Poole coupes has been monitored by means of ecological studies using both permanent quadrats and Levy point techniques. The former technique is best suited to record changes in composition, the latter to detect structural changes such as increase in height and density.



LOCATION OF THE PROJECT 4 COUPES

FIGURE 19

The return of the vegetation to the burnt areas was very rapid. Within a year, shrubs and herbs covered 60% of the surface and greatly reduced the risk of erosion. A highly significant proportion of the returning vegetation was legumes, (*Kennedya*, *Bossiaea*, *Acacia*) which can be expected to restore nitrogen removed in the logs and lost in the regeneration burns. The young karri trees had by the end of the first year, reached a height of 1 to 2 m. The stocking of young karri trees is uniform over the entire logged area, and given adequate protection from fire during the vulnerable early stages, a dense stand of karri appears to be assured.

Measurements 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 streamflow 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 sample different topographic locations. A further two boreholes have been located close by but outside the actual coupe area 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 groundwater samples is measured using a conductivity meter and the sediment load is estimated by filtration on an 0.45 micromillimetre (μm) millipore filter.

RESULTS

Rainfall

Analysis of rainfall data for the three long term recording centres nearest to the experimental coupes (Nannup, Pemberton and Manjimup) clearly shows that rainfall in the area for 1975-77 and 1979 has been below the long term average (Table 13).

TABLE 13 ANNUAL RAINFALL (mm) AT LONG TERM RECORDING CENTRES IN THE LICENCE AREA

	NANNUP	PEMBERTON	MANJIMUP
1975	851	1117	922
1976	832	1124	1022
1977	739	984	898
1978	960	1170	1052
1979	553	1009	894
LONG TERM AVERAGE	985	1258	1066

The within-coupe rain gauges used in this study have revealed an increase of approximately 10% in the amount of rainfall reaching the ground after cutting reduced interception by tree crowns (Kelsall Steering Committee 1978). This agrees well with local (Butcher 1977) and Eastern States studies (Smith 1974) of eucalypt and pine stands.

Groundwater Levels

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 recorded was a sharp rise at the beginning of winter to reach a plateau which lasted until summer when a steady fall started.

Mean groundwater levels increased in all four coupes following cutting while mean levels in the control boreholes remained relatively static over the same period (Figure 20).

As a broad generalisation, groundwater tables rose much more rapidly in bores situated in the high and intermediate rainfall zones (Crowea, Poole, Iffley coupes). The changes were apparent within a few months of cutting. By contrast in the Mooralup coupe bores, situated in the low rainfall zone, the changes did not become apparent until May-June 1978, one year after the completion of logging. The rises ranged from 2 m in Poole and Crowea coupes down to 1 m in Iffley coupe and only a few centimetres in Mooralup coupe.

The patterns observed in the Licence Area parallel patterns observed in areas cleared for agriculture (Greenwood 1979) and bauxite mining (Hunt Steering Committee 1978). On this basis it may be expected that there will be a drop in groundwater level as regenerating vegetation recovers its original leaf area, which may take as little as 5 years (Carbon and others 1979).

Streamflow

The volumes of monthly rainfall and monthly streamflow for each coupe are illustrated in Figure 21.

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 of streamflow in the interval. Herbert and Ritson (1976) have shown that if measurements are taken three times per week a reasonably accurate, though conservative, estimate of streamflow is obtained. Since 1977 the streamflow has been 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 rainfall of similar magnitude in both years. The streamflow increased still further in 1978, as the rainfall that year was higher than in the two preceding years. The effect persisted into 1979 which was a dry year. Despite a lower rainfall, the streamflow was comparable to 1977.

To clarify the situation regarding streamflow before and after cutting, streamflow is expressed as a percentage of nett rainfall (throughfall as measured from beneath canopy rain gauges) in Table 14. A similar trend was evident in all four coupes. Streamflows accounted for a relatively small percentage of the rainfall input in 1976. A large increase was recorded in 1977, the year of cutting, and a further increase in 1978, probably associated with the higher rainfall that year. The percentages remained at a high level in 1979 when a low rainfall was recorded but they were below the 1978 level. It appears that following the cutting of trees in the coupes in the summer of 1976-77, the reduced interception and evapotranspiration resulted in a greater proportion of the incoming rainfall becoming streamflow.

TABLE 14 STREAMFLOW AS A PERCENTAGE OF NETT RAINFALL

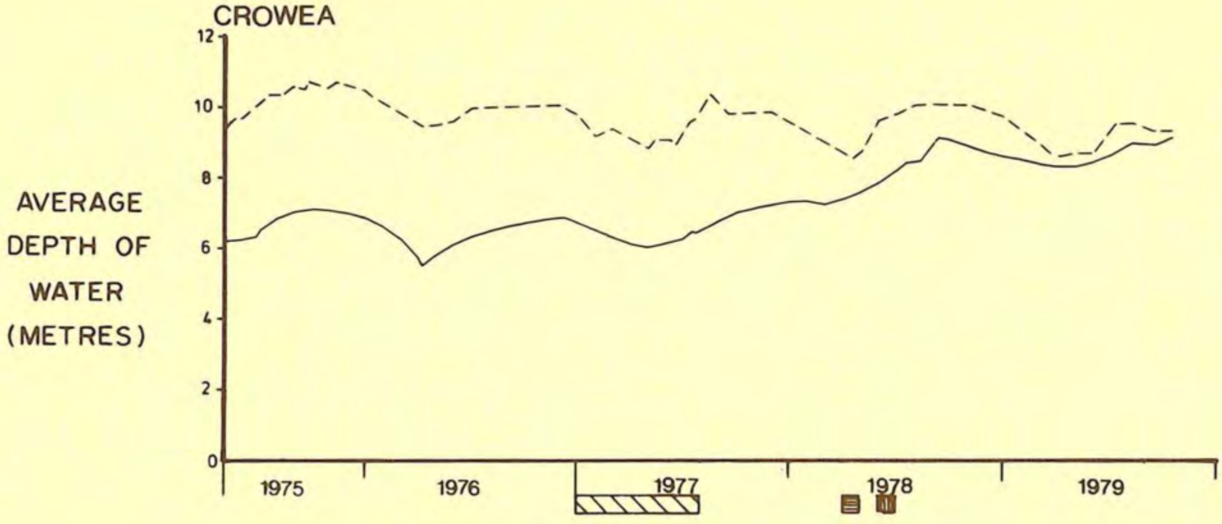
	IFFLEY	CROWEA	POOLE	MOORALUP
1976	7.6	13.3	4.7	0.01
1977	12.8	24.4	8.9	0.70
1978	25.5	35.9	34.2	4.20
1979	20.6	30.1	24.2	0.03

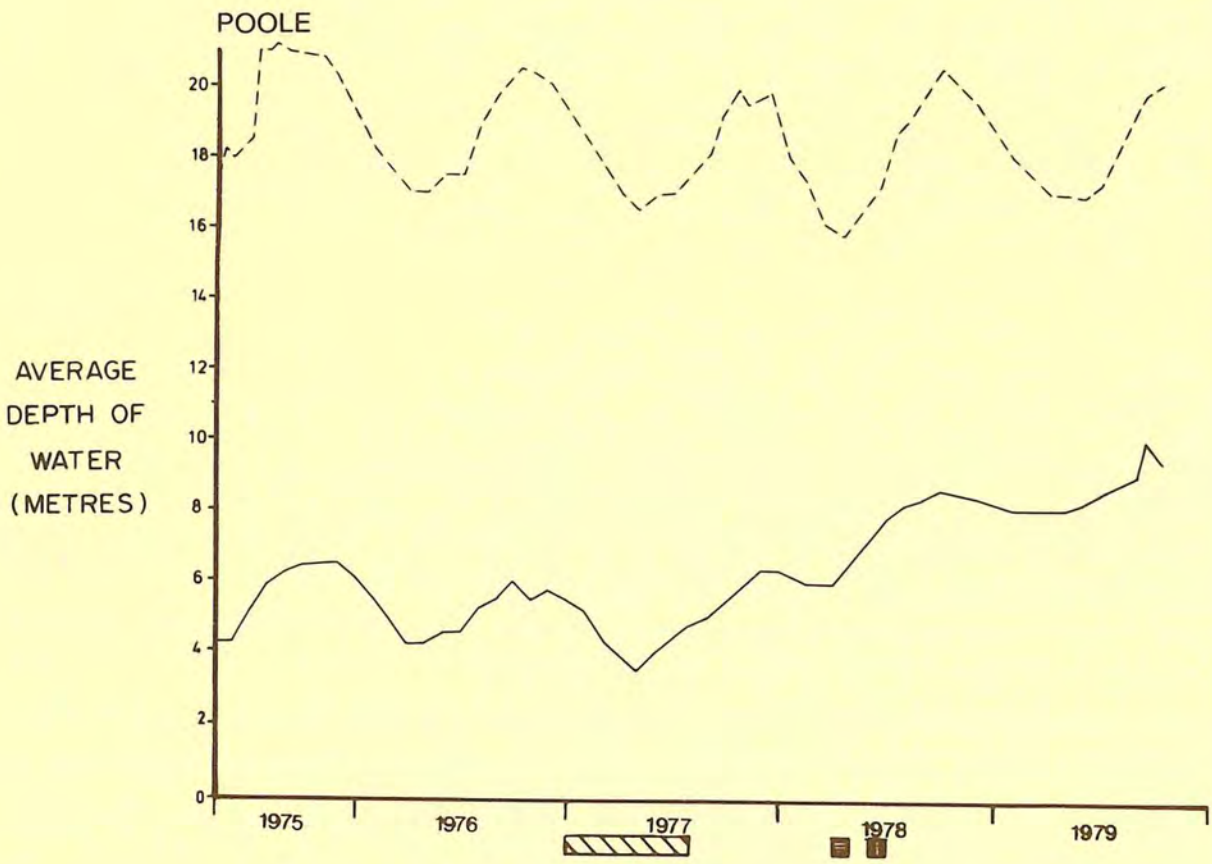
The responses were to some degree influenced by the topography and climate characteristic of the individual coupes. The Iffley and Crowea coupes, which combine medium to high rainfall with a moderately strong dissection of the landscape, had a regular run-off response even before cutting. In the more mildly dissected Poole and Mooralup coupes the response was initially less regular. Following the cutting, the run-off response became regular in Poole coupe, which falls into the intermediate rainfall zone, but remained very variable in Mooralup coupe. It is probable that in Mooralup coupe, the situation is similar to the Yerraminnup catchments studied in Project 2, namely that both stream and ground flow are minimal because the evapotranspiration uses up the bulk of the incoming low rainfall. As a result, the surface streams flow only during and following periods of intense rainfall.

There was, however, the possibility that part of the outflow from the Mooralup catchment was in the form of a subsurface flow. To clarify this point, additional seismic studies were carried out. These indicated that the gauging station was underlain by solid rock at shallow depth, and that the risk of subsurface flow is not great.

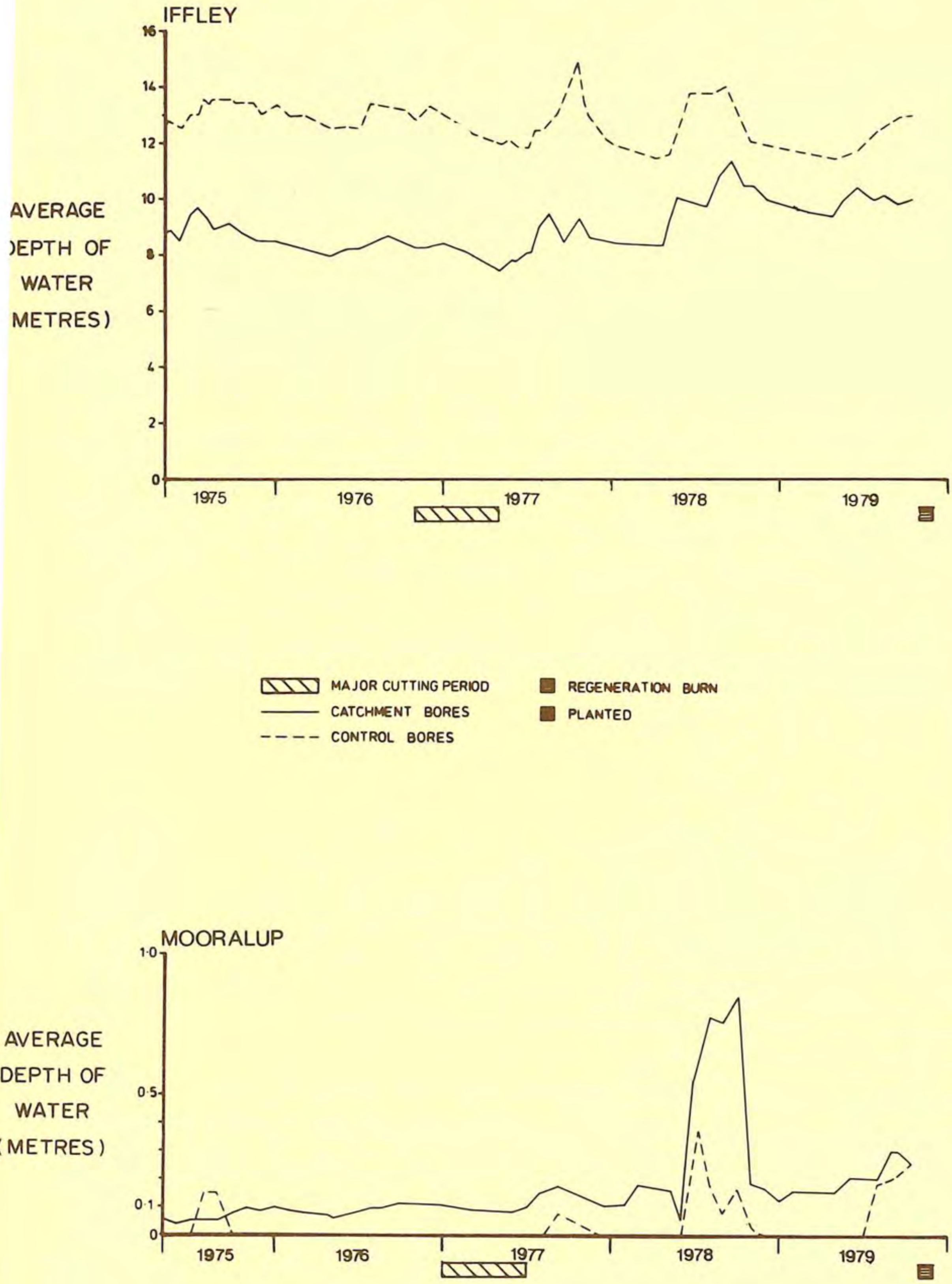
Salinity

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



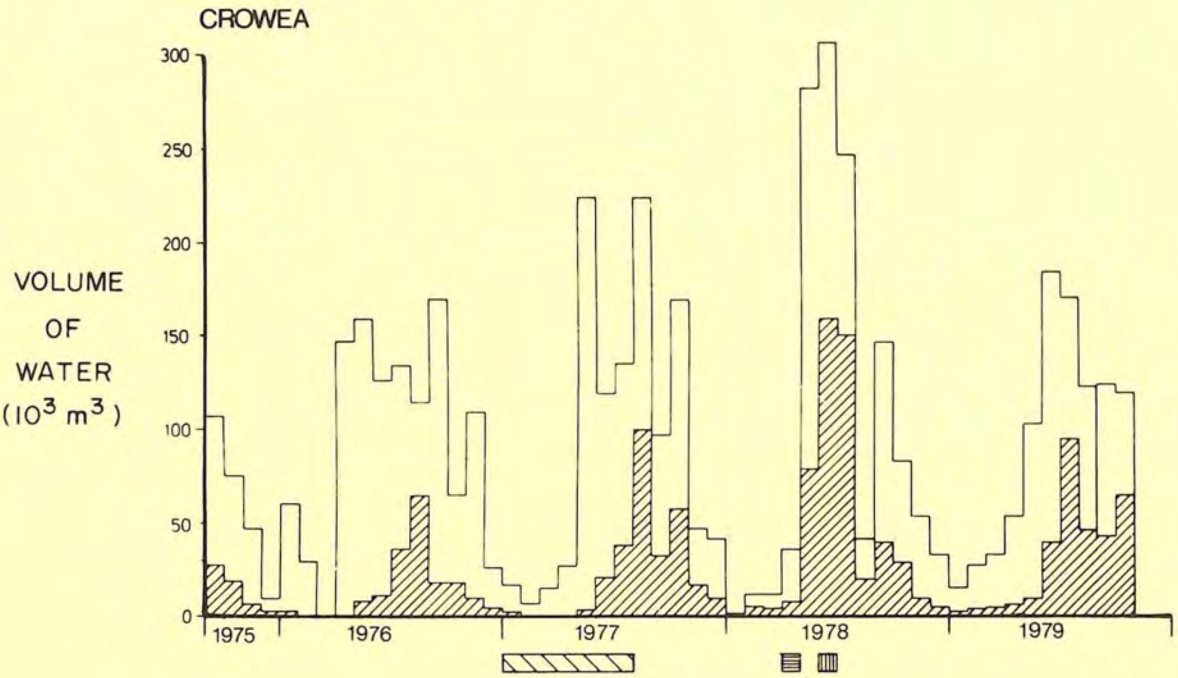


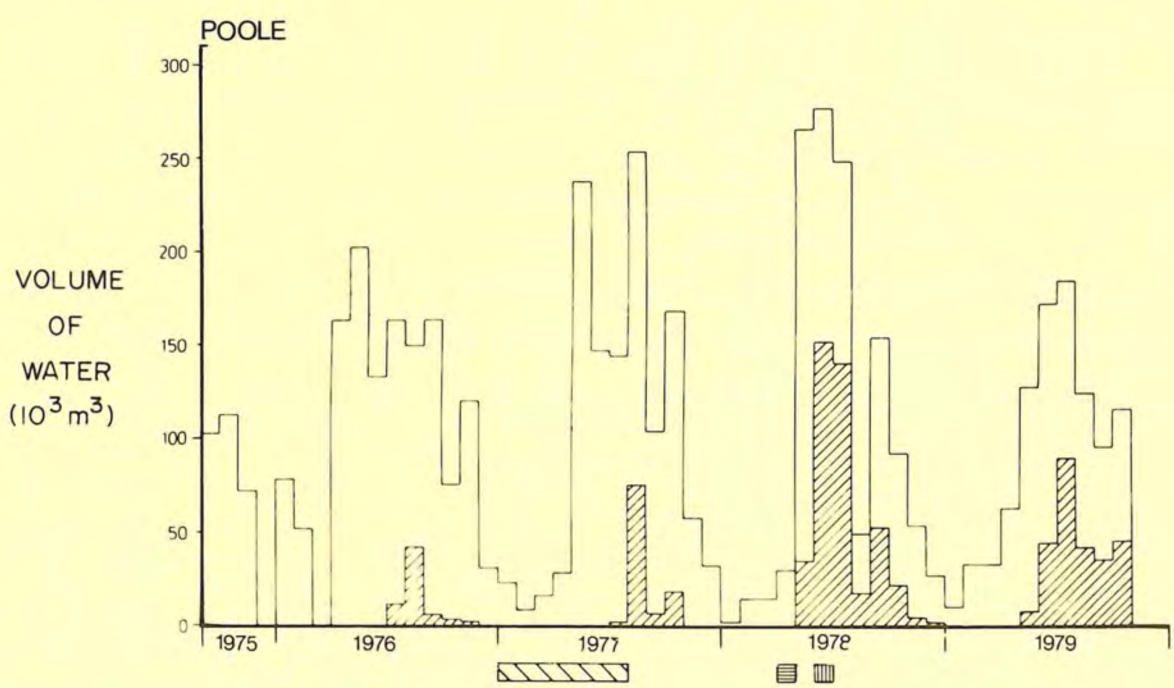
CHANGES IN PROJECT 4



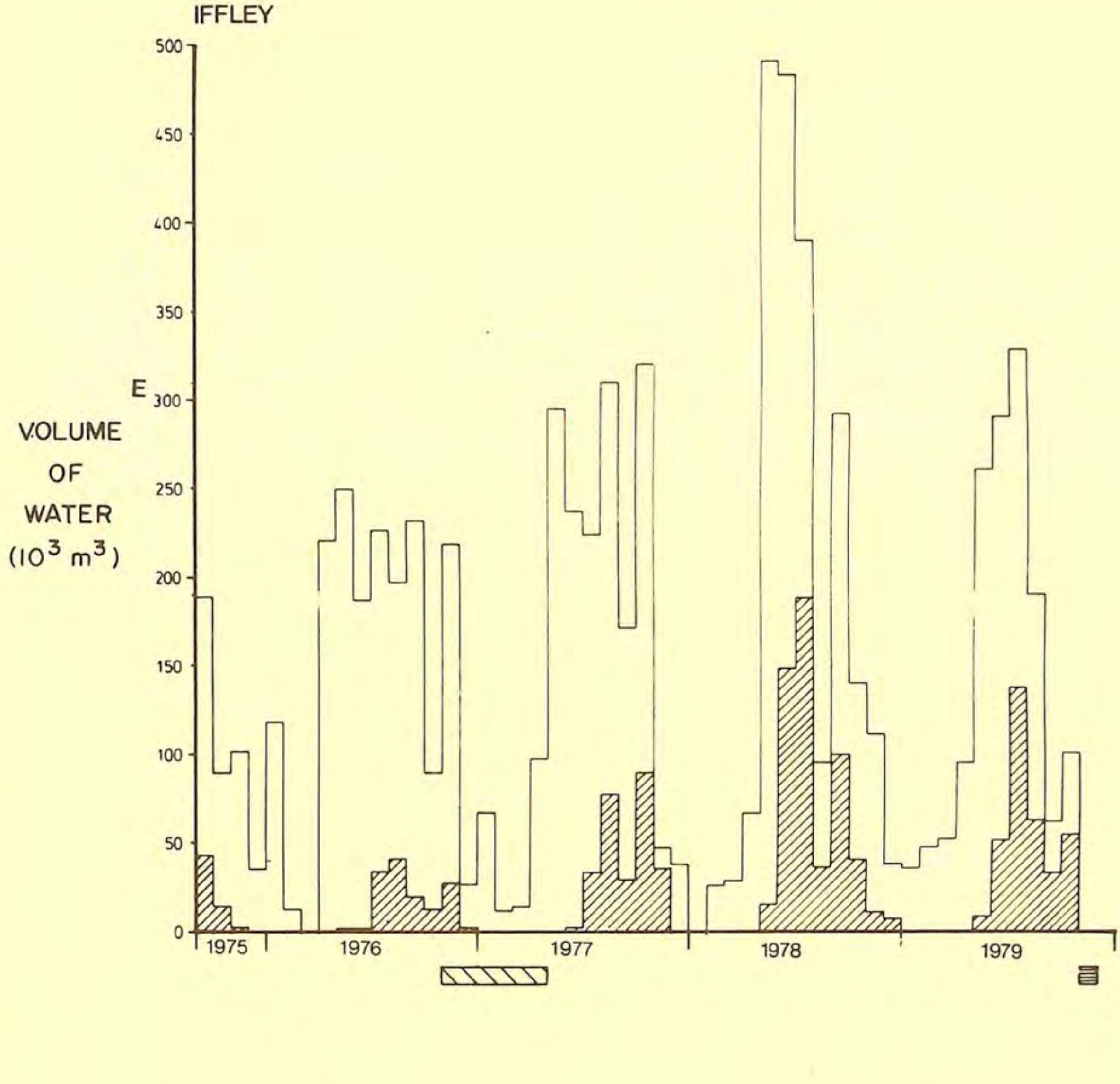
GROUNDWATER LEVELS 1975–1979

FIGURE 20





VOLUMES OF MONTHLY RAINFALL AND STREAMFLOW



IN PROJECT 4 COUPES 1975–1979

FIGURE 21

As with the analysis of groundwater levels, the interpretation of groundwater salinity is complicated considerably by the variations observed between boreholes (Figure 22).

Following the cutting of the forest in the summer of 1976-77 the salinity of water in the bores was reduced in the two jarrah coupes (Iffley and Mooralup) while in the karri coupes (Crowea and Poole) there was no clear-cut trend. The results from the first two coupes imply either a leakage from perched water tables or increased infiltration. To which degree either process is involved is the subject of further study.

Stream water salinity and total salt flow are presented in Figure 23 and mean weighted salinity in Table 15.

TABLE 15 MEAN WEIGHTED STREAM SALINITY (mg/L TSS)

	IFFLEY	CROWEA	POOLE	MOORALUP
1976	372	143	103	No flow
1977	334	151	114	131
1978	292	169	138	110
1979	442	199	201	131

In Iffley coupe the total salts exported increased in 1977, following cutting, increased again in 1978 and fell in 1979 to a level that was still higher than the pre-cutting export figure for 1976. Mean weighted stream salinity fell in 1977 and 1978 due to streamflow increases that were greater in proportion than the increases in salt export, but increased in 1979, probably due to the low rainfall of that year.

Minimum salinity levels, which generally occurred at periods of maximum streamflow, fell from between 200 and 300 mg/L prior to cutting to between 150 and 250 mg/L in the two years after cutting. Maximum salinity levels, coinciding with minimum streamflow, increased in this period. This increase almost certainly results from an increased contribution to streamflow of the deep groundwater. Because the associated streamflow is small, the salt flow is probably not significant.

Following cutting of Crowea coupe the total salt export increased and mean weighted stream salinity rose from around 150 mg/L through 160 to 199 mg/L in 1979. Minimum salinity levels differed little before and after cutting, while maximum concentrations showed a distinct rise from 1977.

Poole coupe showed a similar pattern of events to those at Crowea coupe except that mean weighted salinity of the streamflow rose only slightly in the first one and a half years after cutting but it rose significantly in 1979 as in Iffley coupe. Again the low 1979 rainfall may be implicated.

Streamflows at Mooralup coupe were intermittent both before and after cutting. The one exception was 1978, the first year after cutting, which coincided with the highest rainfall recorded during the period of this study. Salinity levels fluctuated very little both within and between years, and salt exports appeared directly related to the quantity of streamflow, from the limited data available.

Reviewing the data given above it is clear that Iffley coupe shows anomalously high levels of salinity of streamflow for the rainfall zone in which it occurs. Johnston and others (1980) have previously identified an anomalously high level of storage of soluble salts in this catchment. Similarly, the low level of 130 mg/L reported for Mooralup coupe in the low rainfall zone also appears anomalous, but is not unusual in catchments of comparable size and position where surface and shallow sub-surface flows of relatively salt-free water contribute the bulk of the streamflow.

The data from Iffley coupe in particular emphasise that stream salinity is not related simply to the average 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 and others (1980) still hold, it is to be noted that departures from this trend can be expected when smaller catchments are investigated in detail.

The total salt flow in all coupes was slightly greater in 1977 than in 1976, and was considerably greater in 1978 and 1979. This effect is largely due to increased streamflow alone in Mooralup and Iffley coupes and to a combination of increased streamflow with somewhat higher salinity in Crowea and Poole coupes.

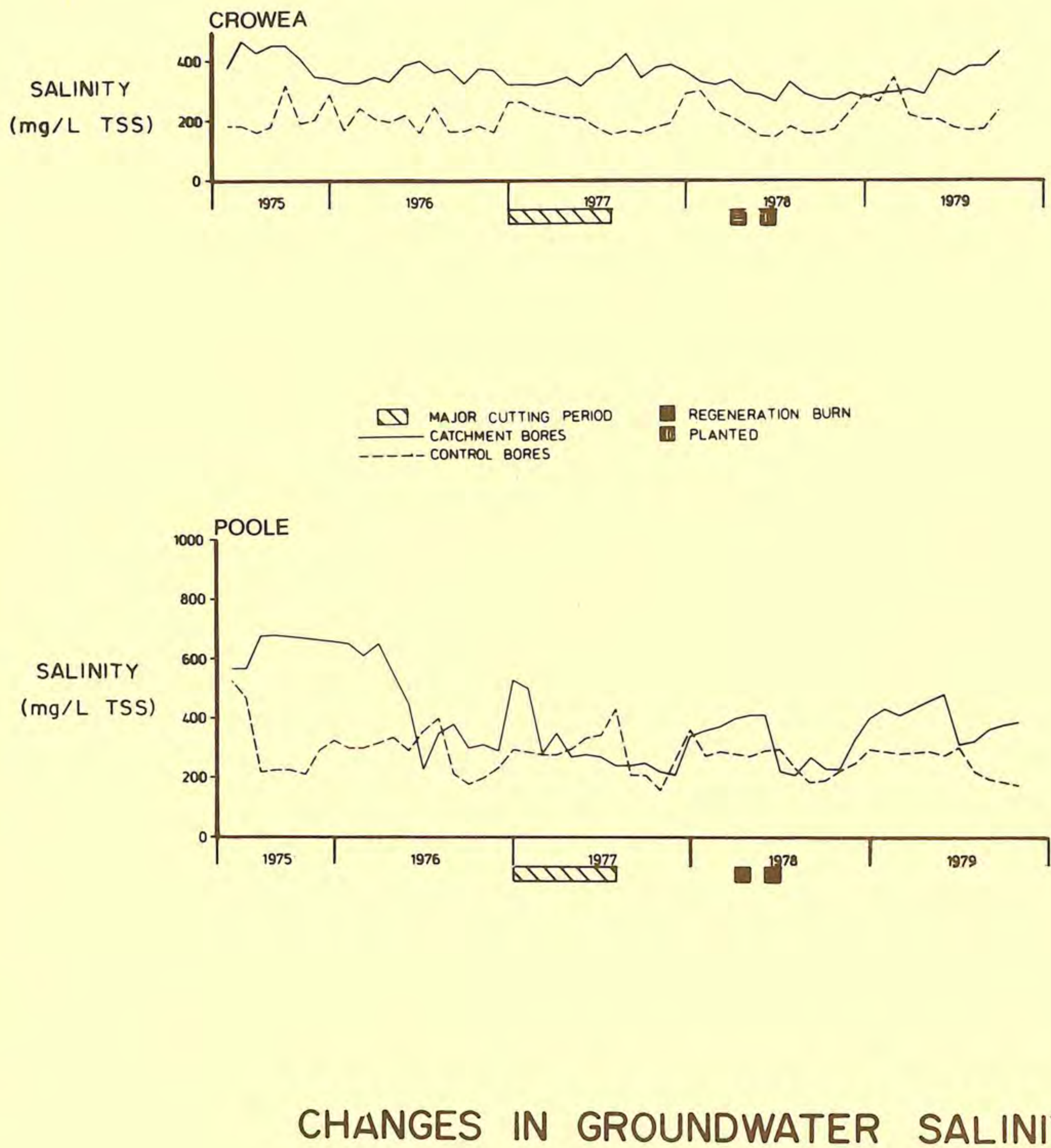
Stream Sediment Levels

Measures of sediment levels in the stream waters were made weekly, commencing in Iffley, Crowea and Poole coupes in 1976, and in Mooralup coupe in 1977. The data are presented in Figure 24.

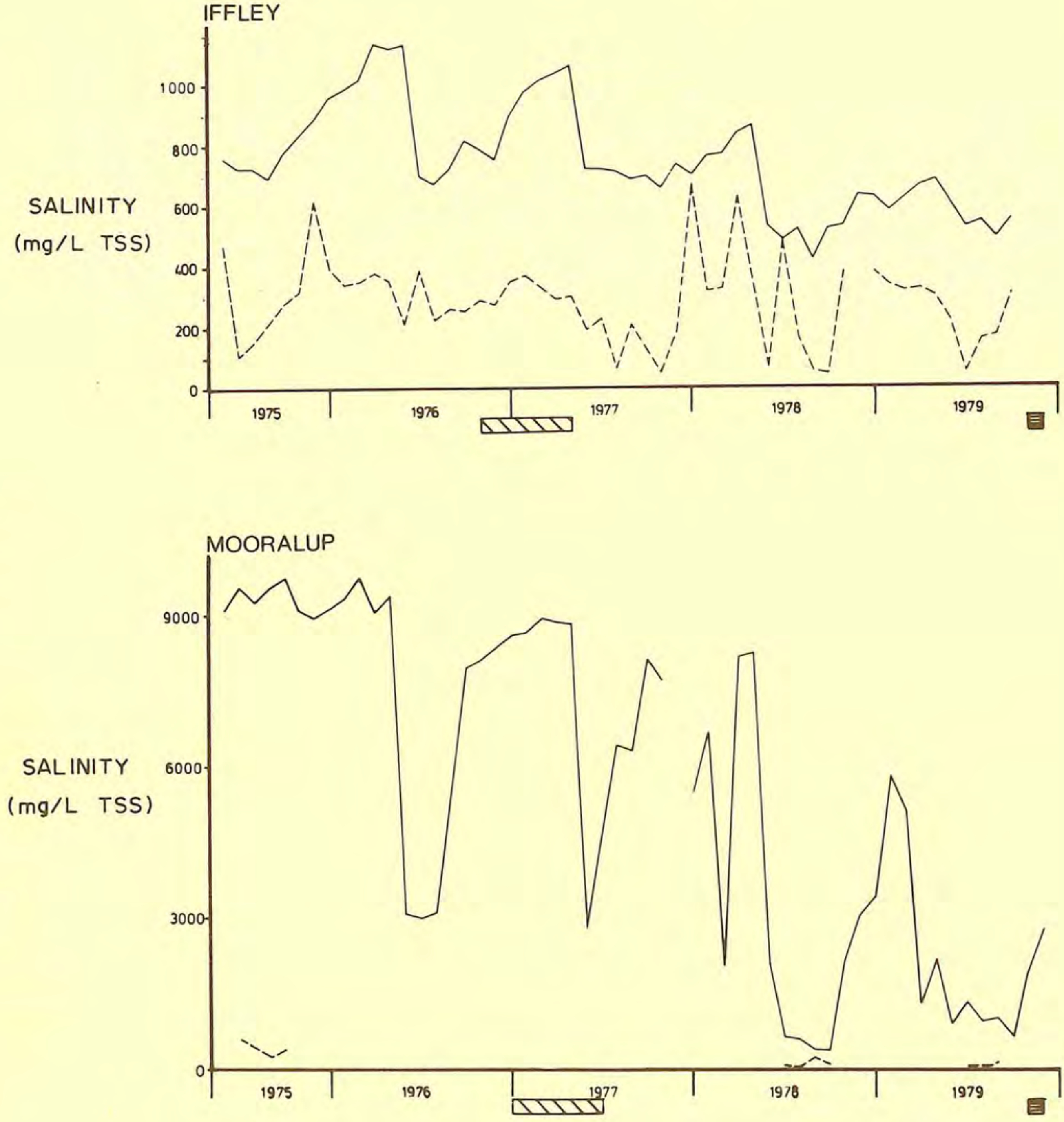
In Iffley coupe higher maximum levels of sediment in stream water were recorded in 1977 to 1979 than before cutting in 1976.

In Poole and Crowea coupes there was no change in maximum sediment levels following cutting.

All four coupes, however, carried more sediment for a longer period in streamflow following cutting, indicating an increase in sediment exports. Estimates of annual sediment exports in stream water for the four coupes are shown in Table 16. With the exception of Mooralup coupe, where sporadic streamflows made the assessment of cutting effects difficult, there was a strong trend to increased exports of sediments following cutting, the highest level being reached in 1978 in which was recorded the highest rainfall and greatest streamflows during the study. The high sediment level recorded for Poole coupe in 1976 was probably due to sediment run-off from earth works, during weir construction.

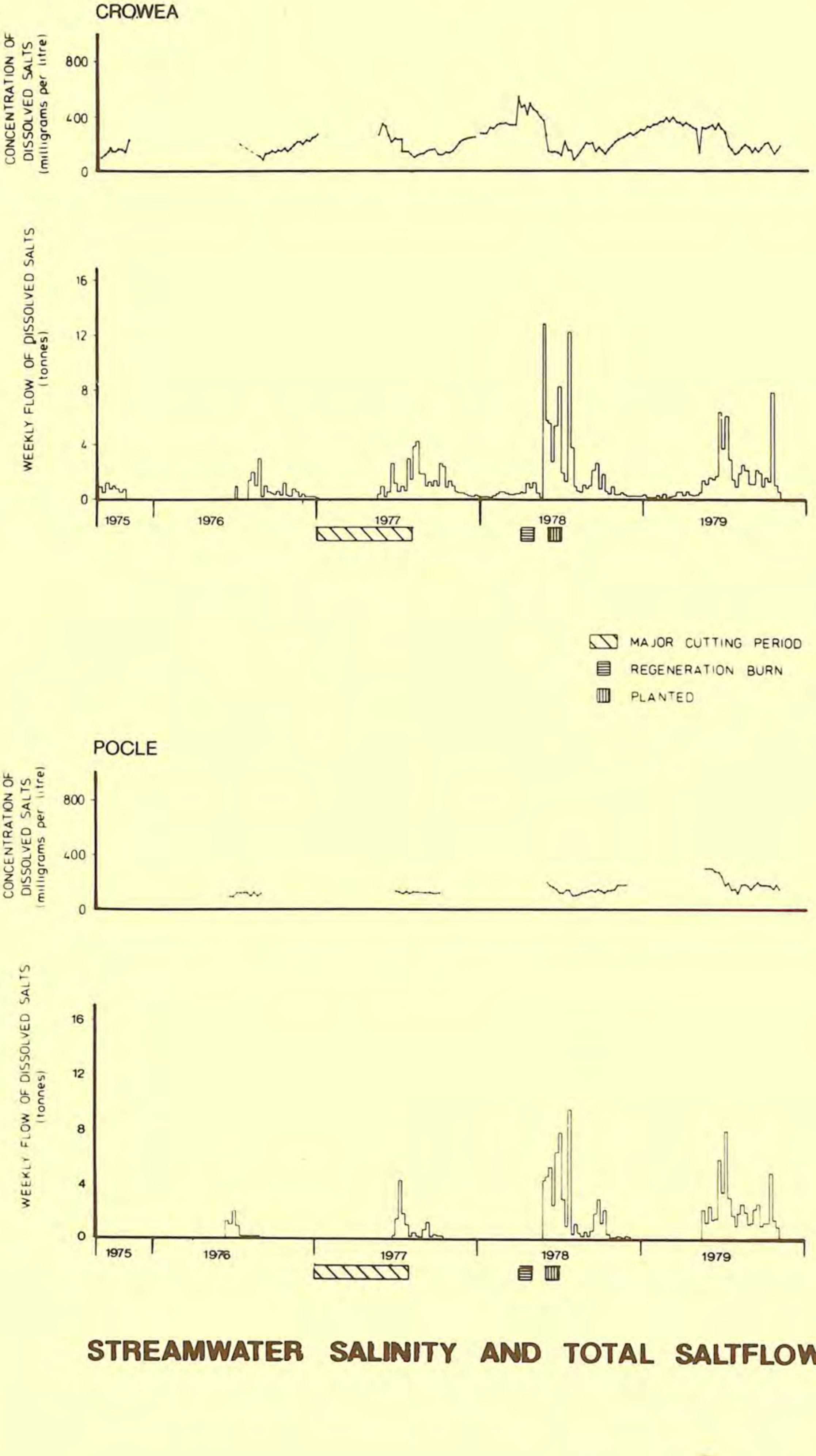


CHANGES IN GROUNDWATER SALINITY

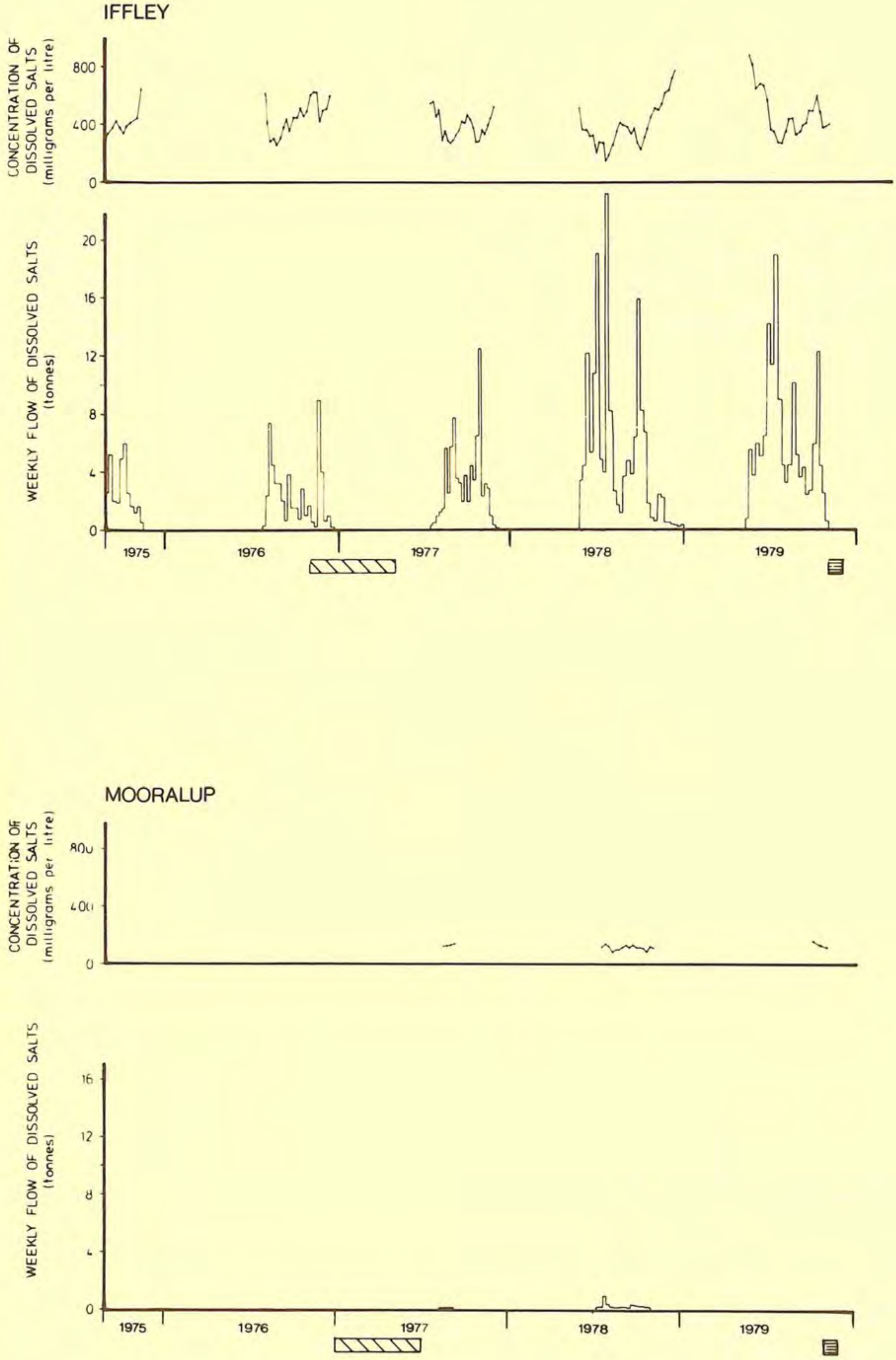


IN PROJECT 4 COUPES 1975–1979

FIGURE 22

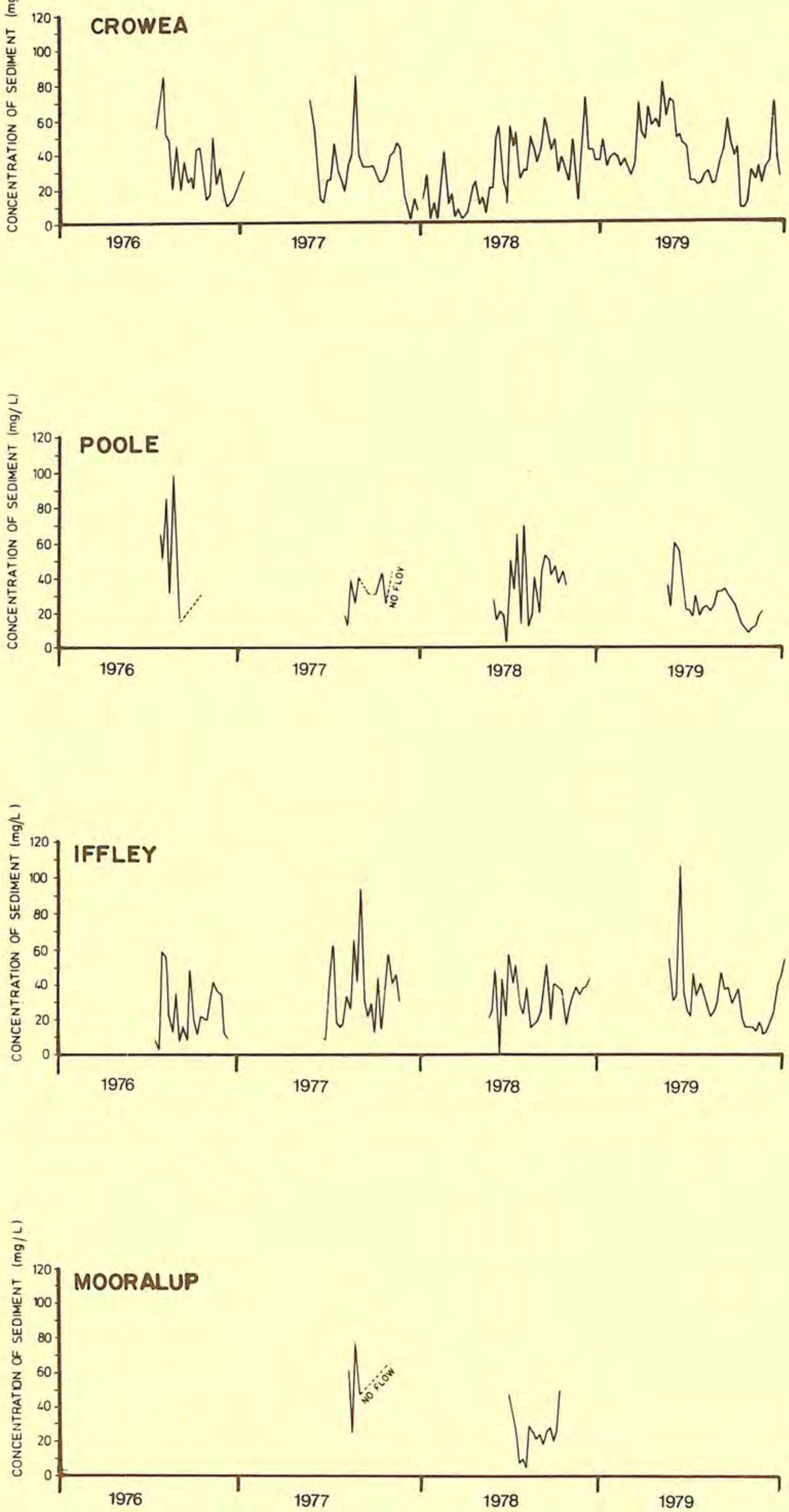


STREAMWATER SALINITY AND TOTAL SALTFLOWS



FOR PROJECT 4 COUPES 1975—1979

FIGURE 23



STREAMWATER SEDIMENT CONCENTRATIONS

FOR PROJECT 4 COUPES 1976—1979

FIGURE 24

TABLE 16 EXPORT OF SEDIMENTS (10^3 kg/km^2) IN STREAM WATER FROM THE PROJECT 4 COUPES

	IFFLEY	CROWEA	POOLE	MOORALUP
1976	2.2	5.1	3.1	N/A
1977	4.0	9.8	1.8	1.2
1978	9.9	17.2	10.7	6.8
1979	6.1	9.9	5.5	0

In addition to monitoring at the four Project 4 coupes, measurements of suspended sediments in streams entering and leaving coupes cut in the winters of 1976 and 1977 were determined by Whitely (1978).

There was a marked variation in the "natural" sediment concentration of the streams studied, varying from 6 mg/L to 128 mg/L. Where there was an increase passing through the logging area, the sediment loads generally returned to the "natural" level within about 2 km downstream.

It was noticable in most coupes that the "natural" sediment load increased upstream from the coupes during wet weather. As this cannot be attributed to logging, some erosion obviously takes place even in undisturbed forest.

In 1976, three of the eight coupes studied showed increased sediments immediately downstream from the logging area. In two coupes the increase was very slight and in the third it was considerable.

The 1977 studies on six coupes gave a somewhat different picture. In dry weather two of the six coupes showed an increase in sediment concentration, but in wet weather this increased to four coupes.

It is evident that logging, particularly during rainy periods, results in greater quantities of sediment reaching the streams in some logging coupes. Why some coupes should show more sediment losses than others is not clear. The differences may be due to the proportion of steep country in certain coupes or to variation in soil properties and logging techniques.

PROJECT 4 SUMMARY

The results to date, which are based on a part season (1975) and the full winter season (1976) prior to cutting and three full winter seasons (1977-1979) following cutting, may be summarised as follows :

1. With the exception of 1978 which was slightly above average, the total rainfall throughout the study area has been below the long term average. More rainfall reaches the soil surface after logging as there is little or no interception by tree crowns.

2. There has been a rise in water table since logging, which ranges from a few centimetres at Mooralup (drier jarrah) coupe, around 1 metre at Iffley coupe, to around 2 metres at Poole and Crowea (wetter karri) coupes.

   This corresponds to similar observations made by the Hunt Committee (1978) in areas mined for bauxite. Water tables can be expected to fall as the logged areas become increasingly revegetated.

3. As expected, streamflow has increased since logging in all four coupes studied. The increase is attributable to increased throughfall following the reduction in the overstorey, and to reduced transpiration.

   There is also some indication of a more rapid response of streamflow to rainfall fluctuations.

4. The total salt flow has increased in all four coupes. This is more attributable to increased streamflow than to increased salinity. In fact, in the winter periods of high flow stream salinity levels have tended to fall since logging. On the other hand the summer levels have increased, but because the associated flow is low the contribution to total salt flow is relatively small.

5. The export of sediments in stream water increased following logging in all four coupes, peaking in 1978 and falling during 1979. This fall is attributable to a combination of lower rainfall and increasing vegetation cover.

   Steps have been taken to counteract this by avoiding logging of erosion-prone catchments during wet periods.

DISCUSSION

Chapter 7

CHAPTER 7

DISCUSSION

A greater understanding of the hydrologic characteristics of catchments in the forested regions of the South West has developed over the last ten years. This growth in knowledge has come from the projects described in the previous four chapters, from similar research projects associated with the effects of agricultural clearing and bauxite mining, and through regional information collected under the State's Water Resources Assessment Programme. In discussing current knowledge as it affects the operations of the woodchip industry experience gained from all these studies is included.

Salinity Risk Areas

The clear felling and regeneration operations can only have a deleterious effect on stream salinity in areas where sufficiently large quantities of soluble salts are present in the landscape. It is possible that some of these salts could be transported to the stream system during the years of reduced transpiration, immediately following clear felling, causing significant stream salinity increases. The drilling programme for salt storage in the Licence Area (Johnston and others 1980) and studies under Project 1 have concentrated on identifying these high risk areas. From this drilling programme and other drilling work in the Darling Range (Stone and others 1980), a regional picture of salt storage has developed which is described below.

Major accummulation of salts have occurred in the lateritic subsoils of the inland Darling Range where the average annual rainfall is less than 900 mm. In these areas average soil solute concentrations are invariably over 2000 mg/L TSS and can be in excess of 20 000 mg/L TSS.

Some 80% of the Warren River Salt load currently comes from these partially cleared low rainfall areas (Project 3). Because of the decision in the original Environmental Impact Statement to restrict clear felling in the north east sector, plus the effect of clearing controls introduced in the Warren River catchment by the Amendments to the Country Areas Water Supply Act (1978), no woodchipping activities are currently permitted within the salt-sensitive north-east sector of the Licence Area bounded by the 900 mm isohyet (i.e. within the low rainfall zone). Clear felling activities should not be permitted in that zone until research results indicate that it is safe to do so on potential water supply catchments.

Prior to clearing, the groundwaters in these salt-laden subsoils are characterised by their limited area, their great depth below the surface and their high salinity. Because the groundwaters rarely have an outlet to the surface stream system, salts which enter the subsoils via infiltration of water from shallow soils have tended to accumulate at depth. Most of the infiltrating water is returned to the atmosphere by transpiration of the deep-rooted tree species leaving the salts behind.

In contrast, in areas where annual rainfall is above 1200 mm, subsoil groundwaters are more extensive and usually discharge to the surface stream system. They therefore provide a means of transmitting salts through the landscape and large accumulations of salts in the subsoils have not generally occurred. As discussed below, there are some local conditions in the high rainfall area conducive to salt accumulation. However, there is evidence that many high rainfall catchments are, in fact, losing salts from their landscape (Project 3; Williamson and others 1979; Department of Agriculture 1974; Peck and Hurle 1973). In bauxite mining areas of the Darling Range, average soil solute concentrations rarely exceed 500 mg/L TSS in regions of annual rainfall over 1200 mm (Johnston and others 1980) In similar rainfall zones of the Licence Area, average soil solute concentrations are 2 to 4 times higher but are still significantly lower than levels encountered in rainfall zones below 900 mm per annum (Stone and others 1980). The higher average salt storage values quoted for the high rainfall zone of the Licence Area are a reflection of the high figures for the Lewin catchments and particularly Iffley coupe. Although large variations occur at a local site scale, the figures obtained for the Iffley coupe cannot be explained by sampling bias alone.

Two distinct geological formations have been identified in Iffley coupe, which indicate sediment deposition over the granitic basement on the western edge of the catchment. The significance of these sediments to salt storage within the coupe as a whole is unknown, but drilling the sediments has revealed much lower figures (Furness 1980). Because of these geological differences, the sub-soil characteristics of Iffley coupe are considered atypical of the high rainfall Darling Range region. Attempts to explain the large variations in soil solute concentrations which occur at the local scale have usually shown that concentrations in the valley floors are higher than those in the divides (Johnston and others 1980), although the reverse was noted in one case (Herbert and others 1978).

Differences in sub-surface soils and geology as well as surface topography, combine to produce local conditions which may either assist accumulation or assist leaching of salts at a particular site. Because of these complex site specific differences, it is unlikely that any accurate prediction of soil solute concentration at a point will be possible.

The transition from the high rainfall salt leaching areas to the low rainfall salt accumulating areas is similarly complex. As shown in Project 2, small differences in the groundwater regime of the Sutton Group of catchments can significantly influence the stream salinity pattern and the catchment salt balances. Some of the difficulties of obtaining high correlations of surface landform characteristics with salt load and salinity data in Project 1, are no doubt related to unmeasured variations in geology and groundwater characteristics, as well as the problems of inter-correlation of land use and landscape variables. It is currently considered that the prediction of salt storage data, from annual average rainfall and surface topographic features, will always remain an uncertain procedure at the small catchment scale. This is principally because the geology and soil types at depth are unknown and appear to play an important role in affecting local salt storage.

As noted in Projects 1 and 2 and other stream sampling programmes carried out by the Public Works and Forests Departments, streamflow salinity in excess of 500 mg/L TDS, and on some small catchments in excess of 1000 mg/L TDS, can occur where permanent clearing has taken place in the 900 to 1100 mm rainfall zones. Undisturbed forested catchments in similar rainfall zones, have mean annual salinity levels which are generally less than 250 mg/L and invariably less than 500 mg/L TDS (Public Works Department 1977).

In contrast, forest logging activities followed by successful regeneration in the intermediate rainfall zone, have not caused measurable increases in stream salinity. The catchments of Tanjannerup and Millstream Brooks, tributaries of the Blackwood River with mean catchment rainfalls of approximately 1000 mm, were heavily logged following the First World War and unwanted species and poor quality stems removed during the 1930s. Successful regeneration has occurred and mean salinity levels in the 1950s and 1960s were below 250 mg/L, TDS (Department of Agriculture 1974). For more than 20 years, these two streams have been the sources for Nannup and Bridgetown water supplies, which are amongst the freshest in the State.

Similarly, logging from the 1950s and subsequent regeneration in the 900 to 1100 mm rainfall zone of the upper Shannon and Deep River catchments has not caused any measurable salinity changes (Project 3; Public Works Department 1980) in those areas.

The temporary nature of the reduced transpiration demand, and therefore of the risk to salinity increase as a result of forest operations compared with permanent clearing, has also been highlighted by a study carried out by CSIRO on the leaf areas of different aged forest stands in the Manjimup Region (Carbon and others 1979). It has been shown that regeneration following clear felling can establish leaf areas similar to mature forest types within five years.

Changes in Groundwater

Discussion here is based primarily on results from Project 4 (see Chapter 6), as groundwater responses from Project 2 (see Chapter 4) have only identified pre-treatment groundwater characteristics. Significant increases in the level of sub-soil groundwaters have been identified on three of the coupes following clear felling and small increases were apparent on the remaining (low rainfall) Mooralup coupe. As regeneration commenced only two years ago, no reductions in groundwater levels have been noted to date. Leaf area studies noted above suggest that groundwaters could be expected to rise for a period of up to 5 years before any levelling off was observed. Increases in the stream salinity of low flows on Iffley, Crowea and Poole coupes suggest increased groundwater discharge to the stream. Observation of increased seepages, more rapid response to rainfall and lower salinity levels at peak flow rates also suggest significant changes in the shallow soil moisture regime.

Changes in Stream Flow and Salinity

Significant increases in streamflow have occurred since clear felling (see Chapter 6). The increased rate of response to rainfall and observations of increased seepage following clear felling, suggest that increases have mainly occurred at high flows. Experience from the Collie catchments suggests that much of the increased flow has been generated from precipitation on, and drainage from, much larger areas of saturated shallow soils extending upslope from the streamline. Accurate assessment of changes in streamflow from the Project 4 catchments is complicated by the lack of control catchments and the dry year of 1979. More accurate assessments will be possible when Project 2 catchments are clear felled.

Increases in the annual flow weighted average stream salinity on Iffley, Crowea and Poole coupes in 1979, reflect both increased groundwater response and the effect of the dry year of 1979. While these effects cannot be effectively isolated, it is clear that the changes in salinity are not dramatic, particularly when considered in the context of natural stream salinity variation between drought and flood years. The largest increase in annual salinity was on Iffley coupe where the mean and variability of salinity in the pre-clearing state was highest and salt storage is anomalously high for its rainfall zone. As noted above, the small groundwater responses in Mooralup coupe, reflect the limited available water to recharge groundwaters in the dry 1979 year on this lower rainfall coupe. It is conceivable that in these low rainfall regions where groundwaters are often well below the surface, the regeneration may result in sufficient water consumption before saline groundwaters could rise and intersect the soil surface. It follows that if regeneration is rapid there may be no measurable increases in stream salinity in the high salt storage zone, while small increases may occur temporarily in intermediate rainfall areas of moderate salt storage, where groundwaters are closer to the surface stream prior to clear felling. Because of the very high salt storages and the consequences if saline discharges did occur from the low rainfall areas, no such conclusion should be drawn until the trial clear felling and regeneration has been carried out at Yerramminup Creek (Project 2) and the results thoroughly studied.

Sediment

Regular sediment monitoring was not carried out before 1976 in the Licence Area, so the sediment loads before the recent clear felling programme commenced are not well known. As discussed in Chapter 5 (Project 3), sediment loads measured to date range between less than 2 and less than 8 tonnes per square kilometre. These sediment loads are very low by world standards. Most quoted sediment loads are over 100 tonnes per square kilometre (Vanoni 1975) as lower sediment loads rarely pose engineering problems and therefore have rarely been monitored in detail. The range of sediment yields possible is highlighted by a study of 253 stations in the Upper Mississippi Basin, where yields ranged between 5 and 2500 tonnes per square kilometre (Inter-agency Task Force 1967). Sediment yields from the Ord River catchment are approximately 600 tonnes per square kilometre.

Differences in sediment yields are a consequence of differences in soil type, topography, vegetation, rainfall and land use. Forested catchments are among the most stable of landscapes but even here the loads obtained under Project 3 are low. For example, undisturbed humid catchments under tropical forest in Kenya and Eastern Australia recorded minimum loads of 20 to 30 tonnes per square kilometre. Although the sediment yields are low, some evidence exists to suggest that natural loads are higher in the higher rainfall steeper sections of the Licence Area (Project 3). In addition, changes in the sediment behaviour after clear felling have been noted in Projects 3 and 4. Following clear felling, sediment yields from the three high rainfall catchments (Iffley, Poole and Crowea coupes) range between 8 and 13 tonnes per square kilometre and have tended to carry higher sediment concentrations for longer periods. Project 2 catchments in their forested calibration phase have yielded less than one tonne per square kilometre.

Sediment loads from the coupes could in fact be higher, because weekly sampling would miss the peak concentrations of sediment at high flows. Higher sediment loads could also be expected if the coupes had been cut during winter. The highest sediment loads of the major streams have occurred on the catchments with the highest level of clear felling operations, which are Dombakup Brook and the Weld River (see Project 3). High concentrations occurred during winter operation even though stream protection areas were left uncut.

Results from monitoring both upstream and downstream of coupes cut in the winters of 1976 and 1977, showed greater quantities of sediment reaching the streams, although this did not happen in all coupes (Project 4). Investigations are continuing of the differences in the proportion of steep country or variations in soil type and logging techniques which may explain differences between coupes.

The seriousness of these changes should not be overstated. Disturbance is not permanent and even if sediment loads approach 20 tonnes per square kilometre, these are not high loads by world standards. Evidence of the effect of winter logging in 1977 on Dombakup Brook was noted (see Project 3) but high concentrations were not repeated in 1978. The sediment loads obtained from the large streams are not considered an engineering problem in major dam construction, although problems could develop with small pipehead structures. Ecological considerations, particularly the effect on aquatic biota, may be more important. Of concern is the possible loss through sedimentation of deep pools which provide the necessary low summer water temperature for fish. Plans to monitor deep pools on the major river systems are being considered to see if any permanent accretion is occurring.

As noted in the introduction, stricter regulations have been progressively imposed on the industry to minimise the impact of logging activities. The most effective of these is the insistence that log stockpiles be built up during dry weather so that the logging of vulnerable areas can be stopped during very wet weather. In addition, tighter control has been imposed on the location of snig tracks and roads, as both local and Eastern States studies have indicated that construction of tracks and roads, particularly in the proximity to streams, is the chief source of sediment (Gilmour 1971; Langford and O'Shaughnessy 1977).

References

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

Carbon, B.A., Bartle, G.A. and Murray, A.M., 1979. *Leaf area index of some eucalypt forests in South West Australia.* Aust. For. Res. 9, 323-326.

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.

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, 1974. *The influence of land use on stream salinity in the Manjimup area, Western Australia.* Technical Bulletin No. 27.

Furness, L.J., 1980. *The occurrence of coal at Iffley coupe.* Mines Department, Western Australia, Record (in preparation).

Gilmour D.A., 1971. *The effects of logging on stream flow and sedimentation in a North Queensland rain forest catchment.* Comm. For. Rev. 50,39.

Greenwood, E.A.N., 1979. *The phenomenon of transpiration and its importance in the management of the hydrologic cycle.* Proceedings of Hydrology and Water Resources Symposium Perth, 1979, 133-137.

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.

Herbert, E.J., Shea, S.R. and Hatch, A.B., 1978. *Salt content of laterite profiles in the Yarragil catchment, Western Australia.* Forests Department, Western Australia, Research Paper No. 32.

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.

Hunt Steering Committee, 1976. *Research into the effects of bauxite mining in the Darling Range.* Department of Industrial Development, Western Australia, Review.

Hunt Steering Committee, 1978. *Research into the effects of bauxite mining on the water resources of the Darling Range.* Department of Industrial Development, Western Australia, Review.

Interagency Task Force, 1967. *Upper Mississippi River comprehensive basin study. Fluvial Sediment, Appendix G.* United States Corps of Engineers.

Johnston, C.D., McArthur, W.M. and Peck, A.J., *Distribution of soluble salts in soils of the Manjimup Woodchip Licence Area, Western Australia.* CSIRO, Division of Land Resources Management, Perth, Technical Paper No. 5.

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

Kelsall Steering Committee, 1978. *Research into the effects of the Woodchip Industry on water resources in South Western Australia.* Department of Conservation and Environment, Western Australia, Bulletin No. 31.

Kirkby, M.J. (ed), 1979. *Hillslope Hydrology.* John Wiley and Sons.

Langford, K.J. and O'Shaughnessy, P.J., 1977. *Some effects of forest changes on water values.* Aust. For. 40 , 192-218.

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

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.

Peck, A.J. and Hurle, D.H., 1973. *Chloride balance of some farmed and forested catchments in South Western Australia.*

Pilgrim, D.H., Duff, D.D. and Steele, T.D., 1978. *A field evaluation of subsurface and surface runoff. Two Runoff Processes.* Journal of Hydrology, 38, 609-623.

Public Works Department, Western Australia, 1977. *Streamflow records of Western Australia to 1975.* Government Printer, Western Australia.

Public Works Department, Western Australia, 1980. *Water supply surveys between 1977 and 1979 and hydrologic characteristics of the Warren, Donnelly and Shannon River basins.* Water Resources Section Technical Report (in preparation).

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

Stone, K.A., Stokes, R.A. and Loh, I.C., 1980. *Summary of salt storage characteristics of the Northern Darling Range.* Public Works Department, Water Resources Technical Report (in preparation).

Vanoni, V.A. (Ed), 1975. *Sedimentation Engineering.* American Society of Civil Engineers, New York, 466.

Watkins, D., 1973. *Focus on the marri woodchip project.* Forests Department, Western Australia, Forest Focus No. 12.

White, B.J. and Underwood, R.J., 1974. *Regeneration in the Karri forest community,* Forests Department, Western Australia, 1974.

Whitely, D., 1978. *Sediment in streams near logging areas in the Pemberton District.* Forests Department, Western Australia, Research Paper No. 43.

Williamson, D.R. and Johnston, C.D., 1979. *Effects of land use on salt and water transport.* Western Australian Institute of Technology, Perth, Proceedings, Agriculture and the Environment in Western Australia.

<u>OTHER REFERENCES</u> (not cited)

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

Hingston, F.J. and Gailitis, V., 1976. *The geographic variation of salt precipitated over Western Australia.* Aust. J. Soil Res., 14, 319-35.

Hingston, F.J., Turton, A.G. and Dimmock, G.M., 1977. *Nutrient elements in <u>Eucalyptus</u> <u>diversicolor</u> and <u>Eucalyptus</u> <u>calophylla</u> from the Karri Forest, south-west Western Australia.* CSIRO, Division of Land Resources Management, Perth, Report to the Department of Conservation and Environment.

Johnston, C.D., 1980. *Salt content of soil profiles in bauxite mining areas of the Darling Range, Western Australia.* CSIRO, Division of Land Resources Management, Perth, Technical Paper Series (in press).

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

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 Western Australia.

Membership of the Steering Committee and the Project Study Group

Appendices

APPENDIX 1 MEMBERSHIP OF THE STEERING COMMITTEE

(at 31 December 1979)

STEERING COMMITTEE

CHAIRMAN	K.J. Kelsall	Public Works Department
	D.B. Collett	Public Works Department
	J.J. Havel	Forests Department
	R.H.B. Hebbert	University of W.A.
	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.A. Perry	C.S.I.R.O.
	T.C. Stoneman	Department of Agriculture
SECRETARY	D.H. Dale	Department of Conservation and Environment

ALTERNATE MEMBERS

K.L. Barrett	Public Works Department
G.P.W. Lowe	Metropolitan Water Board
F.H. McKinnell	Forests Department
A.J. Peck	C.S.I.R.O.
A.F. Trendall	Mines Department

LIAISON OFFICERS

PROJECT		
1	T.C. Stoneman	Department of Agriculture
2	D.B. Collett	Public Works Department
3	D.B. Collett	Public Works Department
4	J.J. Havel	Forests Department

APPENDIX 2 MEMBERSHIP OF THE PROJECT STUDY GROUPS

(at 31 December 1979)

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.I. White	Forests
T.T. Bestow	Mines
W.M. McArthur	C.S.I.R.O.
K.L. Barrett	P.W.D.

PROJECT 2

Paired Catchment Study

STUDY GROUP

K.L. Barrett (Convener)	P.W.D.
F.H. McKinnell	Forests
P.E.S. Christenson	Forests
D. Whitely	Forests
L.J. Furness	Mines
D.F. Barrett	P.W.D.
I.C. Loh	P.W.D.
P. Hulbert	P.W.D.
P.M. Roberts	P.W.D.

PROJECT 3

Monitoring at
Stream Gauging Stations

STUDY GROUP

K.L. Barrett (Convener)	P.W.D.
P. Kimber	Forests
D.F. Barrett	P.W.D.
B.L. Chester	P.W.D.
P. Hulbert	P.W.D.
I.C. Loh	P.W.D.
P.M. Roberts	P.W.D.

PROJECT 4

Monitoring of
Ground Water Hydrology

STUDY GROUP

F.H. McKinnell (Convener)	Forests
P. Kimber	Forests
D. Whitely	Forests
T.T. Bestow	Mines
L.J. Furness	Mines
A.J. Peck	C.S.I.R.O.
K.L. Barrett	P.W.D.

WOODCHIP LICENCE AREA BOUNDARY

STATE FOREST

PROJECT 1 STUDY AREA

PROJECT 2 PAIRED CATCHMENTS

PROJECT 3 MAJOR CATCHMENTS

PROJECT 4 OPERATIONAL COUPES

LOCATION OF THE RESEARCH PROJECTS IN THE WOODCHIP LICENCE AREA

N

0 20
kilometres