Stream and Ground Water Response to Logging and Subsequent Regeneration in the Southern Forest of Western Australia

Interim results from paired catchment studies

by H. Borg, P. D. King and I. C. Loh

Report No. WH 34

October 1987

Water Authority of Western Australia

Stream and Ground Water Response to Logging and Subsequent Regeneration in the Southern Forest of Western Australia

Interim results from paired catchment studies

by

H. Borg,

P. D. King

and

I. C. Loh

Report No. WH 34 **October 1987**

Water Authority of Western Australia

Water Resources Directorate

Surface Water Branch

CONTENTS

Page

Figures

Tables

ERRATA

Page 52 : The values on the y-axis for the Manjimup graph are wrong. The correct values should be 200 mm higher, i.e. the current 400 should read 600, the current 600 should read 800, and so on.

ERRATA

Page 94 : The values in the two columns for Yerraminnup North are wrong. The correct values are :

Yerraminnup North valley bores	Yerraminnup North slope bores
5.96	13.73
5.76	13.53
6.20	13.70
6.20	13.85
6.21	13.76
6.35	13.89
6.01	13.72
5.71	13.57
6.49	13.99
6.47	13.97
5.98	13.82
6.17	13.98

Page 104 : The given separation of valley bores and slope bores is wrong. The correct separation is:

March Road

	valley bores			slope bores	
bore number	6078202	6078205	6078206	6078201	6078207
1975					
1976	.29	4.45	3.01	9.78	11.27
1977	.10	5.12	3.58	10.10	11.62
1978	+.42	4.99	3.67	10.52	11.78
1979	+.38	4.72	3.74	10.44	11.91
1980	+.19	4.65	3.94	10.64	12.16
1981	+.15	4.67	4.14	10.76	12.20
1982	+1.09	4.16	3.89	10.34	12.17
1983	+2.44	2.96	3.49	10.04	11.91
1984	+2.74	2.06	2.19	9.34	11.51
1985	+2.84	1.76	.69	7.84	9.71
1986	+2.44	1.86	.69	6.94	8.91
depth to bottom of bore (m)	21.77	13.20	13.22	18.70	15.82
soil surface elevation at bore (m)	177.44	184.17	199.11	201.05	213.77

Summary

1) Two pairs (Lewin North and South, and Yerraminnup North and South) and one group of three (March Road, April Road North and South) small catchments were instrumented in 1975-76 to study the effect of heavy selection cutting or clear-felling and subsequent regeneration in the southern forest of Western Australia on streamflow quantity and quality, and ground water levels. After six to seven years of data had been collected to calibrate the hydrologic behaviour of the catchments in a group against each other, four of the seven catchments (Lewin South, Yerraminnup South, March Road and April Road North) were logged between January 1982 and April 1983. Regeneration to forest began within a year after the completion of logging. The hydrologic effect of logging and regeneration was evaluated by comparing the data obtained in the logged catchment(s) with those from the unlogged catchment in each group.

2) During the period covered by this report (1975-76 to 1986 inclusive) the annual rainfall in the southern forest of Western Australia was generally below the long-term mean. This may have influenced the magnitude of the hydrologic response to logging, but probably not the general trends.

3) Annual streamflow in all four logged catchments increased for two to three years as a result of logging, and then declined again as the vegetation recovered. The largest increase (175 mm) occurred at Lewin South.

4) Flow-weighted mean annual stream sediment concentrations at Lewin South and March Road were higher than normal during logging and for two to three years after its completion, but then reverted to pre-logging levels. The largest observed increase was about 17 mg/L and occurred at March Road. This

catchment was logged through the wet season while others were not. At April Road North and Yerraminnup South, where a strip of forest was retained along the streams, no significant increase in sediment concentrations was registered.

5) Flow-weighted mean annual stream salinity at Lewin South increased from 1982 until 1985 and then levelled off. At March Road it decreased in 1982, increased in 1983 and continued to rise in each following year. However, the rate of rise since 1984 was smaller than before. At April Road North it increased until 1983, then fell until 1985 when it was only slightly above the level it would have been at without logging, but rose again in 1986. Except in 1983 when a slight increase occurred, the flow-weighted mean annual stream salinity at Yerraminnup South was less than it would have been without logging, even though this catchment is in the low rainfall zone which was initially considered to be the most likely region where logging might lead to high stream salinity. The largest observed increase was 164 mg/L and occurred at March Road. In all four catchments the flow-weighted mean annual stream salinity after logging remained below 500 mg/L TSS, the upper limit for high-quality drinking water, and, except at March Road, even below 200 mg/L TSS.

6) Bore water levels rose sharply for two years (1983 and 1984) as a consequence of logging, but in most areas there has since been a decline in the rate of rise or even a slight decline of the bore water levels, concurrent with the progressing regeneration. The largest rise (3.73 m) in a group of bores occurred at March Road. Retaining a strip of forest along a stream reduced the magnitude of the rise in the stream area.

7) Due to the rainfall pattern and the short hydrologic record since logging the data from this study alone do not permit any definite conclusions about the future trends in ground water levels, streamflow and stream salinity in the four cut-over research catchments. However, the trends observed so far and their agreement with observations from nearby catchments with longer post-logging records suggest that serious salinity problems are not likely to develop and that after 10 to 15 years of regeneration or less ground water, streamflow and stream salinity are likely to return the level they would have been at had there been no logging. Further monitoring of these parameters is recommended to confirm this and to assess whether streamflow from regenerating stands will eventually be less than from the mature stands they replaced as observed in Victoria.

8) To date there is no evidence to indicate that in the southern forest of Western Australia clear-felling of karri stands and heavy selection cutting of jarrah stands leads to serious or long-lasting increases in stream sediment concentrations and salinity as long as the cut-over areas are regenerated to forest soon after the completion of logging. Where due to local circumstances there is a potential for large increases in stream sediment concentrations or salinity as a result of logging, it can be reduced by the retention of forest strips along streams. In light of the research results presented here and by Borg et al. (1987) the restriction of logging in the low rainfall zone to light selection cutting which is currently in place can be lifted and heavy selection cutting allowed.

1. Introduction

The southern forest of Western Australia is defined as the forested land in the State which drains into the Southern Ocean. The catchments monitored for this research are located in a part of the southern forest that covers 884 100 ha around the town of Manjimup and has been referred to as the Woodchip Licence Area since the establishment of a woodchip mill in Manjimup in 1975 (Fig. 1, inside back cover). The mean annual rainfall in this area ranges from over 1400 mm near the coast to less than 700 mm further inland (Fig. 2). About 80% of the annual precipitation falls in a wet season from May through October.

Depending on weather fluctuations between years, mean annual rainfall and other site conditions, a forest stand in the area typically returns 60 to 80% of the annual precipitation to the atmosphere by transpiration. Evaporation of rainfall intercepted by vegetation, commonly referred to as interception, accounts for another 10 to 20%. Evaporation from the soil surface and organic litter generally removes less than 10%, and streamflow between 0 and 20% of the annual precipitation. There are usually no significant changes in soil and ground water storage from one year to the next. Further details on the water balance in the region are given by Borg *et al*. (1987).

Rain and dry fallout introduce salt to the soils of the region, which was transferred into the atmosphere from oceanic spray (Hingston and Gailitis 1976). The top two to four metres of a soil profile are generally well leached of salt by a variety of hydrologic processes, but substantial amounts have accumulated at greater depths during the last few thousand years. The accumulated amount increases with decreasing mean annual rainfall (Johnston *et al*. 1980).

Logging removes vegetation and therefore reduces transpiration and interception. More water thus becomes available for the other hydrologic processes. Evaporation from the soil surface and organic

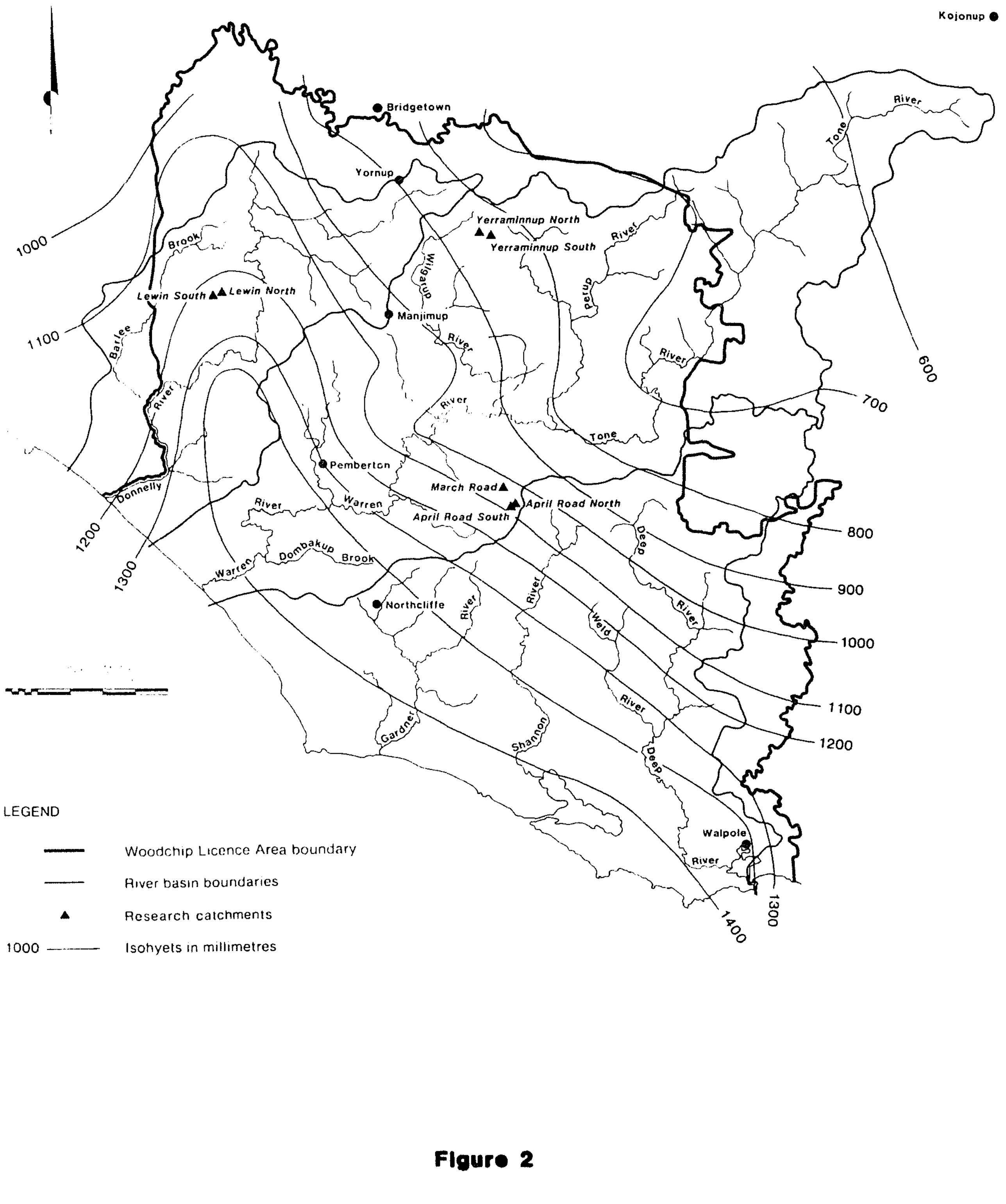


Figure 2

Mean annual rainfall in the research area. (Data from Loh and King 1978.)

litter on the soil surface, streamflow and soil and ground water recharge increase. The latter leads to a rise in the ground water level which mobilises some of the salt stored in a soil profile. As a result salt discharge to the streams may increase, which in turn may cause an increase in stream salinity if an increase in salt discharge is not balanced by an increase in streamflow (Borg et al. 1987). Most of the salt in the streams of south-west Western Australia is contributed by ground water, while most of the water originates from 'shallow subsurface runoff' (Stokes and Loh 1982; Stokes 1985; Williamson et al. 1987). The soils of the region typically consist of 30 to 100 cm of highly permeable sandy to loamy material on top of 5 to 20 m of clay with low permeability (McArthur and Clifton 1975). Water which is perched and flows downslope on top of this clay layer is called shallow subsurface runoff.

How fast and how far a disturbance of the water and salt regime by logging can be reversed depends on how quickly and how close new vegetation will return transpiration and interception to pre-logging levels. It had long been recognised that the permanent removal of the native perennial vegetation and its replacement with annual crops and pastures can lead to large and persistent salinity increases in the streams of south-west Western Australia (Wood 1924; Burvill 1947; Peck and Hurle 1973) as well as increases in stream sediment concentrations (Abawi and Stokes 1982). However, little was known about the influence of logging and subsequent regeneration on stream salinity and sediment concentrations.

For a variety of reasons the (then) Forests Department of Western Australia changed its logging system in the southern forest from relatively light selection cutting to clear-felling of karri stands in 1967, and to heavy selection cutting of jarrah stands in 1970 (Borg et al. 1987). As under the former system all cut-over areas were regenerated to forest. The change in logging system was implemented in the Woodchip Licence Area. Karri (Eucalyptus diversicolor) is the principal species where the mean annual rainfall exceeds 1100 mm and does not usually occur where the mean annual rainfall is less than 1000 mm. Jarrah (Eucalyptus marginata) dominates areas with 1100 to 650 mm annual rainfall, but is also present in areas of higher rainfall where site conditions are not suitable for karri.

Heavy selection cutting and clear-felling, both followed by regeneration of the cut-over areas to forest, had been practised in the southern forest from the late 1920s to about 1940. No obvious effect on stream water quality was noted then. However, no specific attempt was made to monitor any possible effect. The scientific community was just beginning to uncover the connection between increases in stream salinity and clearing for agriculture. Consequently, logging and subsequent regeneration to forest, a temporary and less severe hydrologic disturbance than clearing for agriculture, was not perceived to affect stream salinity.

By the early 1970s the effect of agricultural clearing on stream salinity was more firmly established and the public began to become aware of the problem. Heavy selection cutting and clear-felling are a more significant hydrologic disturbance than light selection cutting so that their re-introduction raised some concern about their influence on stream salinity and, to a lesser extent, on stream sediment concentrations (Forests Department of Western Australia 1973).

In 1973 the West Australian Minister for Conservation and Environment therefore arranged the formation of a Steering Committee to conduct research into the effects of heavy selection cutting and clear-felling on the water resources in the southern forest. The Steering Committee initiated a number of research projects which were then conducted by various government departments (Steering Committee 1978, 1980). The Public Works Department of Western Australia (which in 1985 became part of the Water Authority of Western Australia) in co-operation with other government departments was given the task to undertake several paired catchment studies.

These studies commenced in 1975 with three main objectives, namely:

(1) to determine the magnitude and duration of any change in stream salinity due to logging;

(2) to determine the magnitude and duration of any change in stream sediment concentration due to logging;

(3) to determine the long-term (20 to 100 years) effect of logging and subsequent regeneration on streamflow volumes.

The third objective was a response to observations from Victoria which indicated that after several years of regeneration streamflow from regrowth stands was less than from the mature stands they replaced (Brookes 1950; Brookes and Turner 1963; Kuczera 1985). The southern forest contains the largest undeveloped surface water resources in south-west Western Australia (Collins and Barrett 1980). Plans to utilise these resources would be affected if such a reduction in streamflow would occur.

The paired catchment studies have been reported on twice before (Steering Committee 1978, 1980). This report reviews the data available at the beginning of 1987 and thus supercedes the two previous progress reports.

Results from similar but less sophisticated studies conducted by the Forests Department of Western Australia (which in 1985 became part of the Department of Conservation and Land Management W.A.) with assistance from other government departments have recently been published as well (Borg et al. 1987). That report also contains a more detailed description of the climate, vegetation, forestry and hydrology of the southern forest than is presented here.

2. Experimental Methods

2.1 Instrumentation and measurements

Two pairs (Lewin North and South, and Yerraminnup North and South) and one group of three (March Road, April Road North and South) small catchments were selected in 1975 to represent a combination of mean annual rainfall, forest type, soils and topography found in the southern forest. The locations of the seven catchments, together with the distribution of the mean annual rainfall in the region are shown in Figure 2. Some characteristics of the catchments are listed in Table 1 and detailed catchment maps are given in Appendix W.

All catchments were instrumented in the same fashion. Rainfall was measured near the catchment outlets using a 203 mm diameter tipping bucket rain-gauge with a 0.2 or 0.25 mm tip connected to a chart recorder to provide a continuous record of rainfall intensity and volume. All trees and tall vegetation were cleared from an area two tree heights in diameter around the rain-gauge to eliminate their effect on rainfall measurements.

At the outlet of each catchment a V-notch weir was constructed with a stilling basin behind the weir. Such an installation is shown in Figure 3. A floatwell was connected to each stilling basin and attached to a chart recorder to supply a continuous record of the water level in the stilling basin which was then converted to streamflow using a relationship between the water level in the stilling basin and flow over the weir. Every day at 9.00 am and whenever the water level passed one of the 5 cm gradations in the floatwell, an automatic pump sampler took a water sample from the stilling basin near the bottom end of the V-notch. The samples were analysed for suspended sediments less than 0.063 mm in diameter and electrical conductivity. Most of the time the samples were also analysed for chloride content and less frequently for total soluble salts (TSS). Chloride constitutes about 48% of the total soluble salts at Lewin North and South, March Road and April Road North and

Table 1 : Some characteristics of the seven small catchments selected for this study.

catchment	location	size (ha)	mean annual rainfall long-term[1] (mm)	mean annual rainfall during study (mm)	mean annual pan evaporation[2] (mm)	forest type	soils
Lewin North (control)	115° 51' 54" E 34° 12' 48" S	133	1240	1089	1220	jarrah	laterites, red earths and yellow duplex soils
Lewin South	115° 51' 30" E 34° 13' 6" S	90	1230	1089	1210	jarrah, 10ha of karri along the stream	laterites, red earths and yellow duplex soils
March Road (control)	116° 20' 18" E 34° 28' 48" S	261	1040	963	1295	karri and jarrah mixed	laterites, red earths and yellow duplex soils
April Road North	116° 21' 36" E 34° 30' 12" S	248	1070	981	1295	karri and jarrah mixed	laterites and yellow duplex soils
April Road South	116° 21' 18" E 34° 30' 36" S	179	1080	997	1290	karri and jarrah mixed	laterites and yellow duplex soils
Yerraminnup North (control)	116° 18' 36" E 34° 8' 48" S	253	850	748	1365	jarrah	laterites and yellow duplex soils
Yerraminnup South	116° 19' 42" E 34° 9' 24" S	183	830	732	1370	jarrah	laterites and yellow duplex soils

[1] estimated from Figure 2 with consideration of the data collected during this study

[2] estimated from Commonwealth Bureau of Meteorology (1987)

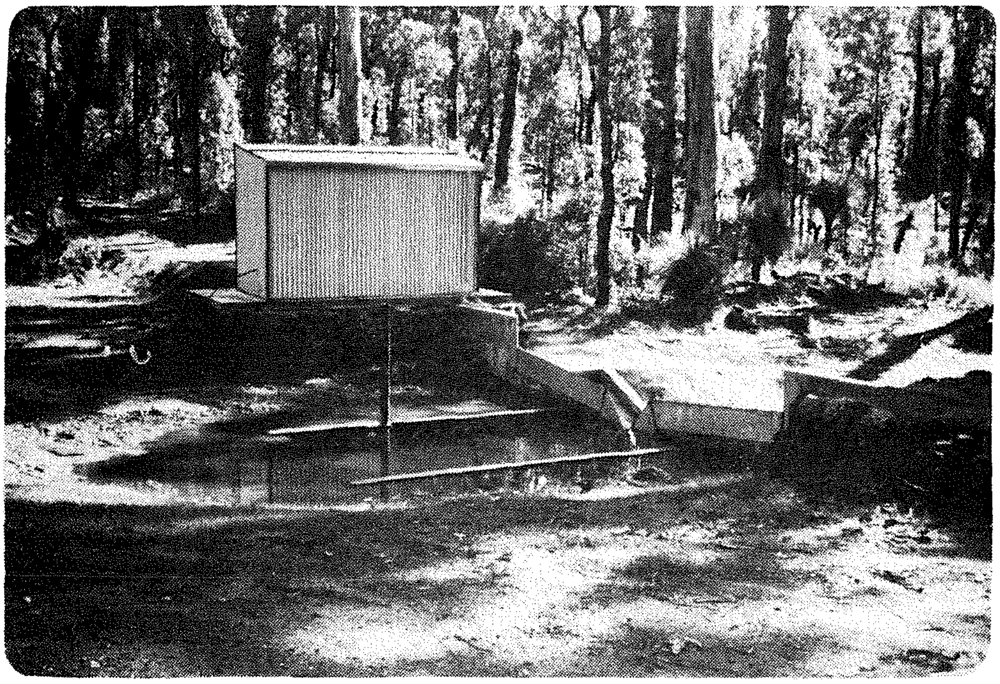


Figure 3

Schematic of the type of gauging station constructed in the seven research catchments. (The photograph shows the gauging station at Lewin South, but the other six are very similar.)

South, and about 40% at Yerraminnup North and South. In this report salinity is discussed in terms of TSS only. Electrical conductivity was converted to TSS using the correlations between TSS and electrical conductivity given in Appendix V.

Linear interpolation was applied to construct a continuous salinity record for each gauging station from the recorded discrete one. This continuous record was then multiplied by the continuous streamflow record and integrated to compute the amount of salt which passed through the gauging station on each day. The daily salt loads where then summed to obtain the annual salt load. This value was finally divided by the annual streamflow volume to yield a flow-weighted mean annual stream salinity. The sediment record was treated in the same fashion.

Between 17 and 29 bores were auger-drilled to bedrock in each catchment to monitor ground water levels. They were placed to cover valley, midslope and upslope areas. All bores were drilled and constructed by the Mines Department of Western Australia and in the same fashion as the bores in the study reported on by Borg et al. (1987). Bore construction details can be found there and in Martin (1980). The locations of the bores are given in Appendix W. Bore water levels were measured about once a month.

Data collection in the Yerraminnup catchments commenced in June 1975. Rainfall for the earlier part of the year was estimated from correlations with gauging stations nearby. Streamflow did not start until July so that the 1975 record for streamflow, sediment concentration and salinity was complete. In the other five catchments data collection began in March-April 1976. Rainfall for the earlier part of the year was again estimated from correlations with neighbouring gauging stations, and the record for streamflow, sediment concentration and salinity was complete since there was no flow until later in the year.

In a paired catchment study neighbouring catchments are monitored for several years while they are in a natural state to correlate their hydrologic responses. One catchment is then 'treated' in some fashion while the other one is left undisturbed. Logging was the treatment applied in this study. Hydrologic parameters in the untreated catchment vary due to weather fluctuations only. In the treated catchment they are subject to the same weather fluctuations plus those caused by the treatment. The hydrologic response that would have occurred in the treated catchment without treatment is estimated using the correlations with the untreated catchment based on the pre-treatment data. The difference between this estimate and the observed response is treatment effect.

2.2 Logging and regeneration

Four of the seven small catchments monitored in this study were to be logged (Lewin South, March Road, April Road North, Yerraminnup South) and the other three to remain unlogged (Lewin North, April Road South, Yerraminnup North). The latter are hereafter called control catchments. Lewin North serves as the control catchment for Lewin South, April Road South as the control catchment for March Road and April Road North, and Yerraminnup North as the control catchment for Yerraminnup South. Logging commenced in January 1982, after six to seven years of hydrologic monitoring for calibration purposes, and was completed in April 1983. Stands dominated by karri were clear-felled, and stands dominated by jarrah were logged using heavy selection cutting. These are the usual logging systems applied to these stand types in the southern forest since 1967 and 1970, respectively (Borg et al. 1987). Regeneration began within one year after the completion of logging.

At Lewin South and Yerraminnup South logging was stopped during the wetter part of the 1982 winter as required under the normal dieback fungus (Phytophthora cinnamomi) control procedures for jarrah forest. Karri forest is not affected by this fungus and is therefore frequently logged during parts of the wet season. To assess the effect of winter logging on stream sediment concentrations logging at March Road was continued throughout the wet season while soil disturbance remained within the limit given in the logging regulations for the region. For comparison, logging at April Road North was stopped at the beginning of the wet season. In the April Road North and Yerraminnup South catchments a strip of forest 100 and 50 m wide, respectively, was left unlogged on each side of the streams to investigate how this would influence the rise in ground water levels and stream sediment concentrations anticipated as a consequence of logging. The location of these forest strips, commonly also referred to as stream buffers, is shown in Appendix W. They covered a total area of 25 ha at April Road North, and 22 ha at Yerraminnup South. Further logging and regeneration details are given in Table 2.

Table 2 : Summary of logging and regeneration details for the four research catchments logged for this study.

catchment	logging period	logging method	wood volume extracted (m^3)	regeneration
Lewin South	Jan. 1982 to Dec. 1982	heavy selection cutting in jarrah stands with an average of 7 m^2/ha basal area retention, equivalent to 11% overstorey vegetation cover; clear-felling in karri stands	jarrah sawlogs : 3610 karri sawlogs : 330 karri chiplogs : 340 marri chiplogs : 4785	jarrah areas : waste disposal burn in Nov. 1983, then left to regenerate naturally karri areas : waste disposal burn in Feb. 1984, then hand-planted with nursery-raised karri seedlings
March Road	Jan. 1982 to March 1983	clear-felling	jarrah sawlogs : 18772 karri sawlogs : 8448 karri chiplogs : 10436 marri chiplogs : 37254	waste disposal burn in March 1983, then hand-planted with nursery-raised karri seedlings
April Road North	Jan. 1982 to March 1983	clear-felling except for a 200 m wide strip of forest along the main stream which was left uncut (25 ha)	jarrah sawlogs : 6776 karri sawlogs : 9703 karri chiplogs : 6427 marri chiplogs : 24518	waste disposal burn in March 1983, then hand-planted with nursery-raised karri seedlings
Yerraminnup North	Jan. 1982 to April 1983	heavy selection cutting with an average of 5 m^2/ha basal area retention, equivalent to 10% overstorey vegetation cover, except for a 50 m wide strip of forest along the streams which was left uncut (22 ha)	jarrah sawlogs : 2740 marri chiplogs : 4380	waste disposal burn in Oct. 1983, then left to regenerate naturally

3. Results

3.1 General remarks

A graphical summary of annual values of rainfall, streamflow, stream sediment concentration, stream salinity, minimum bore water level and vegetation cover in the seven research catchments since 1975-76 is shown in Figure 4. These and other data are given in tabular form in the Appendices. The numbers on top of the rainfall bars state the ratio between the rainfall in the respective year and the mean annual rainfall for 1926 to 1976 inclusive. Streamflow data are presented as annual streamflow volumes per unit catchment area and are expressed in units of millimetres to allow direct comparisons with annual rainfall. Streamflow bars are plotted inside the rainfall bars and at the same scale. The numbers at the top of the streamflow bars give the annual streamflow as a fraction of the rainfall in the respective year. Stream sediment levels are represented by the concentration of suspended sediments less than .063 mm in diameter, and stream salinity by the concentration of total soluble salts (TSS). All stream sediment concentrations and stream salinities shown are flow-weighted mean annual values.

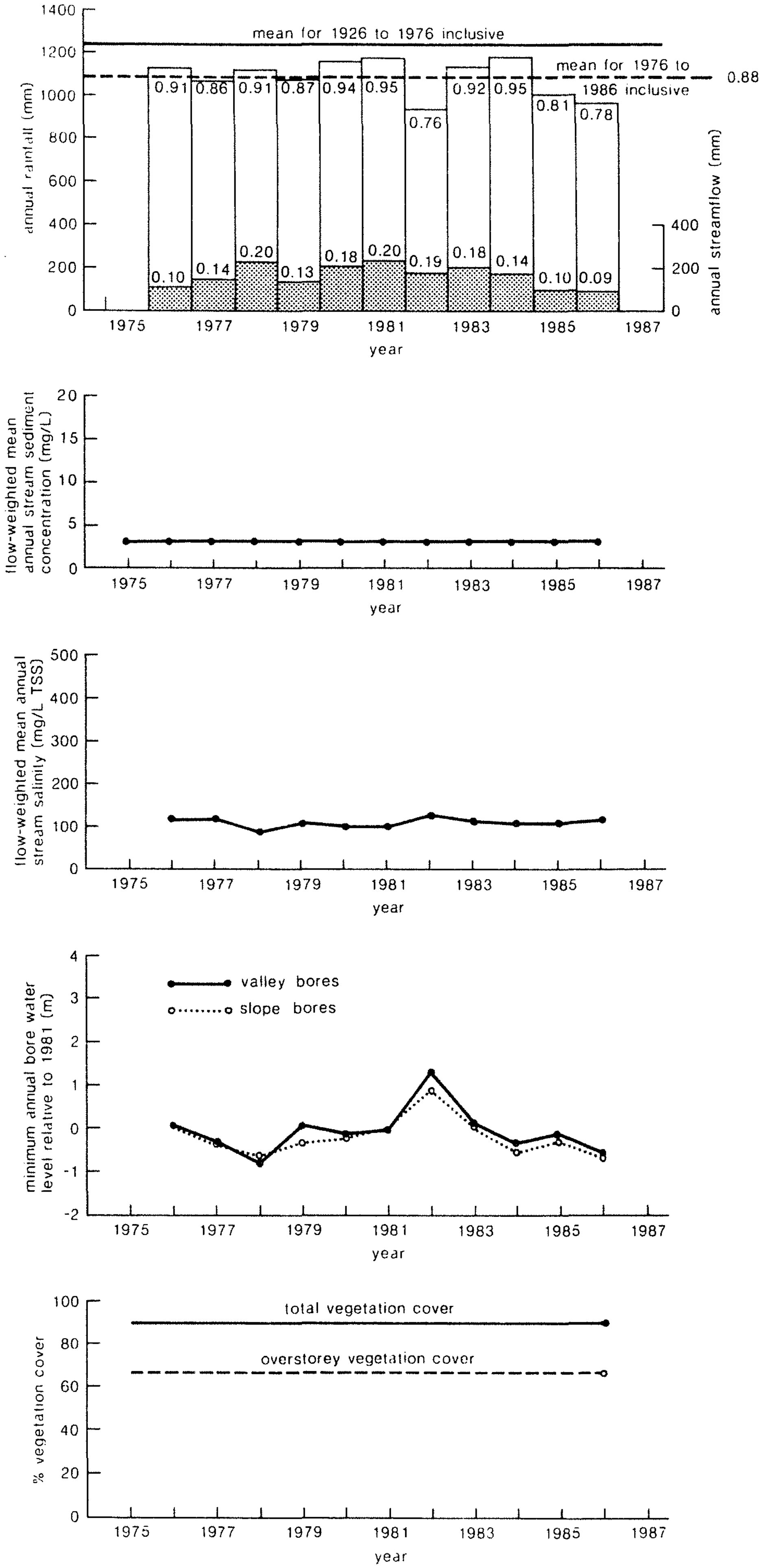
In each catchment bores in the valleys were analysed as one group, and bores on the slopes as another. Ground water status in a given year is represented by the average of the minimum water levels of the bores in each group in that year, relative to the 1981 value. In the Yerraminnup catchments the bores did not become operational until June 1975, and in the other catchments not until March-April 1976 when some bores were already past their minimum water level. This should be considered when referring to their 1975 and 1976 bore water level data, respectively. Further note that minimum bore water levels occur near the beginning of the wet season and are therefore affected considerably by the rainfall in the previous year.

All vegetation cover data were extracted from a survey by Stoneman et al. (1987). The values for 1986 were obtained in the research catchments, but all others were inferred from other information from

Figure 4

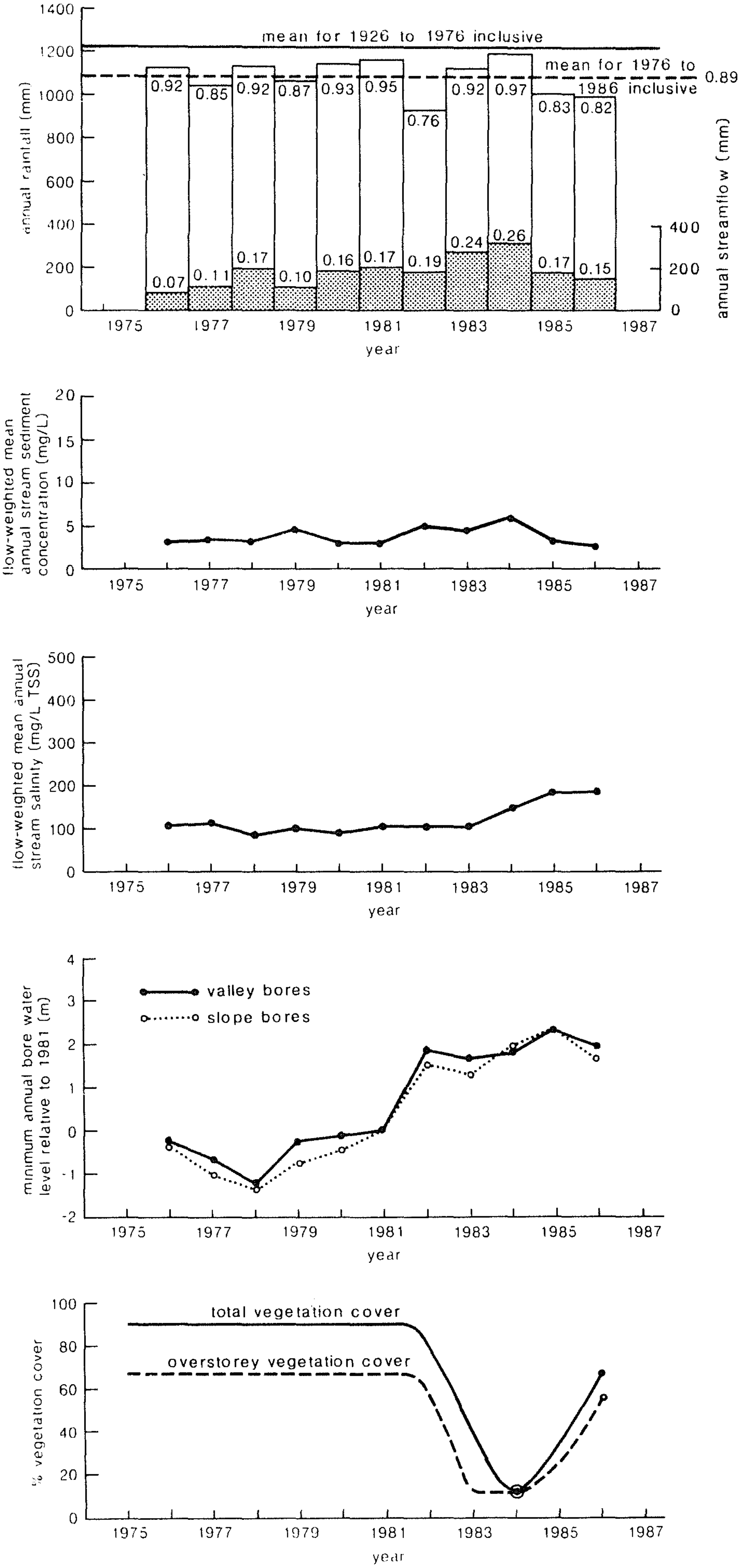
Annual values of rainfall, streamflow, flow-weighted mean stream sediment concentration and salinity, minimum bore water level (averaged for groups of bores) and vegetation cover in the seven research catchments from 1975 to 1986. (The numbers at the top of the rainfall bars give the ratio between the rainfall in the respective year and the mean annual rainfall for 1926 to 1976 inclusive. The numbers at the top of the streamflow bars give the annual streamflow as a fraction of the rainfall in the respective years.)

Lewin North

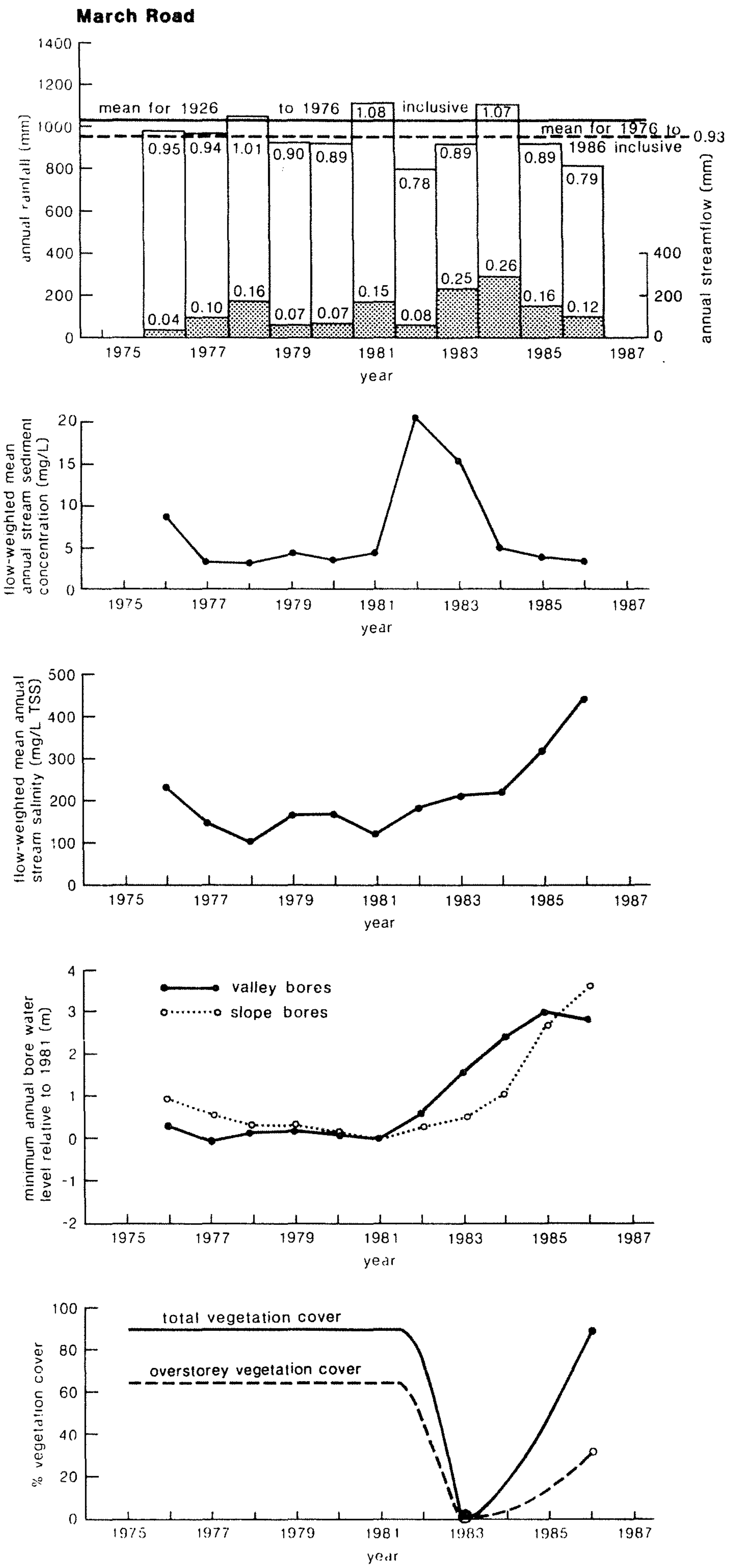


mean for 1926 to 1976 inclusive
mean for 1976 to 1986 inclusive
0.88
0.91
0.86
0.91
0.87
0.94
0.95
0.76
0.92
0.95
0.81
0.78
0.10
0.14
0.20
0.13
0.18
0.20
0.19
0.18
0.14
0.10
0.09
annual rainfall (mm)
annual streamflow (mm)
year
flow-weighted mean annual stream sediment concentration (mg/L)
year
flow-weighted mean annual stream salinity (mg/L TSS)
year
valley bores
slope bores
minimum annual bore water level relative to 1981 (m)
year
total vegetation cover
overstorey vegetation cover
% vegetation cover
year

Lewin South

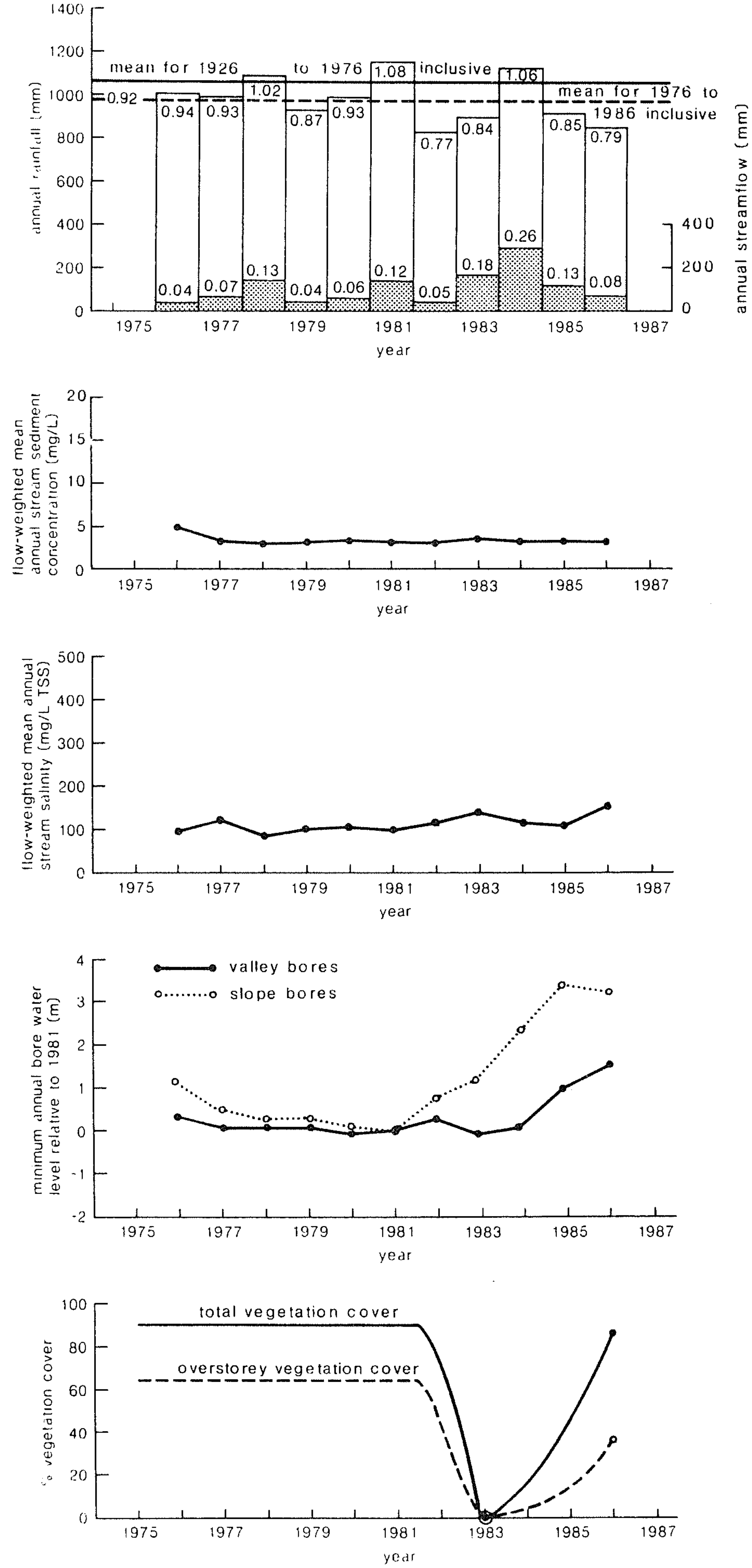


mean for 1926 to 1976 inclusive
mean for 1976 to 1986 inclusive
0.89
0.92
0.85
0.92
0.87
0.93
0.95
0.76
0.92
0.97
0.83
0.82
0.07
0.11
0.17
0.10
0.16
0.17
0.19
0.24
0.26
0.17
0.15
annual rainfall (mm)
annual streamflow (mm)
1400
1200
1000
800
600
400
200
0
1975
1977
1979
1981
1983
1985
1987
year
flow-weighted mean annual stream sediment concentration (mg/L)
20
15
10
5
flow-weighted mean annual stream salinity (mg/L TSS)
500
300
100
valley bores
slope bores
minimum annual bore water level relative to 1981 (m)
4
3
2
1
-1
-2
total vegetation cover
overstorey vegetation cover
% vegetation cover
100
80
60
40

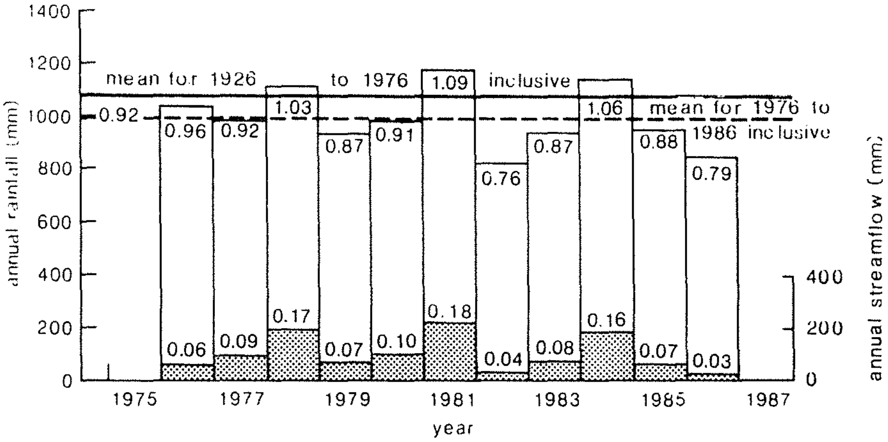


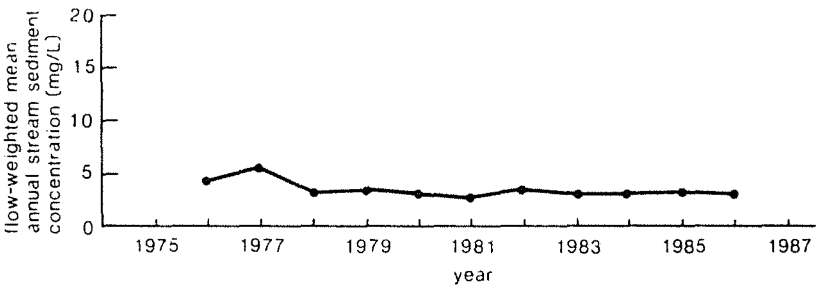
March Road
mean for 1926 to 1976 inclusive
mean for 1976 to 1986 inclusive
0.93
0.95
0.94
1.01
0.90
0.89
1.08
0.78
0.89
1.07
0.89
0.79
0.04
0.10
0.16
0.07
0.07
0.15
0.08
0.25
0.26
0.16
0.12
annual rainfall (mm)
annual streamflow (mm)
year
flow-weighted mean annual stream sediment concentration (mg/L)
year
flow-weighted mean annual stream salinity (mg/L TSS)
year
valley bores
slope bores
minimum annual bore water level relative to 1981 (m)
year
total vegetation cover
overstorey vegetation cover
% vegetation cover
year

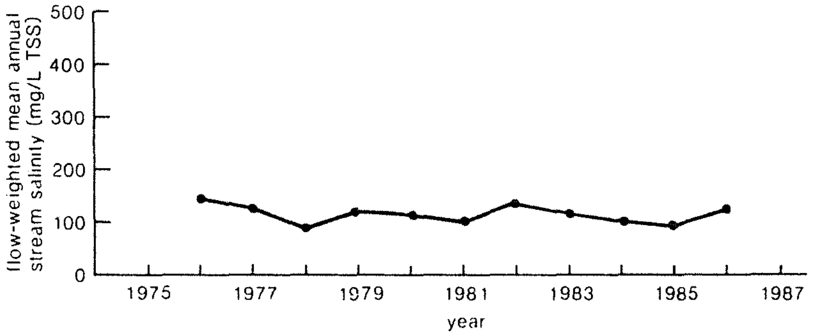
April Road North

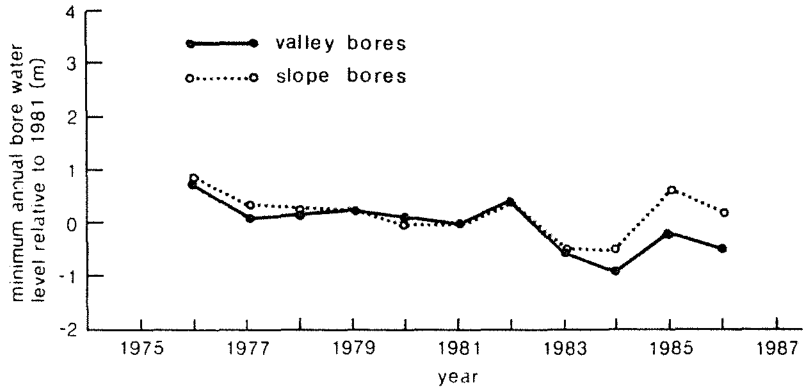


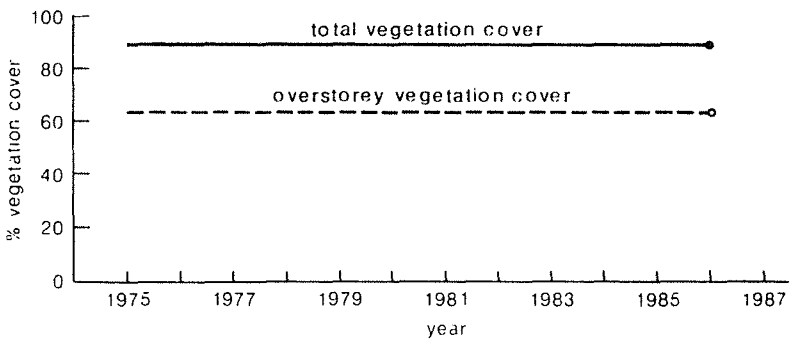
April Road South



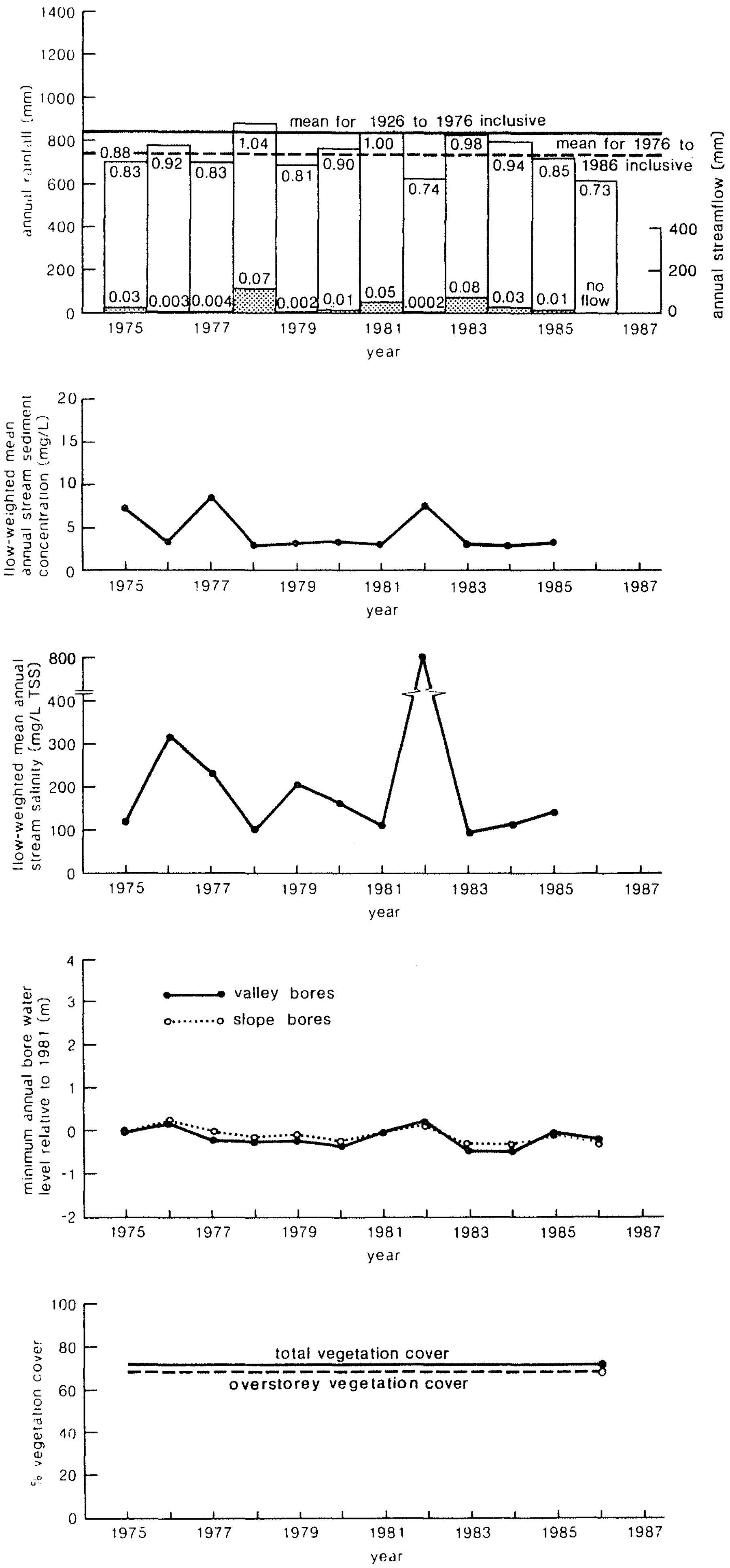




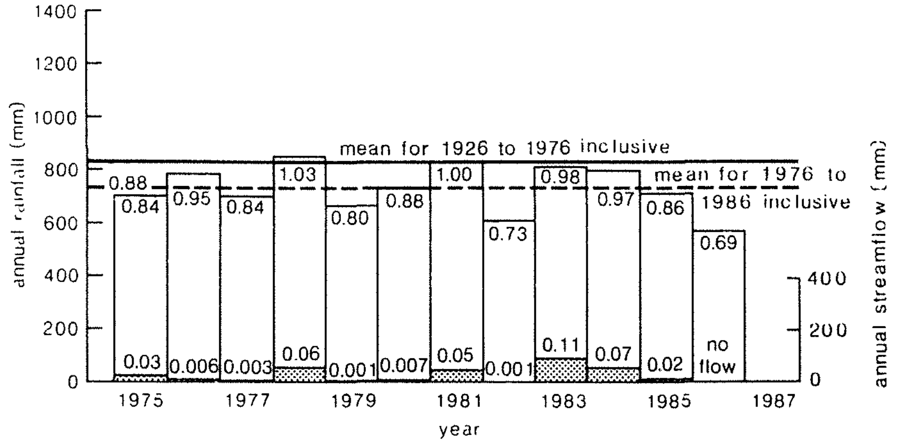


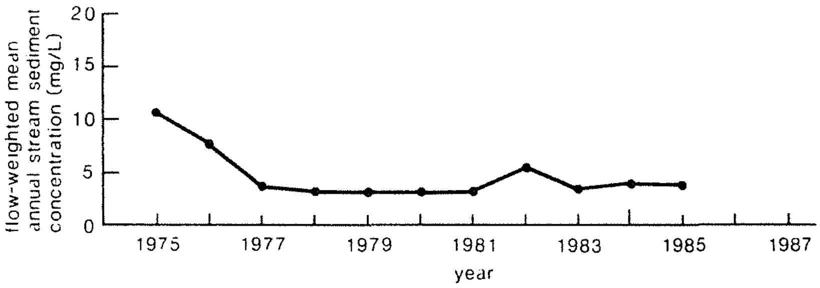


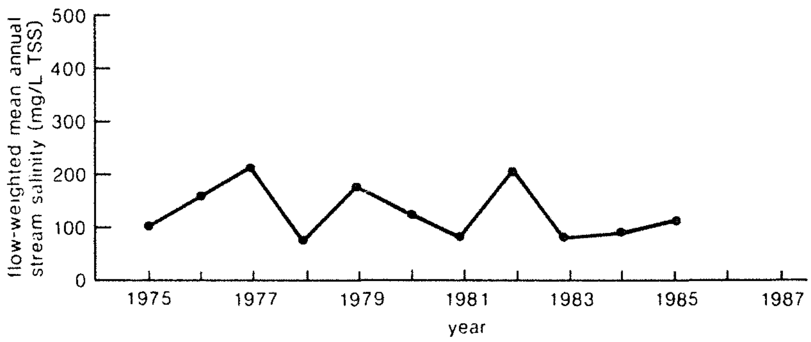
Yerraminnup North

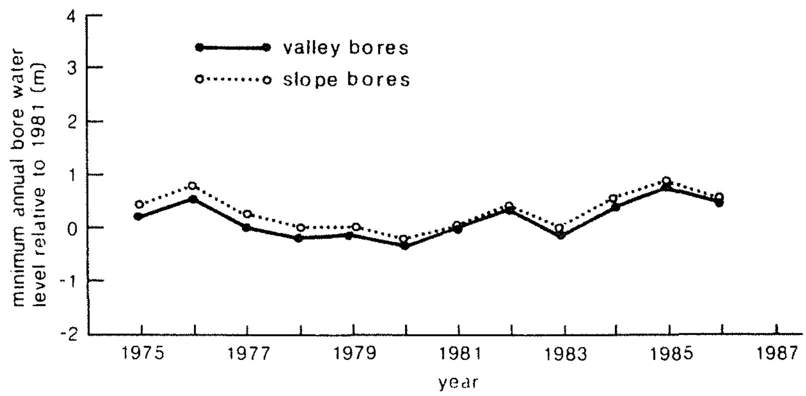


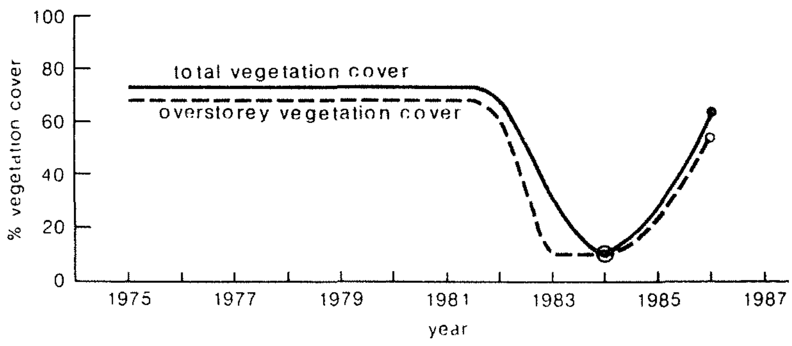
Yerraminnup South











the survey. At March Road and April Road North clear-felling and the following controlled burn reduced the vegetation cover to zero for a short period in 1983 before it began to grow back. At Lewin South and Yerraminnup South selective cutting reduced the overstorey vegetation (i.e. tree) cover to 11 and 10%, respectively. The waste disposal burns then reduced the understorey vegetation cover to zero so that overstorey and total vegetation cover were equal and at a minimum for some time in 1984 before regeneration began. Clear-felling brings about a bigger reduction in vegetation cover, and hence transpiration and interception, than selection cutting. Therefore, all other conditions being equal, it makes more water available for increases in streamflow and ground water level, too.

The vegetation cover grew back quickly in all four logged catchments. In 1986 the overstorey vegetation cover was 82% of the estimated pre-logging value at Lewin South, 48% at March Road, 59% at April Road North, and 74% at Yerraminnup South. The corresponding values for total vegetation cover use were 85%, 101%, 97% and 92%. The high values for overstorey cover at Lewin South and Yerraminnup South were mostly due to old trees retained by the selective cutting in these catchments.

The data from Stoneman et al. (1987) indicate that the overstorey cover in regenerating karri stands, like those at March Road and April Road North, reaches the density of unlogged stands after some ten years of growth, continues to increase for another ten years and then stabilises at a higher value than is typical for unlogged stands. Total vegetation cover reaches the unlogged value within five years, rises for five more years and subsequently remains above the unlogged value. In regenerating jarrah stands, like those at Lewin South and Yerraminnup South, overstorey and total vegetation cover exceeds 70% of the value for unlogged stands within five years of growth, 90% within ten years, and reaches the unlogged level in 20 to 30 years. To date, the vegetation cover in the four cut-over research catchments has grown back at least at that rate or faster.

Annual rainfall since the beginning of the paired catchment studies and the response of streamflow, stream sediment concentration, stream salinity and ground water level to logging and subsequent regeneration in the cut-over research catchments are discussed in more detail in the following sections.

The hydrologic response to logging and subsequent regeneration is influenced by the annual rainfall. Therefore, the following presentation frequently differentiates between three rainfall zones which are defined as:

high rainfall zone	= areas where the long-term mean annual rainfall is greater than 1100 mm;
intermediate rainfall zone	= areas where the long-term mean annual annual rainfall is between 1100 mm and 900 mm;
low rainfall zone	= areas where the long-term mean annual rainfall is less than 900 mm.

3.2 Rainfall

The distribution of the mean annual rainfall in the southern forest region was presented in Figure 2. The isohyets are based on the average annual rainfall from 1926 to 1976 inclusive at 100 locations (Loh and King 1978). Figure 4 gives the annual rainfall measured in the seven research catchments since 1975-76. These data show that the average annual rainfall for this period was 7 to 12% below the 1926-1976 mean estimated from Figure 2. Similar trends were also observed at other rainfall gauging stations in the region (Borg *et al*. 1987).

Years with low rainfall are not unusual, but a period of below average rainfall of such length was not previously recorded in the area. This is illustrated by the annual rainfall data for Bridgetown and Manjimup plotted in Figure 5, particularly the

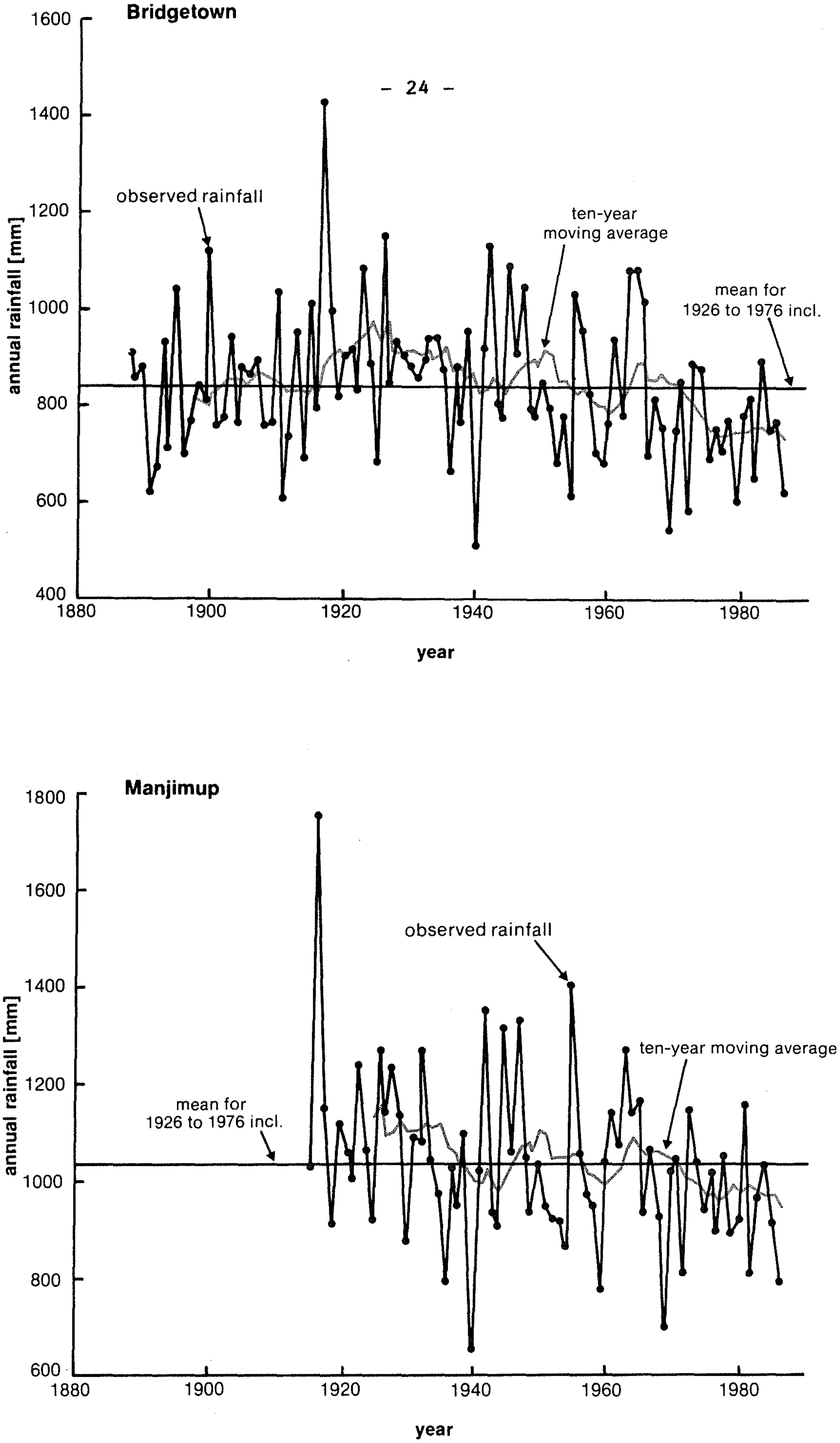


Figure 5

Annual rainfall at Bridgetown and Manjimup from the opening of the gauging stations to 1986 inclusive. (Data from Commonwealth Bureau of Metereology records.)

10-year moving average. However, the rainfall records for the region are too short to determine whether the current sequence of low rainfall is really abnormal, or whether the average rainfall for 1926 to 1976 is a true representation of the long-term mean.

If the observed rainfall was below normal, care must be taken in extrapolating the results into the future when a return to higher rainfall may alter the effects of logging and regeneration on streamflow quantity and quality, and bore water levels. Higher rainfall typically generates more surface and shallow subsurface runoff and hence more streamflow, as well as more ground water recharge which leads to higher ground water levels. Higher ground water levels in turn lead to an increased discharge of salt to the streams. The effect on stream salinity depends on how much an increase in salt discharge is compensated by an increase in streamflow. More surface runoff carries the potential for more erosion and hence higher stream sediment concentrations. However, erosion is more affected by short-term rainfall intensities which lead to high surface runoff rates than by the total annual rainfall. Wetter years therefore do not necessarily result in higher stream sediment concentrations.

Prior to logging the annual rainfall recorded in the catchments which were to be logged and in their respective control catchment were well correlated. After logging the annual rainfall recorded at Lewin South and March Road was consistently higher, 2% on the average, than in their respective control catchments (Appendix N). Logging did not affect the relationship between April Road North and Yerraminnup South and their respective control catchments because in these two catchments the rain-gauges are located within the strips of forest along the streams which were left uncut. This suggests that removing the tall vegetation from an area two tree heights in diameter around a rain-gauge allows some 98% of the annual rainfall to reach the gauge, while some 2% are intercepted by the surrounding vegetation.

3.3 Streamflow

Figure 4 summarises the annual streamflow data for all seven catchments. Prior to logging the annual streamflow in neighbouring catchments was well correlated, but since logging it increased in all logged catchments compared to the control ones (Appendix O). The increased annual streamflow was due to a combination of longer flow durations (Appendix P) and higher flow rates (Appendix Q, R and S). Like most small streams in the region, the streams in the seven research catchments flow only for part of the year. Flow generally begins a few weeks into the wet season and stops a few weeks after the end of the wet season.

Substituting the annual flows observed in the control catchments since 1982 into the appropriate regression equations in Appendix O estimates the annual flows which would have occurred in the logged catchments had they not been logged. The difference between these estimates and the annual flows observed in the logged catchments is plotted in Figure 6 and represents the effect of logging on annual streamflow. The data show that the annual streamflow in all four catchments increased for two to three years as a result of logging and then decreased again as the vegetation recovered. Extrapolating the data suggests that at Lewin South, March Road and April Road North annual streamflow will return to the level it would have been at without logging by about 1989-90, six to seven years after the beginning of regeneration. At Yerraminnup South, where streamflow is naturally low as a consequence of the dry conditions, low rainfall and high potential evapotranspiration, this may have happened by 1986, after three years of regeneration.

Increases in streamflow already occurred in 1982, the year most of the logging took place. The largest increases in streamflow were generally observed in the winter following the regeneration burns when vegetation cover and hence transpiration and interception were smallest. At March Road the largest increases in annual streamflow therefore occurred in 1983, and at Lewin South and Yerraminnup South in 1984. The regeneration burn and replanting in the April Road

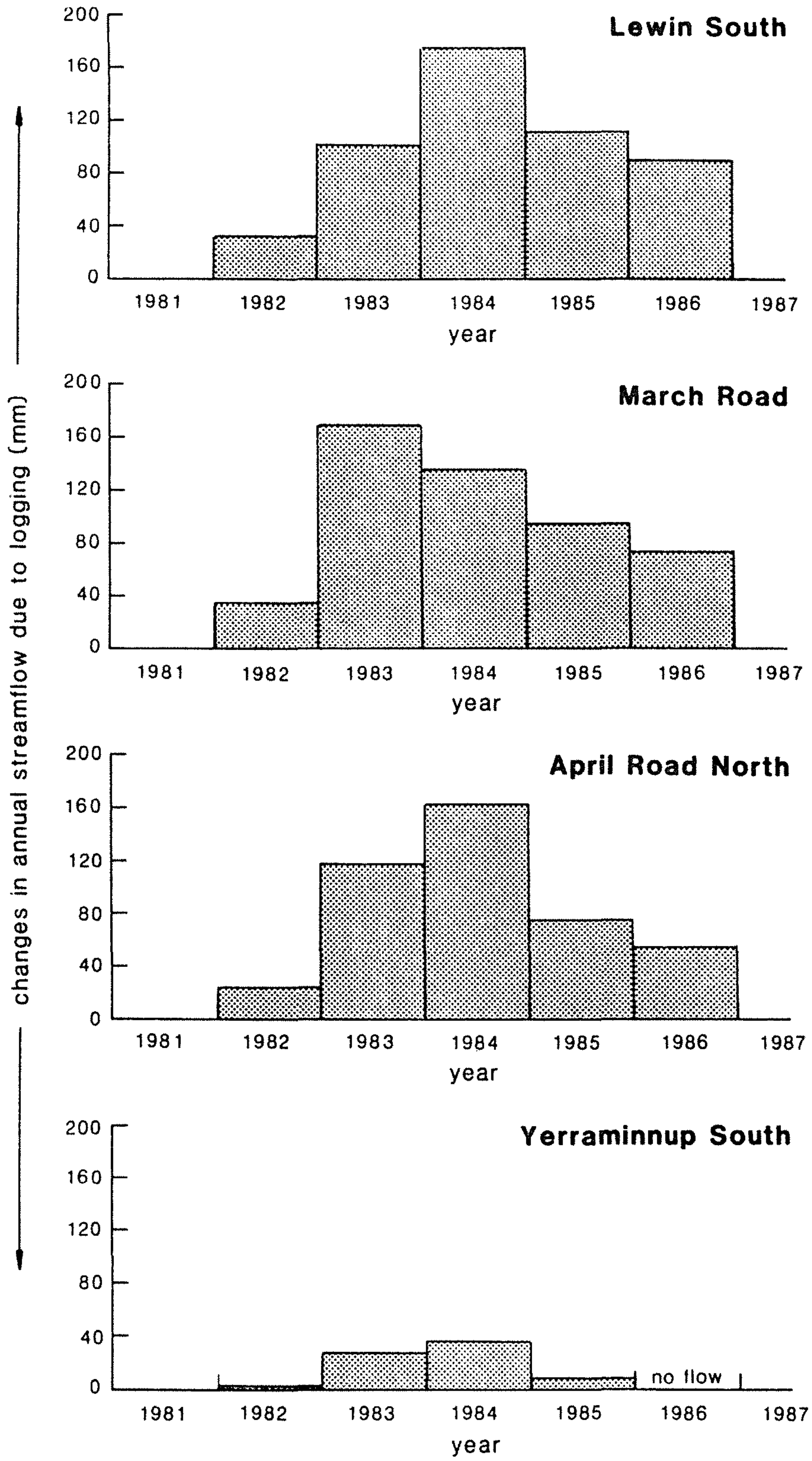


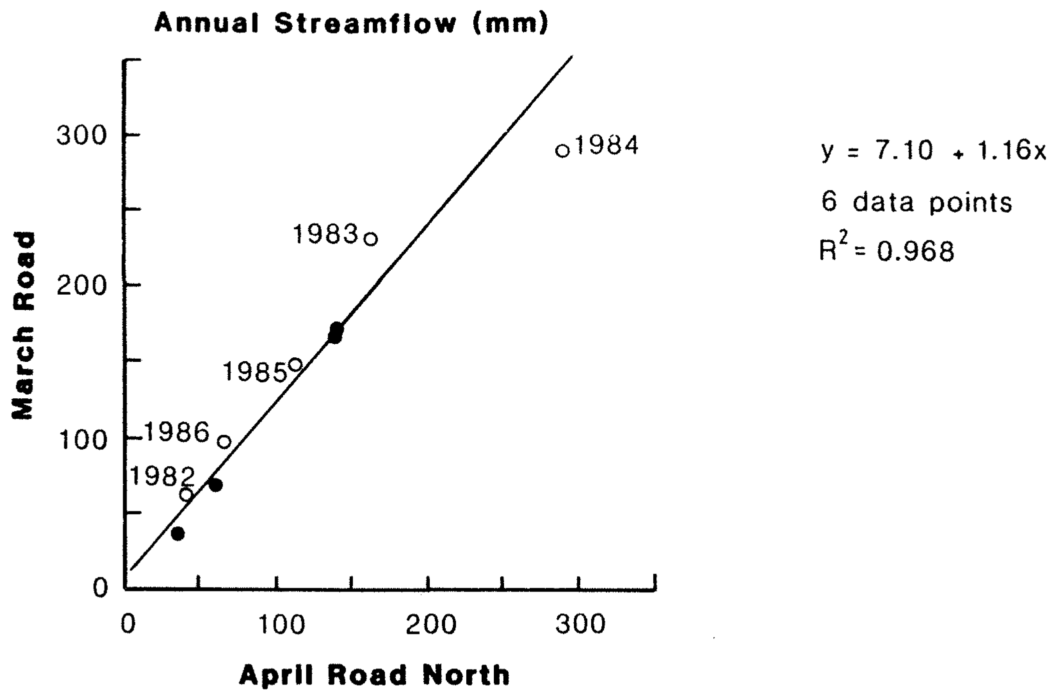
Figure 6

Changes in annual streamflow in the four cut-over research catchments due to logging.

North catchment were carried out at the same time as in the nearby March Road catchment. Nevertheless, the maximum increase in annual streamflow at April Road North was recorded in 1984. No reason for this different behaviour was obvious. Data from experimental catchments near Collie, about 100 km north of Manjimup, suggest that in south-west Western Australia most of the increased streamflow after logging comes from increased shallow subsurface runoff, and only a relatively small amount from increased surface runoff and, in some areas, from increased ground water discharge (Williamson et al. 1987).

The annual streamflow in the March Road catchment, which was clear-felled, and in the neighbouring April Road North catchment, which was also clear-felled except for a strip of forest 100 m wide along each side of the main stream, are compared in Figure 7. Before logging they were closely related. After logging the annual flow at March Road was slightly higher in most years, but averaged over the entire period affected by logging (1982-86) the difference was less than 1 mm. It is likely that due to the geology and topography of the April Road North catchment (Martin 1986) most of its streamflow is generated in the areas drained by the tributaries of the main stream (Appendix W), all of which were clear-felled. This would explain why the forest retained along the main stream had only a small effect on the annual streamflow relationship with March Road, even though it covers some 10% of the April Road North catchment area.

Annual streamflow generally increases with annual rainfall (Collins and Barrett 1980; Appendix B), and increases in annual streamflow due to logging also tend to increase with annual rainfall (Stoneman et al. in preparation). Figure 4 indicates that the annual rainfall in the catchments increased from 1982 to 1983-84 and then decreased again, similar to the annual streamflow in the cut-over catchments relative to the control catchments (Fig. 6). Annual streamflow typically increases for one to two years as a result of logging and then decreases again as the vegetation recovers (Hibbert 1967; Bosch and Hewlett 1982; Borg et al. 1987). The trends exhibited in Figure



year	observed flow at March Road (mm)	predicted flow at March Road (mm)	absolute difference (mm)	relative difference (%)
1982	61	55	6	11
1983	231	199	32	16
1984	290	346	-56	-16
1985	149	140	9	6
1986	98	85	13	15
			mean = 0.4	

Figure 7

Annual streamflow at March Road (stream area logged) in relation to annual streamflow at April Road North (stream area not logged.) (The regression is based on the data from 1976 to 1981 inclusive.)

6 are consistent with these observations, but the magnitude of the changes in streamflow is probably influenced by the variations in annual rainfall. Any extrapolation of the data should therefore be viewed with caution. More data, particularly from years with relatively high rainfall, are required to ascertain whether the annual streamflow in the logged catchments will actually return to pre-logging levels by 1989-90 after six to seven years of regeneration, or earlier in the case of Yerraminnup South.

From related studies in the region, where four catchments were logged in 1976-78 and regeneration began in 1978-79, Borg et al. (1987) estimated that in cut-over areas in the high rainfall zone the annual streamflow is likely to return to pre-logging levels after 11 to 12 years of regeneration, and possibly after only six years of regeneration in cut-over areas in the low rainfall zone. The difference between these estimates and the ones derived from Figure 6 probably arises from the fact that the period since 1982, when the data in Figure 6 were collected, includes the years with the lowest annual rainfall since 1975 (Fig. 4).

The total increase in streamflow since logging and the highest increase in a year at Lewin South were of similar magnitude as at March Road and April Road North, although there is more rainfall at Lewin South. However, the Lewin South catchment was selectively cut while the other two were clear-felled. Had it been clear-felled as well, there would have been a bigger increase in streamflow. The much smaller increases at Yerraminnup South are mostly a response to the dry conditions in this area, but were also moderated to some degree by the selection cutting.

In forested catchments in Victoria it was observed that, after several years of regeneration, streamflow in regrowth stands was less than in the mature stands they had replaced (Brookes 1950; Brookes and Turner 1963; Kuczera 1985). This was apparently due to higher transpiration from the regenerating stands (Landford 1976) although there were no distinct differences in vegetation density (Kuczera 1985). No such response has been observed in the southern forest of Western Australia so far which may at least in part be due to the absence of suitable streamflow information. Nevertheless, it is a distinct possibility in regenerating jarrah stands and especially in regenerating karri stands since the latter attain a higher vegetation density than unlogged stands (Stoneman et al. 1987).

To date, the data available from the paired catchment studies reported on here are insufficient to assess whether regenerating stands in the southern forest of Western Australia may eventually yield less streamflow than the mature stands they replaced. Further monitoring is required to evaluate this. However, should a reduction in streamflow from regrowth stands occur they can be thinned to reduce transpiration and interception which leads to an increase in streamflow (Shea et al. 1975; Stoneman et al. in preparation).

3.4 Stream sediment concentration

Figure 4 shows the flow-weighted mean annual concentration of suspended sediments less than 0.063 mm in diameter, hereafter simply referred to as sediment concentration, for all seven catchments from 1975-76 to 1986. Concentrations below 5 mg/L cannot be determined accurately. A concentration of 5 mg/L can be visualised as two pulverized sandgrains mixed with 1 litre of water. Most water samples which contained less than 5 mg/L of suspended sediments were registered as <5 mg/L on the data base, although in some cases the actual measured value was registered. For consistency all these values were set equal to 3 mg/L in the calculation of the flow-weighted mean annual sediment concentrations.

Under mature forest conditions the suspended sediment concentration in all catchments was always less than 10 mg/L, and in most years less than 5 mg/L (Appendix E). As a result of logging it rose slightly at Lewin South in 1982 and 1983 to a maximum in 1984 when vegetative cover was at a minimum since burning was not carried out until late 1983 and early 1984 in this catchment. The 1984 sediment concentration may have been amplified by the fact that this was the wettest year in the Lewin area since the beginning of this study (Fig. 4). The sediment concentration was below 5 mg/L again in 1985, and 1986. Road construction caused a small increase in sediment concentration at March Road in 1981. Logging then brought about a concentration of 20 mg/L in 1982, the highest value observed during the study in this or any other catchment. Recall that logging continued throughout the winter of 1982 at March Road, while there was no logging during the winter month in the other catchments. The sediment concentration at March Road was also relatively high in 1983, probably as a result of the regeneration burn early in that year. Since then the sediment concentration has declined sharply and in 1986 was well below 5 mg/L again.

No change in sediment concentration was observed at April Road North and in the Yerraminnup South catchment a notable increase occurred only in 1982 when most of the logging took place. Recall that in both catchments a strip of forest was retained along the streams. The data indicate that these strips were effective in preventing virtually all of the additional sediment produced as a result of logging from reaching the streams. Other studies have also shown that the retention of vegetation strips along streams can prevent increases in stream sediment concentrations due to logging. Strips less than 30 m wide have been found to be effective, although the required width depends on the steepness of the terrain and other factors (Clinnick 1985). However, stopping the logging during the wet season at April Road North and Yerraminnup South probably kept the amount of sediment generated small in the first place (see Lewin South). Furthermore, rainfall and hence surface runoff in these two catchments are relatively low, especially at Yerraminnup South. As a result of these factors any increase in stream sediment concentration due to logging would probably have been small even without retaining the forest along the streams, and most likely so at Yerraminnup South in the low rainfall zone.

A variety of processes contribute to potential increases in soil erosion and stream sediment concentrations as a result of logging. For erosion to take place soil particles must first be dislodged from larger aggregates. This can be achieved by the impact energy of raindrops, especially during high intensity rainfall events. Vegetation absorbs much of the impact so that its removal frees more energy. Logging also exposes more soil. However, there is usually still a lot of litter on the ground to shield the soil. Hence, raindrops may not always be significant in dislodging soil particles. Falling trees, and to a greater degree their removal and the associated movement of machinery also break up soil aggregates. Surface runoff subsequently transports dislodged material away. The higher the flow volume, the more can be removed. Fast moving water can also dislodge particles, and on long or steep slopes surface runoff may reach sufficient velocities to do so. Vegetation, shrubs and grasses in particular, slow the water movement, which causes some of the sediment to settle, and also filter out some of the sediment. Clearing of vegetation therefore allows more sediment to reach the streams. Reducing surface flow velocities and filtering are the two mechanisms which make the retention of vegetation strips along streams effective in preventing increases in stream sediment concentrations due to logging.

Litter also slows down surface runoff and filters out sediment. Cut-over areas are usually burnt prior to regeneration to dispose of the waste from logging. Much of the litter may thereby be destroyed, particularly if the burn is very hot. Fire can make the soil surface water repellent for some time which reduces infiltration and increases surface runoff. Hence, logged areas are prone to erosion from the time of burning until some vegetation has grown back. This was evident in the relatively high stream sediment concentrations observed at March Road and Lewin South after the regeneration burns.

Some dislodged particles are washed into the soil and thus block soil pores. Raindrops can compact the top few millimetres of soil. Falling trees, their removal and movement of machinery can also compact soils, and to greater depths. These processes cause a reduction in infiltration capacity. This increases the probability that the rainfall rate exceeds the infiltration rate, and hence the chance for additional surface runoff to be generated. Compacted soil is eventually loosened up by growing roots and cyclic wetting and drying. Since this takes time, a lowered infiltration capacity may persist for some years after logging. Soils are most susceptible to compaction and break-up of aggregates when they are moist. Logging during the wet periods therefore carries a greater potential for soil erosion and increases in stream sediment concentration than logging during dry periods. This was demonstrated by the relatively high concentrations observed at March Road in 1982 where logging continued during wet periods. Since more trees are felled and removed, which in turn exposes more soil and involves more movement of heavy machinery, clear-felling has more potential for soil disturbance and hence soil erosion than selection cutting.

Logging roads are densely compacted and therefore produce a lot of surface runoff. If there is no adequate drainage, such road runoff can cause serious erosion in adjacent areas or on the road itself. Heavy traffic on logging roads also tends to pulverize the road surface and thus create an additional source of sediments. Logging roads are often a significant source of sediments. However, if they are well constructed, away from the streams, with good drainage facilities, with few sections with steep gradients and few stream crossings, they do not present a problem. Further information on the effect of logging on erosion and stream sediment concentration is given by Brown (1985).

The increased stream sediment concentrations observed at March Road and particularly Lewin South as a result of logging are not large in absolute terms as one can visualise from the sandgrain analogy given above. This can be attributed to the relatively small amounts of surface runoff in the region, even after logging (Stokes and Loh 1982; Williamson et al. 1987), the mostly gentle topography, and the stable soils. Sand and clay are the dominant soil textures. Sand particles are generally too big to be moved by the low surface flow rates, and the cohesive clay is hard to dislodge from the large and stable aggregates it forms. Silt is the soil texture most susceptible to erosion. It is not very cohesive and hence dislodged easily, and small enough to be transported. However, there is not much of it within the southern forest of Western Australia.

Note that the sediment values given here differ from those in a related report (Steering Committee 1987). The latter were a preliminary estimate of flow-weighted mean annual sediment concentrations calculated using only the discrete sediment samples and the flow rate at the time these samples were collected.

3.5 Stream salinity

Stream salinity is discussed here in terms of flow-weighted mean annual values. Flow-weighted mean annual stream salinity, hereafter simply referred to as stream salinity, and streamflow are related. It is therefore possible to evaluate salinity changes after logging from the nature of this relationship before logging (Appendix T). Note that stream salinity decreases as flow increases and recall that streamflow increased after logging. The change in salinity caused by logging is therefore not the difference between the observed salinity and the salinity predicted by the regression line for the observed flow, but the difference between the observed salinity and the salinity predicted by the regression line for the flow that would have occurred if there was no logging, which is obtained from the regressions in Appendix O. This is illustrated in Figure 8.

The changes in stream salinity due to logging are plotted in Figure 9. In the Lewin South catchment stream salinity increased from the commencement of logging in 1982 until 1985 and then levelled off. At March Road it decreased in 1982, increased in 1983 and continued to rise since, although the rate of rise between 1984-85 and 1985-86 was smaller than in the earlier years. At April Road North stream salinity increased until 1983, then fell until 1985 when it was only

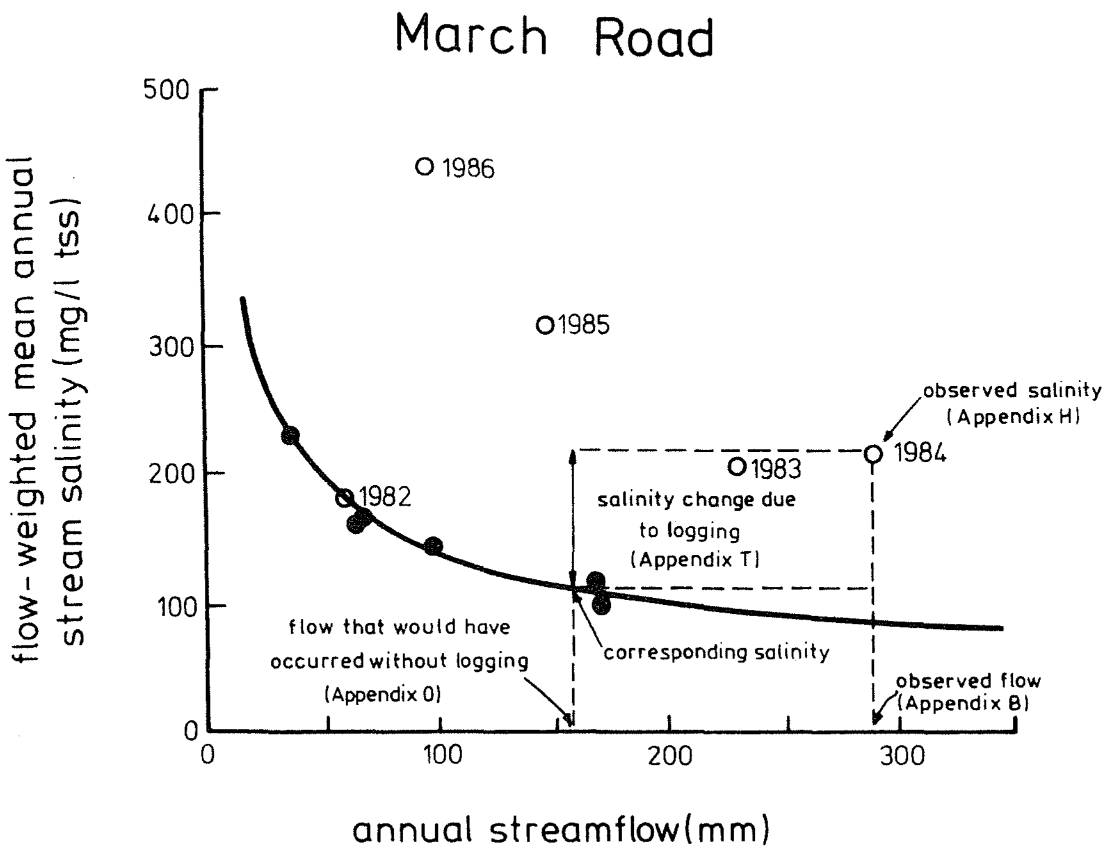


Figure 8

An example how to estimate the change in stream salinity due to logging.

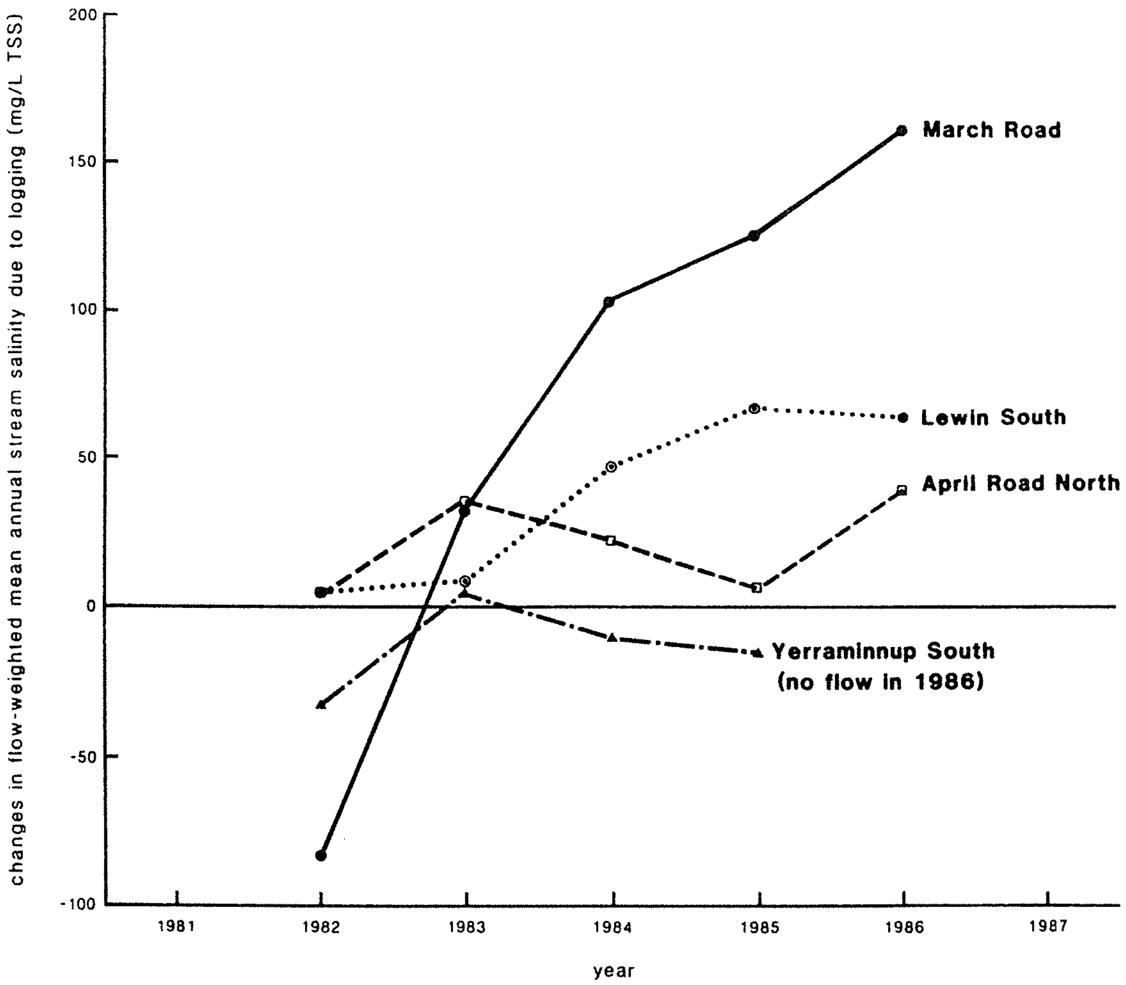


Figure 9

Changes in flow-weighted mean annual stream salinity in the four cut-over research catchments due to logging.

slightly above the level it would have been at without logging, but rose again in 1986. Except in 1983 when a slight increase occurred, the stream salinity at Yerraminnup South was less than it would have been without logging.

Most of the salt in the streams of south-west Western Australia is contributed by ground water, while most of the water originates from shallow subsurface flow (Stokes and Loh 1982; Stokes 1985; Williamson et al. 1987). Streamflow (section 3.3) and ground water levels (section 3.6) increase for some time after logging and then decrease again. An increase in stream salinity after logging as observed at Lewin South, March Road (except in 1982) and April Road North therefore indicates that the increase in the amount of salt discharged to the streams due to the raised ground water level was larger than the amount which could be balanced by the increase in flow. A decrease in stream salinity after logging, as observed at March Road in 1982 and Yerraminnup South (except in 1983), indicates that the increase in flow was larger than required to counter the increase in salt discharge.

In catchments in the high rainfall zone monitored by the Forests Department (Borg et al. 1987), stream salinity reached a maximum three years after the beginning of logging and then started to fall again as the forest grew back. The maximum increase ranged from 50 to 94 mg/L TSS, and the total annual stream salinity remained below 200 mg/L TSS, except in one catchment with atypical features for this rainfall zone. The response in the Lewin South catchment, also in the high rainfall zone, was similar. Stream salinity increased for four years after the beginning of logging and decreased slightly in the fifth year, the last year of record so far. The maximum increase was 68 mg/L TSS, and the highest total annual salinity was 183 mg/L TSS, well below the 500 mg/L TSS considered to be the upper limit for high quality drinking water (Department of Health 1980). The small effect of logging on stream salinity is probably a result of the generally relatively low soil salt contents in this rainfall zone (Johnston et al. 1980).

Because of the large increases in stream salinity observed after replacing forest with crops and pastures (Borg et al. 1987), the low rainfall zone, where soil salt contents are generally high (Johnston et al. 1980), was considered to be the most likely location where logging might lead to high stream salinities (Steering Committee 1978, 1980). Contrary to this assumption stream salinity in the Yerraminnup South catchment (830 mm long-term mean annual rainfall) was generally lower after logging than before. The uncut forest retained along the streams helped to reduce the ground water rise after logging (section 3.6) and hence the amount of additional salt discharge by ground water. However, similar results were also obtained in the Mooralup catchment (880 mm long-term mean annual rainfall) discussed by Borg et al. (1987) where the stream areas were cut. Before and after logging annual stream salinity was usually below 200 mg/L TSS in both catchments.

As a result of the dry conditions, low rainfall and high potential evapotranspiration, ground water in the low rainfall zone is generally well below the soil surface. Furthermore, the selective cutting of jarrah forest, which ensures that there is some transpiring vegetation present at all times, combined with the dry conditions leaves little water for net ground water recharge in a given year. If regeneration begins soon after logging, as in the two catchments mentioned above, the combination of these factors seems to prevent a rise in ground water level large enough to lead to an increase in stream salinity, even without the extra precaution of leaving the forest along the streams uncut.

At April Road North in the intermediate rainfall zone, the biggest increase in stream salinity was 42 mg/L TSS and the highest total salinity was 154 mg/L TSS, values similar to those observed in the high rainfall zone. The forest strip retained along the main stream at April Road North reduced the rise in ground water level along the stream which may have helped to keep the salinity increase small. However, before and after logging the ground water level in this catchment was closer to the surface on the slopes than in the valley (Appendix K and M). Salt discharge by ground water increases the closer the ground water level is to the soil surface. Most of the salt discharge before and after logging therefore probably occurred on the slopes which raises the question how significant the forest strip along the stream actually was in limiting the increase in stream salinity in this catchment.

Prior to logging, stream salinity in the neighbouring March Road catchment was consistently higher than at April Road North. The maximum salinity increase and the highest total salinity after logging were also higher, namely 164 and 439 mg/L TSS, respectively. Soil salt contents are similar in the two catchments (Johnston et al. 1980) and are therefore not responsible for the differences. However, in one valley bore at March Road the water level was above the soil surface most of the time before logging, and continuously as well as higher above the soil surface since logging (Appendix M). Such high bore water levels indicate upward ground water flow, which in south-west Western Australia can discharge large amounts of salt. The area around this bore is possibly the main contributor to stream salinity at March Road.

In all four catchments the flow-weighted mean annual stream salinity since logging was below 500 mg/L TSS, the upper limit for high quality drinking water, and, except at March Road, even below 200 mg/L TSS. Similar to the relationship between annual streamflow and flow-weighted mean annual stream salinity shown in Appendix T, stream salinity within a year is also inversely related to streamflow. During the middle of the wet season, when most of the streamflow takes place, stream salinities are typically below 200 mg/L and often even below 100 mg/L TSS. At the beginning and end of the wet season, when streamflow is low, days with higher stream salinities occur, particularly at March Road. However, this usually involves just a small amount of the total annual streamflow volume in a catchment (Appendix I) and therefore has only a small effect on the flow-weighted mean annual stream salinity.

3.6 Ground water

Prior to logging ground water discharged to the streams in the valley areas of both Lewin catchments, at March Road and April Road South. At April Road North there was ground water discharge at the head of two small tributaries to the main stream in the catchment, but not in the valley of the main stream itself. No ground water discharge to streams occurred in the Yerraminnup group. The ground water system in these seven experimental catchments is described in more detail by Martin (1986).

The lowest ground water level each year generally occurs at the end of the dry season or sometimes a few weeks into the wet season, and the highest ground water level near or a few weeks after the end of the wet season. Both are influenced by variations in rainfall and are typically lower in a dry year than in a wet year. However, variations in the amount and distribution of the annual rainfall generally influence the maximum ground water level much more than the minimum ground water level. The latter thus better represents changes in ground water storage from year to year due to disturbances of the water balance. The minimum water level in each bore was therefore chosen to represent the ground water status in a given year.

Note that bore holes provide an easy pathway for vertical ground water movement. Bore water levels therefore represent the height to which ground water would rise if there was a non-restrictive flowpath. If low permeability retards vertical ground water movement bore water levels often do not correspond to the actual position of the ground water. This was the case for some bores in the Lewin, March Road and April Road catchments where no water was ponded on the soil surface even though the bore water levels were above the soil surface.

Only bores which contained water throughout the study period were considered. The minimum annual water levels for these bores from 1975-76 to 1986 are listed in Appendix M. To evaluate the effect of retaining a strip of forest along a stream on the ground water response to logging, bores near the streams were analysed as one group (valley bores), and the remaining bores as another (slope bores). At April Road North and Yerraminnup South only bores within the forest strips left uncut along the streams were classified as valley bores. In the other five catchments bores which are located within 100 m perpendicular to a stream channel and less than 5 m above it along the perpendicular transect were classified as valley bores. For each bore group in a catchment and each year an average minimum water level was computed and plotted in Figure 4.

The minimum annual water levels for each group of bores in the logged and the respective control catchments are compared in Appendix U. Before logging they were well correlated, but after logging they rose in all logged catchments relative to the unlogged ones. Substituting the minimum annual water level observed in a group of bores in a control catchment since 1982 into the appropriate regression equation in Appendix U yields an estimate of the minimum annual water level which would have occurred in the corresponding group of bores in a logged catchment if the catchment had not been logged. The difference between these estimates and the values observed in the logged catchments represent the effect of logging on minimum annual bore water levels and is plotted in Figure 10. In both bore groups in the four cut-over catchments the minimum annual water level rose sharply from 1982 to 1984 as a result of logging. Except in the slope areas at March Road and the valley areas at April Road North there has since been a decline in the rate of rise, or even a slight decline in the minimum annual bore water level.

After logging ground water recharge increases because transpiration and interception have been reduced. In the lower parts of a catchment, namely the valleys along the streams, ground water recharge is further enhanced by increased flow from upslope. Hence, the bore water levels in the stream areas initially rise more than on the slopes. This was observed at March Road, and less clearly at Lewin South. At April Road North the stream area was not logged and

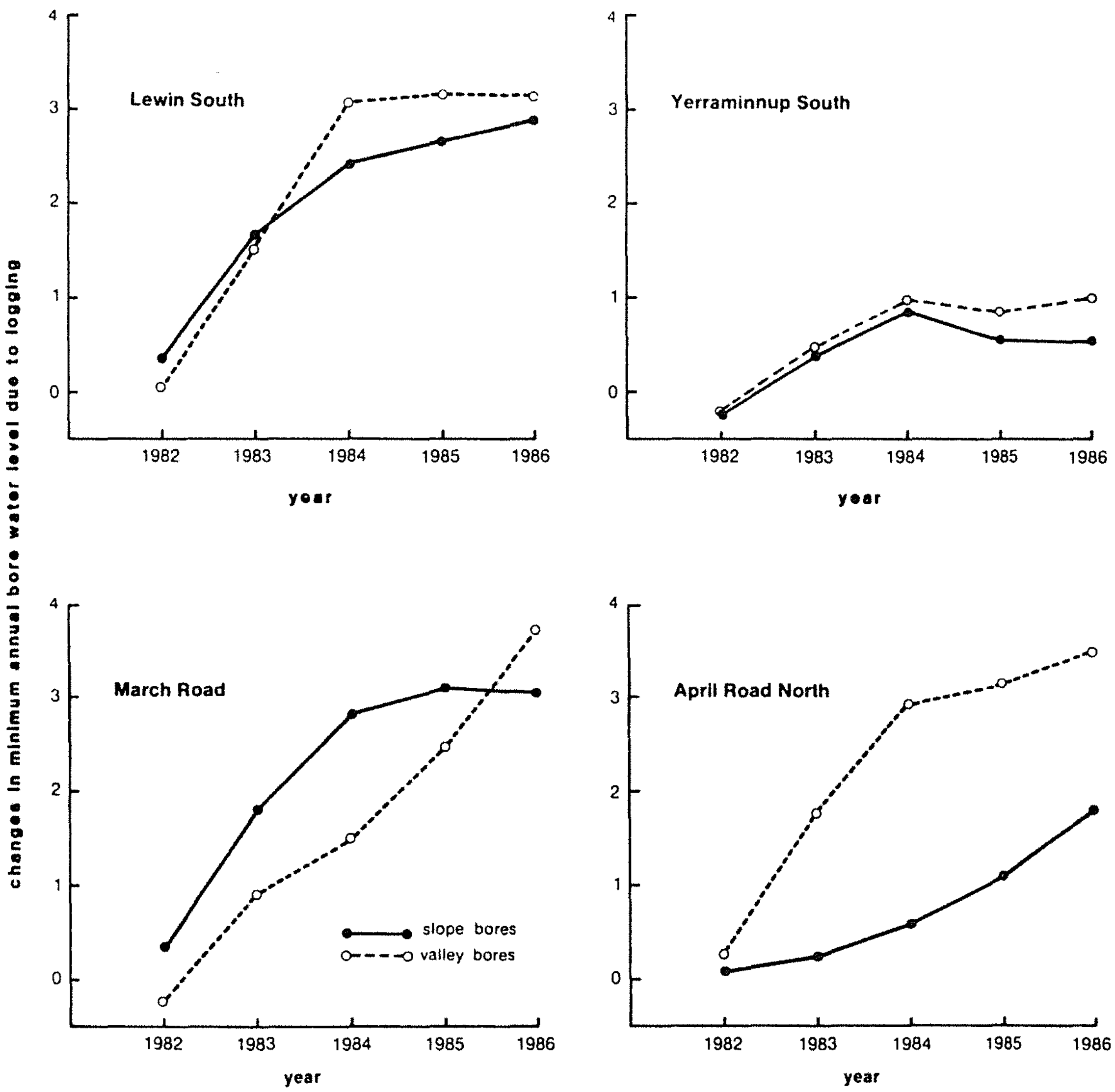


Figure 10

Changes in the minimum annual water level averaged for groups of bores in the four cut-over research catchments due to logging.

the bore water levels there rose considerably less than elsewhere in the catchment. However, they are still rising in the stream area and at an increasing rate while the rate of rise has started to level off in the slope areas. A strip of forest was also retained along the streams at Yerraminnup South. In both groups of bores in this catchment the water level rose by similar amounts until 1984 and since began to recede in the stream area, and to level off in the slope areas. As the stream zones at April Road North and Yerraminnup South were not logged the rise in the bore water levels there was entirely due to recharge from upslope. Had these areas been cut the bore water levels would have risen more because recharge would also have occurred due to a reduction in transpiration and interception.

The bore water level rise at Lewin South, March Road and the slope areas at April Road North was of similar magnitude. However, due to its wetter climate, higher rainfall coupled with lower pan evaporation (Table 1), there would have been a bigger rise at Lewin South had this catchment been clear-felled like the other two. The relatively small rise at Yerraminnup South can be attributed to the dry climatic conditions there, low rainfall combined with high pan evaporation, and was further moderated by the vegetation left by the selection cutting system.

As the vegetation grows back transpiration and interception increase so that ground water recharge decreases. The amount of water removed from the saturated zone by transpiration increases too. This amount is greater the closer the bore water levels are to the soil surface (Hillel 1982). Ground water flow to the soil surface, from where it can evaporate, ground water discharge to the surface water system and lateral ground water flow also tend to increase the nearer ground water is to the soil surface. The bore water level rise is therefore likely to slow earlier in stream areas than on the slopes as it happened at Lewin South, March Road and Yerraminnup South. Because of some unusual features in the ground water system (Martin 1986) the bore water levels at April Road North are actually closer to the surface on the slopes than in the stream zone

(Appendix K and M) so that the water level rise in this catchment slowed earlier in the slope bores.

In the four experimental catchments which were logged in 1976-78 and where regeneration began in 1978-79, bore water levels rose for two to four years after logging and then began to decline again as the vegetation grew back (Borg et al. 1987). Except in the slope areas at March Road and in the valley areas at April Road North the beginning of this trend is evident in the other cut-over areas monitored in this study.

4. Conclusions

In all four cut-over catchments logging led to a rise in ground water levels. This was accompanied by an increase in streamflow. Flow-weighted mean annual stream salinities therefore rose only by relatively small amounts and always remained within the limit for high quality drinking water. In the Yerraminnup South catchment stream salinities were generally even less than they would have been without logging, despite its location in the low rainfall zone which was initially considered to be the most likely region where intensive logging might result in high stream salinities.

Stream sediment concentrations increased significantly only in the March Road catchment. The increase at Lewin South was very small, and at April Road North and Yerraminnup South where the vegetation along the streams was retained, there was virtually no increase at all. After 3 to 4 years of regeneration the sediment concentrations at March Road and Lewin South were back to pre-logging levels. Although still small in absolute terms, the temporary increase in sediment concentrations in the March Road catchment would have been much lower if it had not been logged throughout the wet season.

Due to the rainfall pattern and the short hydrologic record since logging the data from this study alone do not permit any definite conclusions about future trends in ground water levels, streamflow and stream salinity in the four cut-over research catchments. However, the trends observed so far and their agreement with observations from nearby catchments with a longer post-logging record suggest that serious salinity problems are not likely to develop and that after 10 to 15 years of regeneration or less ground water, streamflow and stream salinity are likely to return the level they would have been at had there been no logging. Further monitoring of these parameters is recommended to confirm this and to assess whether streamflow from regenerating stands will eventually be less than from the mature stands they replaced as suggested by data from Victoria.

To date there is no evidence to indicate that in the southern forest of Western Australia clear-felling of karri stands and heavy selection cutting of jarrah stands leads to serious or long-lasting increases in stream salinity, not even in the low rainfall zone, as long as the cut-over areas are regenerated to forest soon after the completion of logging. The same applies to stream sediment concentrations, especially if there is no logging during the wet season. So far logging in the low rainfall was restricted to light selection cutting of sawlogs to contain a perceived high salinity risk. In light of the research results presented here and by Borg et al. (1987) this restriction can be lifted and heavy selection cutting of sawlogs and chiplogs allowed.

The forest strips which were kept along the streams in the April Road North and Yerraminnup South catchment reduced the ground water rise in the valleys due to logging. This probably moderated the associated increase in salt discharge and stream salinity, although it was not obvious from the data. The forest strips did prevent an increase in stream sediment concentrations due to logging. However, even without them any increase would most likely have been small. Hence, in these two catchments their effect was not substantial. However, where there is a potential for large increases in stream sediment concentrations or salinity due to logging, for example in areas with unstable soils or very saline ground water near the soil surface in the valleys, the retention of forest strips along streams will have a greater benefit for the protection of water quality.

5. Acknowledgements

The studies reported on here commenced in 1975 and are still in progress. Preparing this interim report was only a small part of the work carried out to date. Much more time and effort went into the collection and processing of the data. Most of the credit for this report should therefore go to the past and present hydrographic staff at the Manjimup office of the Water Authority of Western Australia, namely Don Barrett, Noel Turner, Ken McIntosh, Peter Helsby, Richard Murton, Ray Findlay, Peter Buckley, Peter Clews, Frank Davies, Trevor York, Mark Williams and Stephen De Munck who collected the data, and to Marie Freakley, Ray Studham, Brad Fuller, Sue Hardie, Joanne Wright, Pinetta Ulgiati, Megan McLuckie, Reneé King and Greg May at the Head Office in Leederville who processed the data.

We also wish to thank Karen Lemnell, Sue Graham and Fiona Carter for typing the manuscript; Mark Bozikovic, Peter Van De Wyngaard, Michael Briggs, Roy Morgan and Fiona Mackie for preparing the figures; Nick Schofield and Michael Martin for reviewing the manuscript; and Debbie Cunningham, Glyn Kernick, Robert Stokes, Allan Waugh, Colin Cicero, John Ruprecht, Amie Seet, Andrew Hukin, Kim Wearne and Peter Lutz for various small but essential contributions.

6. References

ABAWI, G.Y. and STOKES, R.A. (1982). 'Wights catchment sediment study 1977-1981.' Public Works Department of Western Australia, Water Resources Technical Report No. 100.

BORG, H., STONEMAN, G.L. and WARD, C.G. (1987). 'Stream and ground water response to logging and subsequent regeneration in the southern forest of Western Australia. Results from four catchments.' Department of Conservation and Land Management W.A., Technical Report No. 16.

BOSCH, J.M. and HEWLETT, J.D. (1982). 'A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration.' Journal of Hydrology 55:3-23.

BROOKES, J.O. (1950). 'The relation of vegetative cover to water yield in Victorian mountain watersheds.' M. Sc. Thesis, University of Melbourne.

BROOKES, J.O. and TURNER, J.S. (1963). Hydrology and Australian forest catchments. In: Australian Academy of Science, 'Water resources - use and management.' Proceedings of a Symposium at Canberra, A.C.T. Melbourne University Press, Melbourne.

BURVILL, G.H. (1947). 'Soil salinity in the agricultural areas of Western Australia.' Journal of the Australian Institute of Agricultural Science 13:9-19.

BROWN, G.W. (1985). 'Forestry and water quality.' Oregon State University Book Stores, Corvallis.

CLINNICK, P.F. (1985). 'Buffer strip management in forest operations : a review.' Australian Forestry 48:34-45.

COLLINS, P.D.K. and BARRETT, D.F. (1980). 'Shannon, Warren and Donnelly river basins water resources survey.' Engineering Division, Public Works Department of Western Australia, Water Resources Branch Report No. W.R.B. 6.

COMMONWEALTH BUREAU OF METEOROLOGY (1987). 'Climatic Atlas of Australia.' Australian Government Publishing Service, Canberra.

DEPARTMENT OF HEALTH (1980). 'Desirable quality for drinking water in Australia.' Australian Government Publishing Service, Canberra.

FORESTS DEPARTMENT OF WESTERN AUSTRALIA (1973). 'Environmental impact statement on the woodchipping industry agreement proposals for Western Australia.'

HIBBERT, A.R. (1967). Forest treatment effects on water yield. In: Sopper, W.E. and Lull, H.W. (eds.), 'Forest Hydrology.' Pergamon Press, New York. pp 527-543.

HILLEL, D. (1982). 'Introduction to soil physics.' Academic Press, New York.

HINGSTON, F.J. and GAILITIS, V. (1976). 'The geographic variation of salt precipitated over Western Australia.' Australian Journal of Soil Research 14:319-335.

JOHNSTON, C.D., McARTHUR, W.M. and PECK, A.J. (1980). 'Distribution of soluble salts in soils of the Manjimup Woodchip Licence Area, Western Australia.' CSIRO, Land Resources Management Technical Paper No. 5.

KUCZERA, G. (1985). 'Prediction of water yield reductions following a bushfire in ash-mixed species eucalypt forest.' Melbourne and Metropolitan Board of Works, Report No. MMBW-W-0014.

LANGFORD, K.J. (1976). 'Change in yield of water following a bush fire in a forest of Eucalyptus regnans.' Journal of Hydrology 29:87-114.

LOH, I.C. and KING, B. (1978). 'Annual rainfall characteristics of the Warren, Shannon and Donnelly River Basins.' Public Works Department of Western Australia, Water Resources Technical Report No. 78.

MARTIN, M.W. (1980). 'Hydrogeology of the Iffley coupe.' Geological Survey of Western Australia, Hydrogeology Report No. 2197.

MARTIN, M.W. (1986). 'Review of the effect of logging on groundwater in the southern forest of Western Australia. Project 2, paired catchment study.' Geological Survey of Western Australia, Record 1987/6.

McARTHUR, W.M. and CLIFTON, A.J. (1975). 'Forestry and agriculture in relation to soils in the Pemberton area of Western Australia.' CSIRO, Division of Soils, 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.' Water Resources Research 9:648-657.

SHEA, S.R., HATCH, A.B., HAVEL, J.J. and RITSON, P. (1975). The effect of changes in forest structure and composition on water quality and yields from the northern jarrah forest. In: Kikkawa, J. and Nix, H.A. (eds.) 'Managing terrestrial Ecosystems.' Proceedings of the Ecological Society of Australia 9: 58-73.

SMITH, F.G. (1972). 'Vegetation map of Pemberton and Irwin Inlet.' Western Australian Department of Agriculture.

STEERING COMMITTEE (1978). 'Research into the effects of the woodchip industry on water resources in south Western Australia.' (Western Australian) Department of Conservation and Environment, Bulletin No. 31.

STEERING COMMITTEE (1980). 'Research into the effects of the woodchip industry on water resources in south Western Australia.' (Western Australian) Department of Conservation and Environment, Bulletin No. 81.

STEERING COMMITTEE (1987). 'The impact of logging on the water resources of the southern forests, Western Australia.' Water Authority of Western Australia, Report No. WH 41.

STOKES, R.A. (1985). 'Stream water and chloride generation in a small forested catchment in south Western Australia.' Water Authority of W.A., Water Resources Directorate, Hydrology Branch Report No. WH7.

STOKES, R.A. and LOH, I.C. (1982). Streamflow and solute characteristics of a forested and deforested catchment pair in south-western Australia. In: The Institution of Engineers, Australia, 'The first national symposium on forest hydrology.' National Conference Publication No. 82/6. pp 60-66.

STONEMAN, G.L., ROSE, P. and BORG, H. (1987). 'Forest density response following intensive logging operations in the southern forest of Western Australia'. Department of Conservation and Land Management W.A., Technical Report (under review).

STONEMAN, G.L., SCHOFIELD, N.J., and BARTLE, J.R. (in preparation). 'Silviculture for water production in the northern jarrah forest : a review'. Report of the Forest Management Sub-Committee of the (Western Australian) Steering Committee for Research on Land Use and Water Supply.

WILLIAMSON, D.R., STOKES, R.A. and RUPRECHT, J.K. (1987). 'Response of input and output of water and chloride to clearing for agriculture.' Journal of Hydrology 94:1-28.

WOOD, W.E. (1924). 'Increase of salt in soil and streams following the destruction of native vegetation.' Journal of the Royal Society of Western Australia 10:35-47.

Appendices

Appendix A : Annual rainfall in the seven research catchments from 1975 to 1986.

	Lewin North		Lewin South		March Road		April Road North		April Road South		Yerraminnup North		Yerraminnup South	
	rainfall (mm)	ratio[1]	rainfall (mm)	ratio[1]	rainfall (mm)	ratio[1]	rainfall (mm)	ratio[1]	rainfall (mm)	ratio[1]	rainfall (mm)	ratio[1]	rainfall (mm)	ratio[1]
1975											703	.83	699	.84
1976	1130	.91	1131	.92	988	.95	1010	.94	1040	.96	780	.92	786	.95
1977	1069	.86	1046	.85	974	.94	994	.93	997	.92	707	.83	701	.84
1978	1125	.91	1137	.92	1055	1.01	1094	1.02	1117	1.03	883	1.04	851	1.03
1979	1077	.87	1069	.87	932	.90	932	.87	935	.87	690	.81	666	.80
1980	1165	.94	1148	.93	929	.89	992	.93	982	.91	768	.90	729	.88
1981	1181	.95	1166	.95	1121	1.08	1158	1.08	1178	1.09	851	1.00	829	1.00
1982	941	.76	936	.76	807	.78	827	.77	826	.76	628	.74	607	.73
1983	1137	.92	1131	.92	922	.89	898	.84	940	.87	831	.98	816	.98
1984	1184	.95	1198	.97	1114	1.07	1129	1.06	1146	1.06	800	.94	802	.97
1985	1007	.81	1015	.83	927	.89	914	.85	951	.88	722	.85	716	.86
1986	965	.78	1006	.82	821	.79	848	.79	850	.79	618	.73	576	.69
mean for data	1089	.88	1089	.89	963	.93	981	.92	997	.92	748	.88	732	.88
long-term mean[2]	1240		1230		1040		1070		1080		850		830	

[1] ratio between the rainfall in the respective year and the mean annual rainfall for 1926 through 1976

[2] estimated from Figure 2 with consideration of the data in this table

Appendix B : Annual streamflow in the seven research catchments from 1975 to 1986.

	Lewin North		Lewin South		March Road		April Road North		April Road South		Yerraminnup North		Yerraminnup South	
	streamflow (mm)	(%R)[1]	streamflow (mm)	(%R)[1]	streamflow (mm)	(%R)[1]	streamflow (mm)	(%R)[1]	streamflow (mm)	(%R)[1]	streamflow (mm)	(%R)[1]	streamflow (mm)	(%R)[1]
1975											21	3.0	20	2.9
1976	108	9.6	81	7.2	37	3.7	36	3.6	59	5.7	2.4	.3	4.7	.6
1977	144	13.5	110	10.5	98	10.1	66	6.6	92	9.2	2.5	.4	1.9	.3
1978	227	20.2	193	17.0	172	16.3	142	13.0	192	17.2	59	6.7	53	6.2
1979	135	12.5	105	9.8	64	6.9	41	4.4	68	7.3	1.6	.2	.7	.1
1980	208	17.9	183	15.9	68	7.3	60	6.0	98	10.0	9.5	1.2	5.1	.7
1981	232	19.6	201	17.2	169	15.1	141	12.2	217	18.4	45	5.3	42	5.1
1982	175	18.6	177	18.9	61	7.6	41	5.0	29	3.5	.1	.02	.5	.1
1983	203	17.9	275	24.3	320	25.0	165	18.4	73	7.8	69	8.3	90	11.0
1984	171	14.4	315	26.3	290	26.0	291	25.8	186	16.2	21	2.6	55	6.9
1985	96	9.5	177	17.4	149	16.1	114	12.5	62	6.5	7.6	1.1	16	2.2
1986	89	9.2	149	14.8	98	11.9	67	7.9	26	3.1	no flow		no flow	

[1] %R stands for % of annual rainfall

Appendix C : Number of days with flow (N) and average daily flow rate (Q)[1] in the seven research catchments from 1975 to 1986.

	Lewin North		Lewin South		March Road		April Road North		April Road South		Yerraminnup North		Yerraminnup South	
	N (days)	Q (mm/day)	N (days)	Q (mm/day)	N (days)	Q (mm/day)	N (days)	Q (mm/day)	N (days)	Q (mm/day)	N (days)	Q (mm/day)	N (days)	Q (mm/day)
1975											127	.17	130	.15
1976	210	.51	173	.47	207	.18	185	.19	205	.29	110	.02	114	.04
1977	188	.77	159	.69	198	.49	189	.35	191	.48	104	.02	97	.02
1978	201	1.13	154	1.25	203	.85	184	.77	184	1.04	142	.42	142	.37
1979	185	.73	164	.64	211	.30	189	.22	192	.35	54	.03	50	.01
1980	183	1.14	149	1.23	168	.40	161	.37	161	.61	121	.08	126	.04
1981	214	1.08	182	1.10	200	.85	182	.77	188	1.15	134	.34	133	.32
1982	359	.49	210	.84	199	.31	139	.29	136	.21	45	.002	62	.01
1983	157	1.29	179	1.54	189	1.22	148	1.11	125	.58	114	.61	154	.58
1984	207	.83	234	1.35	226	1.28	212	1.37	201	.93	140	.15	178	.31
1985	154	.62	215	.82	229	.65	163	.70	147	.42	85	.09	86	.19
1986	138	.64	174	.86	160	.61	129	.52	117	.22	no flow		no flow	

[1] calculated by dividing the annual flow in Appendix B by the number of days with flow

Appendix D : Instantaneous peak flow rate (Q_p)[1] and maximum flow in one day (Q_d) in the seven research catchments from 1975 to 1986.

	Lewin North		Lewin South		March Road		April Road North		April Road South		Yerraminnup North		Yerraminnup North	
	Q_p (mm/day)	Q_d (mm)	Q_p (mm/day)	Q_d (mm)	Q_p (mm/day)	Q_d (mm)	Q_p (mm/day)	Q_d (mm)	Q_p (mm/day)	Q_d (mm)	Q_p (mm/day)	Q_d (mm)	Q_p (mm/day)	Q_d (mm)
1975											1.55	1.12	1.83	1.23
1976	5.35	4.50	6.18	5.59	1.61	1.30	2.95	1.54	4.56	2.26	.20	.12	.76	.33
1977	7.90	6.62	6.98	5.84	9.15	6.98	8.02	5.67	11.50	7.38	.28	.16	.42	.15
1978	14.76	12.73	16.73	14.67	13.26	11.28	14.44	8.61	19.65	10.84	4.48	3.03	5.74	3.57
1979	6.29	5.24	5.60	4.97	4.23	2.95	3.06	2.10	7.71	4.50	.29	.20	.29	.12
1980	16.06	9.37	16.25	9.55	3.04	2.09	2.97	1.95	7.34	3.70	2.07	.46	1.30	.39
1981	10.83	7.43	10.84	7.89	11.93	8.07	10.83	6.94	16.42	10.23	4.13	1.63	7.05	1.53
1982	8.55	7.21	12.88	10.60	8.46	4.85	4.10	2.44	4.55	2.43	.06	.01	.08	.04
1983	16.35	10.29	28.32	15.34	30.20	10.41	18.43	8.14	9.36	5.54	8.12	3.33	13.16	4.54
1984	10.57	7.71	29.19	13.25	28.96	12.46	21.51	12.43	10.99	5.79	1.57	.93	5.18	2.14
1985	12.78	6.03	32.82	12.25	62.92	18.29	40.69	12.28	17.55	8.25	.83	.57	4.21	1.80
1986	3.44	3.16	14.11	7.79	6.50	3.11	5.45	2.09	1.93	1.31	no flow		no flow	

[1] instantaneous peak flow rate is usually given in m^3/sec or mm/sec but is expressed here in mm/day for easier comparison with other flow data in this report.

Appendix E : Flow-weighted mean annual concentration of suspended sediments less than .063 mm in diameter (mg/L) in the seven research catchments from 1975 to 1986.

	Lewin North	Lewin South	March Road	April Road North	April Road South	Yerraminnup North	Yerraminnup South
1975						7.09	10.50
1976	3.13	3.00	8.64	4.82	4.23	3.13	3.90
1977	3.16	3.06	3.19	3.17	5.46	8.54	3.78
1978	3.01	3.00	3.05	3.02	3.03	3.03	3.07
1979	3.00	4.52	4.43	3.07	3.20	3.00	3.01
1980	3.00	3.00	3.61	3.18	3.15	3.34	3.04
1981	3.00	3.02	4.40	3.09	3.28	3.05	3.00
1982	3.02	5.14	20.17	3.05	6.66	7.73	5.23
1983	3.01	4.24	15.31	3.36	3.12	3.01	3.41
1984	3.02	5.97	4.92	3.09	3.02	3.00	3.80
1985	3.00	3.16	3.85	3.03	3.19	3.20	3.58
1986	3.00	3.18	3.06	3.03	3.04	no flow	no flow

Appendix F

Percentage of the annual streamflow within a given range of stream sediment concentrations in the seven research catchments from 1975 to 1986.

(All sediment concentrations are given in mg/L and refer to suspended sediments <.063 mm in diameter.)

LEWIN NORTH

year	sediment concentration (mg/L) 0 - 5	5 - 10	10 - 20	20 - 50	50 - 100	100 - 200	200 - 500	500 - 1000	flow-weighted mean
1975									
1976	97.4	2.6							3.13
1977	96.9	3.1							3.16
1978	99.8	.1	<.05						3.01
1979	100.0								3.00
1980	100.0								3.00
1981	100.0								3.00
1982	99.4	.6							3.02
1983	99.8	.2							3.01
1984	99.7	.2	.1						3.02
1985	100.0								3.00
1986	100.0								3.00

LEWIN SOUTH

year	sediment concentration (mg/L) 0 - 5	5 - 10	10 - 20	20 - 50	50 - 100	100 - 200	200 - 500	500 - 1000	flow-weighted mean
1975									
1976	100.0								3.00
1977	98.2	1.8							3.06
1978	99.9		<.05	<.05					3.00
1979	74.9	18.3	6.8						4.52
1980	99.9	<.05							3.00
1981	99.9		<.05	<.05					3.02
1982	80.8	7.5	6.9	4.8					5.14
1983	69.1	30.2	.7						4.24
1984	82.2	9.6	.4	7.8					5.97
1985	100.0								3.16
1986	97.8	2.2							3.18

MARCH ROAD

year	sediment concentration (mg/L) 0 - 5	5 - 10	10 - 20	20 - 50	50 - 100	100 - 200	200 - 500	500 - 1000	flow-weighted mean
1975									
1976	55.3	25.3	11.5	4.9	2.5	.5			8.64
1977	99.4	.3		.2	<.05	<.05	<.05	<.05	3.19
1978	99.8	.1	<.05	.1	<.05	<.05	<.05		3.05
1979	88.6	3.8	6.1	1.4	.1				4.43
1980	88.1	11.3	.3	.3	<.05	<.05			3.61
1981	68.4	28.4	2.9	.3	<.05				4.40
1982	16.1	38.7	19.1	14.8	9.2	1.7	.4		20.17
1983	32.2	28.3	10.5	24.6	4.4				15.31
1984	75.8	22.4	.2	1.5	.1				4.92
1985	87.3	12.7	<.05						3.85
1986	100.00								3.06

APRIL ROAD NORTH

year	sediment concentration (mg/L) 0 - 5	5 - 10	10 - 20	20 - 50	50 - 100	100 - 200	200 - 500	500 - 1000	flow-weighted mean
1975									
1976	88.6	4.5	.1	6.7	.1				4.82
1977	99.4	.4	<.05	<.05	.1	<.05	<.05		3.17
1978	99.9	<.05	<.05	<.05	<.05	<.05			3.02
1979	99.7		.1	.2					3.07
1980	94.6	5.4							3.18
1981	99.8	2.2	<.05						3.09
1982	98.5	1.5	<.05						3.05
1983	94.8	5.2							3.36
1984	98.2	1.7	<.05	.1					3.09
1985	99.6	.4							3.03
1986	100.00								3.03

APRIL ROAD SOUTH

year	sediment concentration (mg/L) 0 - 5	5 - 10	10 - 20	20 - 50	50 - 100	100 - 200	200 - 500	500 - 1000	flow-weighted mean
1975									
1976	81.4	16.6	1.6	.4					4.23
1977	84.3	10.7	1.7	<.05	3.2				5.46
1978	99.9	<.05		<.05	<.05	<.05	<.05		3.03
1979	98.8	.6	.1	.4	.1	<.05			3.20
1980	96.9	2.8	.3	<.05					3.15
1981	94.1	5.7	.2	<.05	<.05				3.28
1982	39.4	39.4	20.8	.4					6.66
1983	98.5	.4	1.1	<.05					3.12
1984	99.8	.1	<.05						3.02
1985	99.3	.7	<.05						3.19
1986	99.9	.1	<.05						3.04

YERRAMINNUP NORTH

year	sediment concentration (mg/L) 0 - 5	5 - 10	10 - 20	20 - 50	50 - 100	100 - 200	200 - 500	500 - 1000	flow-weighted mean
1975	84.8	8.6	3.7	1.6	.1	.8	.4		7.09
1976	97.8	2.0	.2						3.13
1977	70.6	4.6	4.7	20.0	.1				8.54
1978	99.3	.7							3.03
1979	100.0								3.00
1980	89.1	10.8	.1						3.34
1981	99.5	.4	.1						3.05
1982		88.1	11.9						7.73
1983	99.9	.1							3.01
1984	100.0								3.00
1985	97.4	1.4	1.2						3.20
1986									no flow

YERRAMINNUP SOUTH

year	sediment concentration (mg/L) 0 - 5	5 - 10	10 - 20	20 - 50	50 - 100	100 - 200	200 - 500	500 - 1000	flow-weighted mean
1975	47.8	33.2	16.2	.8	.9	<.05	.9	.1	10.50
1976	96.9	.3	.1	2.3	.4				3.90
1977	79.5	20.5	<.05						3.78
1978	99.1	.7	.2		<.05				3.07
1979	100.0								3.01
1980	99.6	.2		.2					3.04
1981	100.0								3.00
1982	74.6	16.0	8.7	.7					5.23
1983	92.9	7.1							3.41
1984	85.4	12.0	2.5		.1				3.80
1985	93.5		6.5						3.58
1986									no flow

Appendix G

Number of days with streamflow within a given range of stream sediment concentrations in the seven research catchments from 1975 to 1986.

(All sediment concentrations are given in mg/L and refer to suspended sediments <.063 mm in diameter.)

LEWIN NORTH

year	sediment concentration (mg/L)								total no. of days with flow
	0 - 5	5 - 10	10 - 20	20 - 50	50 - 100	100 - 200	200 - 500	500 - 1000	
1975									
1976	205	5							210
1977	187	1							188
1978	194	3	4						201
1979	185								185
1980	183								183
1981	214								214
1982	355	4							359
1983	155	2							157
1984	205	1	1						207
1985	154								154
1986	138								138

LEWIN SOUTH

year	sediment concentration (mg/L) 0 - 5	5 - 10	10 - 20	20 - 50	50 - 100	100 - 200	200 - 500	500 - 1000	total no. of days with flow
1975									
1976	173								173
1977	148	11							159
1978	152		1	1					154
1979	150	7	7						164
1980	148	1							149
1981	180		1	1					182
1982	188	9	7	5		1			210
1983	163	14	2						179
1984	224	4	1	5					234
1985	215								215
1986	173	1							174

MARCH ROAD

year	sediment concentration (mg/L)								total no. of days with flow
	0 - 5	5 - 10	10 - 20	20 - 50	50 - 100	100 - 200	200 - 500	500 - 1000	
1975									
1976	150	22	16	10	8	1			207
1977	165	5		4	4	13	5	2	198
1978	160	4	5	4	7	21	2		203
1979	147	2	3	9	50				211
1980	128	22	1	2	14	1			168
1981	132	34	10	13	11				200
1982	42	78	48	18	5	7	1		199
1983	67	60	50	11	1				189
1984	190	27	4	1	4				226
1985	222	5	2						229
1986	160								160

APRIL ROAD NORTH

year	sediment concentration (mg/L) 0 - 5	5 - 10	10 - 20	20 - 50	50 - 100	100 - 200	200 - 500	500 - 1000	total no. of days with flow
1975									
1976	144	6	1	20	14				185
1977	172	8	5	1	1	1	1		189
1978	156	1	3	11	10	3			184
1979	145		3	41					189
1980	140	21							161
1981	124	43	15						182
1982	109	24	6						139
1983	135	13							148
1984	199	10	1	2					212
1985	158	4	1						163
1986	129								129

APRIL ROAD SOUTH

year	sediment concentration (mg/L) 0 - 5	5 - 10	10 - 20	20 - 50	50 - 100	100 - 200	200 - 500	500 - 1000	total no. of days with flow
1975									
1976	173	20	7	5					205
1977	135	41	6	8	1				191
1978	155	1		2	12	13	1		184
1979	149	2	3	2	26	10			192
1980	129	15	5	12					161
1981	92	66	19	10	1				188
1982	25	60	42	9					136
1983	85	25	14	1					125
1984	176	24	1						201
1985	134	11	2						147
1986	107	8	2						117

YERRAMINNUP NORTH

year	sediment concentration (mg/L) 0 - 5	5 - 10	10 - 20	20 - 50	50 - 100	100 - 200	200 - 500	500 - 1000	total no. of days with flow
1975	99	11	6	5	3	2	1		127
1976	100	7	3						110
1977	93	2	2	5	2				104
1978	141	1							142
1979	54								54
1980	110	10	1						121
1981	131	1	2						134
1982		41	4						45
1983	112	2							114
1984	140								140
1985	82	1	2						85
1986									

YERRAMINNUP SOUTH

year	sediment concentration (mg/L)								total no. of days with flow
	0 - 5	5 - 10	10 - 20	20 - 50	50 - 100	100 - 200	200 - 500	500 - 1000	
1975	67	35	11	1	1	3	4		130
1976	93	1	2	11	7				114
1977	80	16	1						97
1978	134	2	2		5				143
1979	50								50
1980	123	2		1					126
1981	133								133
1982	52	8	2	2					64
1983	149	5							154
1984	138	24	15		1				178
1985	84		2						86
1986									

Appendix H : Flow-weighted mean annual stream salinity (mg/L TSS) in the seven research catchments from 1975 to 1986.

	Lewin North	Lewin South	March Road	April Road North	April Road South	Yerraminnup North	Yerraminnup South
1975						118	100
1976	118	107	229	96	144	317	157
1977	120	114	142	120	128	231	214
1978	90	85	100	86	90	94	75
1979	112	100	163	101	122	205	176
1980	103	87	167	106	117	160	128
1981	103	103	119	99	103	107	82
1982	130	103	181	116	138	778	207
1983	115	103	208	140	118	94	82
1984	108	145	218	119	103	112	91
1985	109	182	314	111	94	141	114
1986	119	183	439	154	124	no flow	no flow

Appendix I

Percentage of the annual streamflow within a given range of stream salinities in the seven research catchments from 1975 to 1986.

(All salinities are given in mg/L TSS.)

LEWIN NORTH

year	salinity (mg/L TSS) 0 - 100	100 - 200	200 - 300	300 - 400	400 - 500	500 - 700	700 - 1000	1000 - 1500	1500 - 2500	flow-weighted mean
1975										
1976	.2	99.8								118
1977		100.0								120
1978	81.5	18.5								90
1979	20.0	80.0								112
1980	35.4	64.6								103
1981	64.7	35.3								103
1982		99.9	.1							130
1983	10.4	89.6								115
1984	30.7	69.3								108
1985	46.3	53.7								109
1986	<.05	100.0								119

LEWIN SOUTH

year	salinity (mg/L TSS) 0 - 100	100 - 200	200 - 300	300 - 400	400 - 500	500 - 700	700 - 1000	1000 - 1500	1500 - 2500	flow-weighted mean
1975										
1976	27.8	72.2								107
1977	7.1	92.9								114
1978	95.8	4.2								85
1979	74.9	25.1								100
1980	94.0	6.0								87
1981		100.0								103
1982		100.0								103
1983		100.0								103
1984		99.8	.2							145
1985		68.4	31.6							182
1986		79.4	20.6							183

MARCH ROAD

year	salinity (mg/L TSS)									flow-weighted mean
	0 - 100	100 - 200	200 - 300	300 - 400	400 - 500	500 - 700	700 - 1000	1000 - 1500	1500 - 2500	
1975										
1976	<.05	47.3	39.6	7.3	4.3	1.2	.2			229
1977	5.0	88.9	4.4	.8	.9					142
1978	53.9	45.7	.3	.1						100
1979		90.3	9.5	.2	<.05					163
1980		91.4	8.1	.4	<.05	.1				167
1981	26.2	70.1	2.4	1.2	.1					119
1982		74.5	20.8	3.6	.9	.2	<.05	<.05		181
1983	<.05	67.0	27.7	2.1	1.7	<.05	.8	.5	.2	208
1984		66.7	25.7	4.0	.1	2.5	.2	.6	.2	218
1985	<.05	42.9	26.7	14.6	2.6	6.2	3.7	2.2	1.1	314
1986			24.1	35.7	18.6	16.7	.7	3.1	1.1	439

APRIL ROAD NORTH

year	salinity (mg/L TSS) 0 - 100	100 - 200	200 - 300	300 - 400	400 - 500	500 - 700	700 - 1000	1000 - 1500	1500 - 2500	flow-weighted mean
1975										
1976	73.7	26.2		.1						96
1977	1.3	98.7								120
1978	98.6	1.4								86
1979	43.8	56.2								101
1980	.8	99.2								106
1981	57.7	42.3								99
1982		100.0								116
1983	<.05	99.9	.1							140
1984	21.5	77.7	.5	.3						119
1985		99.1	.9							111
1986	.1	96.2	3.7	<.05						154

APRIL ROAD SOUTH

year	salinity (mg/L TSS)									flow-weighted mean
	0 - 100	100 - 200	200 - 300	300 - 400	400 - 500	500 - 700	700 - 1000	1000 - 1500	1500 - 2500	
1975										
1976	.1	93.8	5.6	.5						144
1977	7.9	91.3	.8							128
1978	74.1	25.8	.1							90
1979	14.0	85.8	.2							122
1980	12.8	87.2								117
1981	54.4	45.4	.2							103
1982	8.4	86.8	4.8							138
1983	<.05	99.9								118
1984	34.7	65.3								103
1985	74.0	26.0								94
1986	2.4	97.6								124

YERRAMINNUP NORTH

year	salinity (mg/L TSS)									flow-weighted mean
	0 - 100	100 - 200	200 - 300	300 - 400	400 - 500	500 - 700	700 - 1000	1000 - 1500	1500 - 2500	
1975	29.7	68.4	1.2	.4	.3	<.05				118
1976		.6	62.9	19.3	11.4	3.6	2.2			317
1977		44.0	40.2	14.6	1.2					231
1978	67.4	32.5	.1	<.05						94
1979		65.5	22.9	6.6	4.3	.7				205
1980		93.1	5.6	1.0	.3					160
1981	38.3	60.6	.6	.3	.1	.03				107
1982			1.2	4.5		3.7	64.6	26.0		778
1983	71.2	27.9	.9	<.05	<.05					94
1984	39.6	57.8	2.5	.1						112
1985	13.4	76.9	5.7	1.6	1.9	.5				141
1986										no flow

YERRAMINNUP SOUTH

year	salinity (mg/L TSS) 0 - 100	100 - 200	200 - 300	300 - 400	400 - 500	500 - 700	700 - 1000	1000 - 1500	1500 - 2500	flow-weighted mean
1975	65.1	34.4	.3	.2						100
1976	.6	89.8	7.6	2.0						157
1977		49.5	50.5							214
1978	99.8	.2								75
1979		86.2	13.8							176
1980		100.0								128
1981	98.0	2.0								82
1982		50.7	49.3							207
1983	96.3	3.7								82
1984	89.9	10.1								91
1985	37.1	61.7	1.2							114
1986										no flow

Appendix J

Numbers of days with streamflow within a given range of stream salinities in the seven research catchments from 1975 to 1986.

(All salinities are given in mg/L TSS.)

LEWIN NORTH

year	salinity (mg/L TSS)									total no. of days with flow
	0 - 100	100 - 200	200 - 300	300 - 400	400 - 500	500 - 700	700 - 1000	1000 - 1500	1500 - 2500	
1975										
1976	2	208								210
1977		188								288
1978	94	107								201
1979	19	166								185
1980	17	166								183
1981	51	163								214
1982		321	38							359
1983	6	151								157
1984	29	178								207
1985	13	141								154
1986	2	136								138

LEWIN SOUTH

year	salinity (mg/L TSS)									total no. of days with flow
	0 - 100	100 - 200	200 - 300	300 - 400	400 - 500	500 - 700	700 - 1000	1000 - 1500	1500 - 2500	
1975										
1976	19	159								173
1977	3	156								159
1978	131	23								154
1979	97	67								164
1980	100	49								149
1981		182								182
1982		210								210
1983		179								179
1984		233	1							234
1985		99	116							215
1986		92	82							174

MARCH ROAD

year	salinity (mg/L TSS) 0 - 100	100 - 200	200 - 300	300 - 400	400 - 500	500 - 700	700 - 1000	1000 - 1500	1500 - 2500	total no. of days with flow
1975										
1976	2	47	64	31	26	35	2			207
1977	1	100	45	19	33					198
1978	25	117	44	17						203
1979		94	93	20	4					211
1980		101	35	7	10	15				168
1981	8	78	56	39	19					200
1982		50	55	25	22	18	18	11		199
1983	21	41	47	15	14	5	21	9	16	189
1984		61	49	25	7	30	16	32	6	226
1985	2	15	32	23	6	27	38	61	25	229
1986			13	33	31	30	14	30	9	160

APRIL ROAD NORTH

year	salinity (mg/L TSS) 0 - 100	100 - 200	200 - 300	300 - 400	400 - 500	500 - 700	700 - 1000	1000 - 1500	1500 - 2500	total no. of days with flow
1975										
1976	98	86		1						185
1977	8	181								189
1978	138	46								184
1979	57	132								189
1980	1	160								161
1981	29	153								182
1982		138	1							139
1983	3	140	5							148
1984	102	100	6	4						212
1985		139	24							163
1986	9	108	10	2						129

APRIL ROAD SOUTH

year	salinity (mg/L TSS)									total no. of days with flow
	0 - 100	100 - 200	200 - 300	300 - 400	400 - 500	500 - 700	700 - 1000	1000 - 1500	1500 - 2500	
1975										
1976	9	150	34	12						205
1977	2	156	33							191
1978	60	121	3							184
1979	40	147	5							192
1980	5	156								161
1981	31	135	22							188
1982	8	105	23							136
1983	16	109								125
1984	26	175								201
1985	23	124								147
1986	7	110								117

YERRAMINNUP NORTH

year	salinity (mg/L TSS) 0 - 100	100 - 200	200 - 300	300 - 400	400 - 500	500 - 700	700 - 1000	1000 - 1500	1500 - 2500	total no. of days with flow
1975	11	80	12	6	13	5				127
1976		8	29	26	20	23	4			110
1977		17	27	46	14					104
1978	41	88	9	4						142
1979		14	16	15	5	4				54
1980		82	18	13	8					121
1981	15	78	13	17	7	4				134
1982			1	1		1	30	12		45
1983	35	60	14	4	1					114
1984	15	84	36	5						140
1985	2	35	13	11	14	10				85
1986										no flow

YERRAMINNUP SOUTH

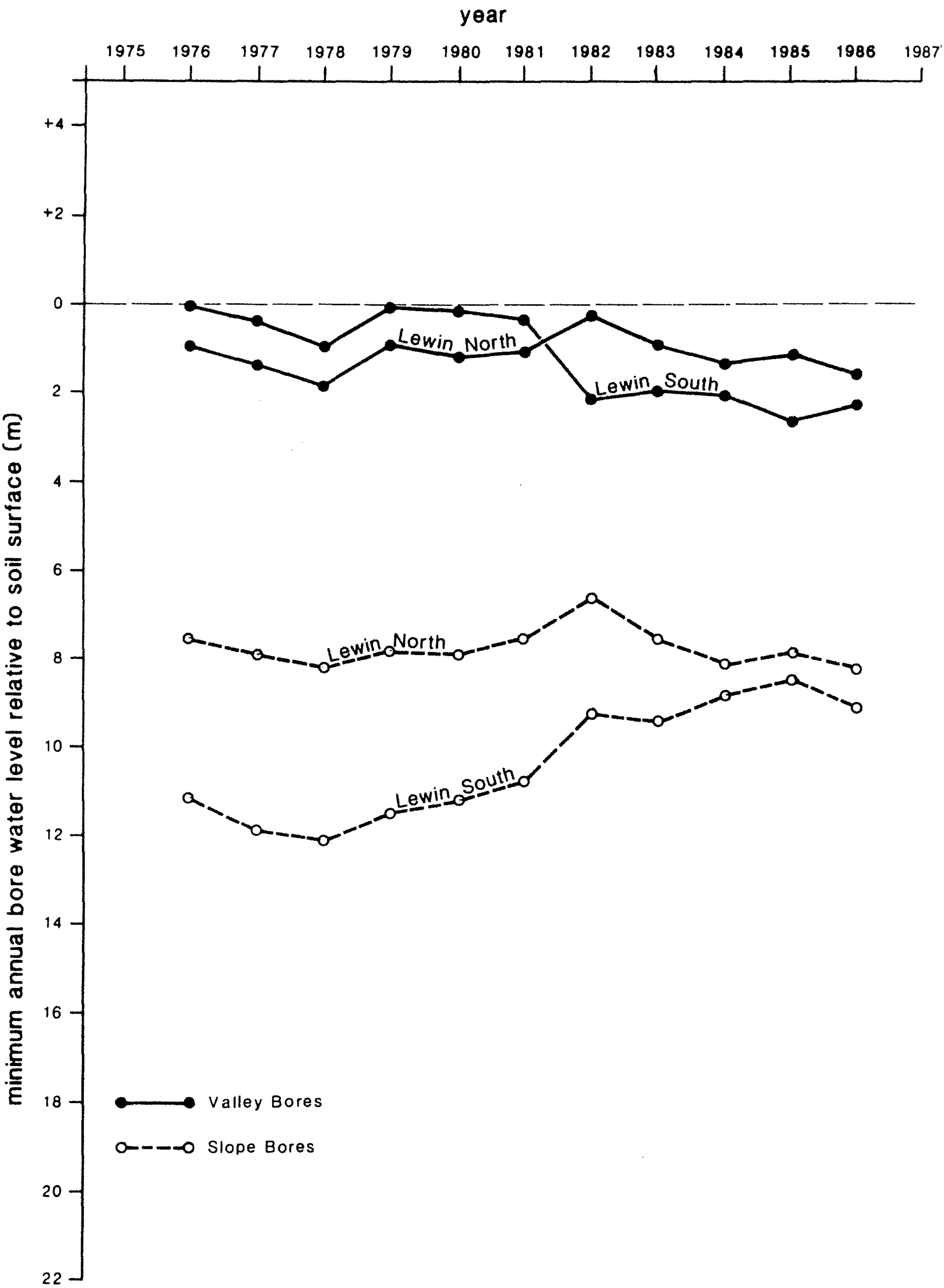
year	salinity (mg/L TSS)									total no. of days with flow
	0 - 100	100 - 200	200 - 300	300 - 400	400 - 500	500 - 700	700 - 1000	1000 - 1500	1500 - 2500	
1975	49	77	3	1						130
1976	11	89	9	5						114
1977		17	80							97
1978	128	15								143
1979		40	10							50
1980		126								126
1981	82	51								133
1982		13	51							64
1983	112	42								154
1984	93	85	36							178
1985	4	56	26							86
1986										no flow

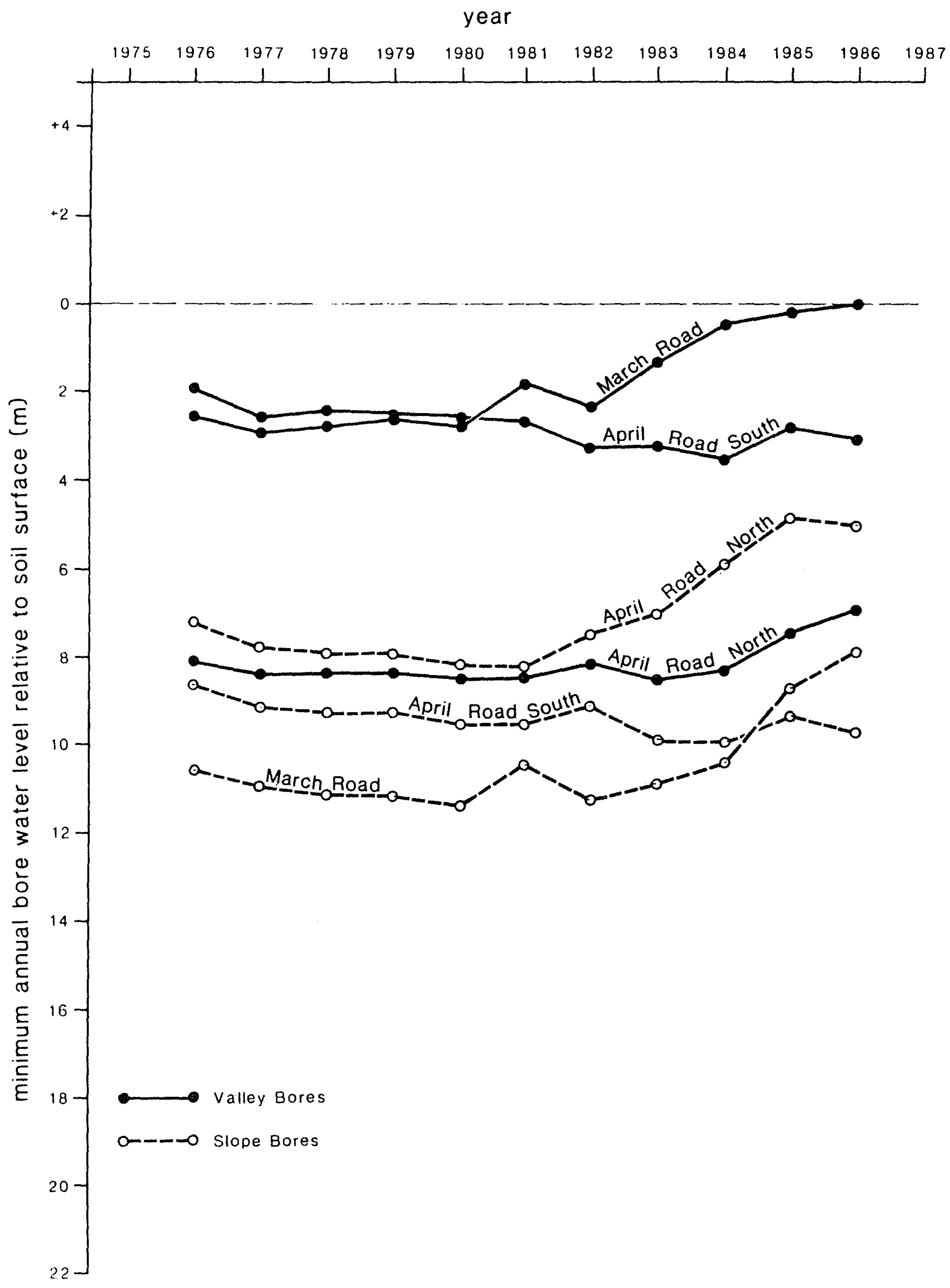
Appendix K

Minimum annual water level averaged for valley bores and slope bores in the seven research catchments from 1975 to 1986.

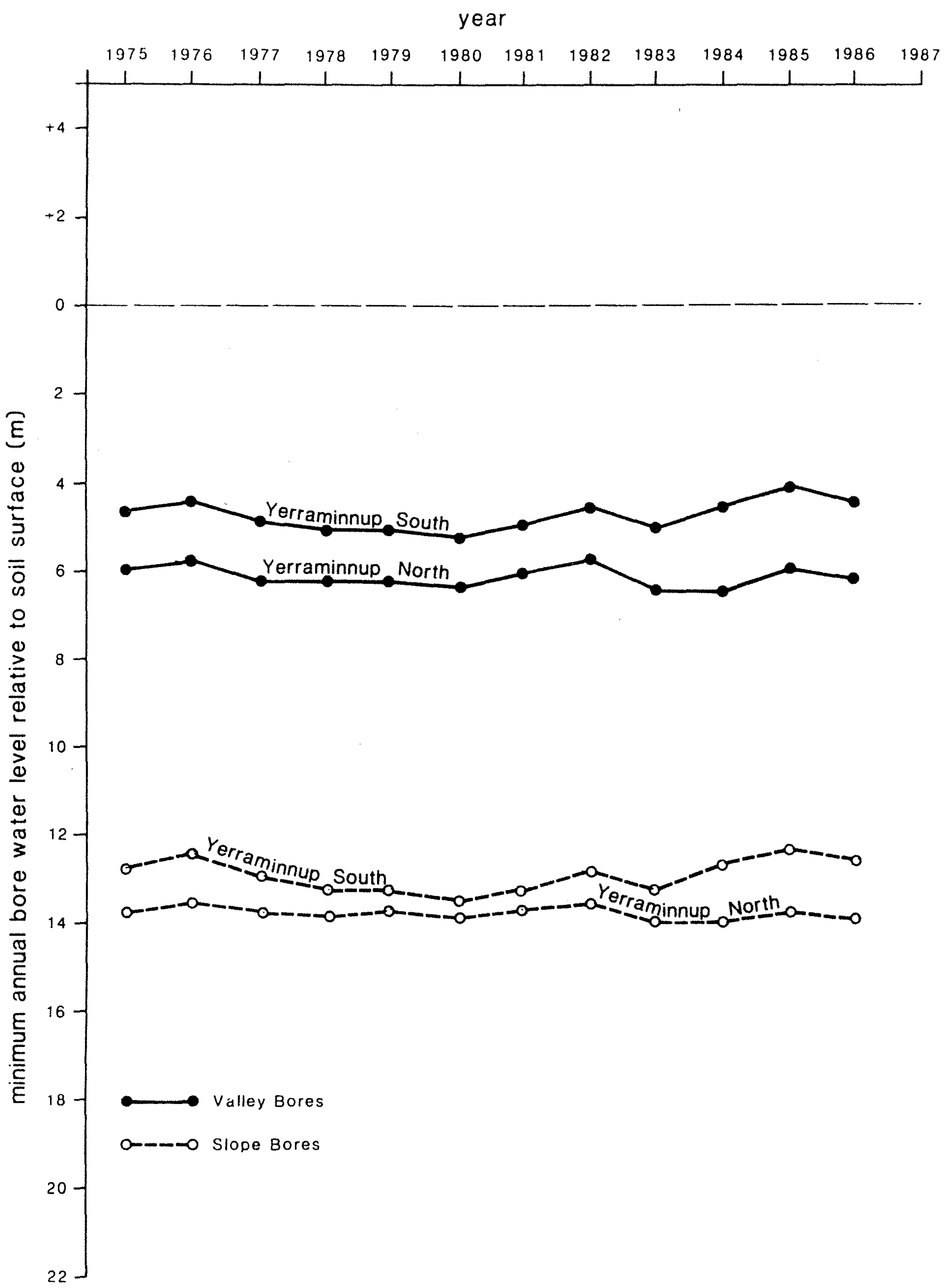
(All bore water levels are given as depth below the soil surface in m. Plus signs indicate the height of the bore water level above the soil surface).

	Lewin North		Lewin South		March Road		April Road North		April Road South		Yerraminnup North		Yerraminnup South	
	valley bores	slope bores	valley bores	slope bores	valley bores	slope bores	valley bores	slope bores	valley bores	slope bores	valley bores	slope bores	valley bores	slope bores
1975											7.85	13.28	4.65	12.78
1976	.98	7.52	+.03	11.13	2.58	10.53	8.09	7.12	1.97	8.66	7.67	13.06	4.33	12.44
1977	1.34	7.90	.35	11.82	2.93	10.86	8.35	7.77	2.56	9.15	8.04	13.26	4.88	12.97
1978	1.82	8.22	.92	12.12	2.75	11.15	8.35	7.98	2.49	9.21	8.05	13.42	5.07	13.23
1979	.97	7.88	+.07	11.51	2.69	11.18	8.36	7.93	2.41	9.27	8.04	13.34	5.02	13.23
1980	1.18	7.80	+.16	11.20	2.80	11.40	8.50	8.15	2.55	9.51	8.16	13.47	5.24	13.42
1981	1.08	7.59	+.32	10.75	2.89	11.48	8.44	8.28	2.66	9.52	7.86	13.30	4.91	13.25
1982	+.28	6.62	+2.15	9.25	2.32	11.26	8.15	7.54	2.22	9.16	7.59	13.15	4.55	12.83
1983	.92	7.57	+1.94	9.48	1.34	10.98	8.52	7.03	3.22	9.95	8.30	13.57	5.05	13.23
1984	1.39	8.11	+2.08	8.83	.50	10.43	8.35	5.90	3.57	9.97	8.30	13.53	4.55	12.65
1985	1.18	7.90	+2.61	8.43	+.13	8.78	7.45	4.90	2.83	9.37	7.86	13.39	4.15	12.40
1986	1.61	8.28	+2.28	9.11	.04	7.93	6.93	5.03	3.13	9.73	8.02	13.57	4.42	12.68


year
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
+4
+2
0
2
4
6
8
10
12
14
16
18
20
22
minimum annual bore water level relative to soil surface (m)
Lewin North
Lewin South
Lewin North
Lewin South
Valley Bores
Slope Bores



year
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
+4
+2
0
2
4
6
8
10
12
14
16
18
20
22
minimum annual bore water level relative to soil surface (m)
March Road
April Road South
April Road North
April Road North
April Road South
March Road
Valley Bores
Slope Bores


year
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
+4
+2
0
2
4
6
8
10
12
14
16
18
20
22
minimum annual bore water level relative to soil surface (m)
Yerraminnup South
Yerraminnup North
Yerraminnup South
Yerraminnup North
Valley Bores
Slope Bores

Appendix L : Minimum annual water level averaged for valley bores and slope bores in the seven research catchments from 1975 to 1986, relative to the 1981 value (m).

	Lewin North		Lewin South		March Road		April Road North		April Road South		Yerraminnup North		Yerraminnup South	
	valley bores	slope bores	valley bores	slope bores	valley bores	slope bores	valley bores	slope bores	valley bores	slope bores	valley bores	slope bores	valley bores	slope bores
1975											.05	-.01	.26	.47
1976	.10	.07	-.29	-.38	.31	.95	.35	1.16	.69	.86	.25	.19	.58	.81
1977	-.26	-.31	-.67	-1.07	-.04	.62	.09	.51	.10	.37	-.19	.02	.03	.28
1978	-.74	-.63	-1.24	-1.37	.14	.33	.09	.30	.17	.31	-.19	-.13	-.16	.02
1979	.11	-.29	-.25	-.76	.20	.30	.08	.35	.25	.25	-.20	-.04	-.11	.02
1980	-.10	-.21	-.16	-.45	.09	.08	-.06	.13	.11	.01	-.34	-.17	-.33	-.17
1981	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1982	1.36	.97	1.83	1.50	.57	.22	.29	.74	.44	.36	.30	.15	.36	.42
1983	.16	.02	1.62	1.27	1.55	.50	-.08	1.25	-.56	-.43	-.48	-.27	-.14	.02
1984	-.31	-.52	1.76	1.92	2.39	1.05	.09	2.38	-.91	-.45	-.46	-.25	.36	.60
1985	-.10	-.31	2.29	2.32	3.02	2.70	.99	3.38	-.17	.15	.03	-.10	.76	.85
1986	-.53	-.69	1.96	1.64	2.85	3.55	1.51	3.25	-.47	-.21	-.16	-.26	.49	.57

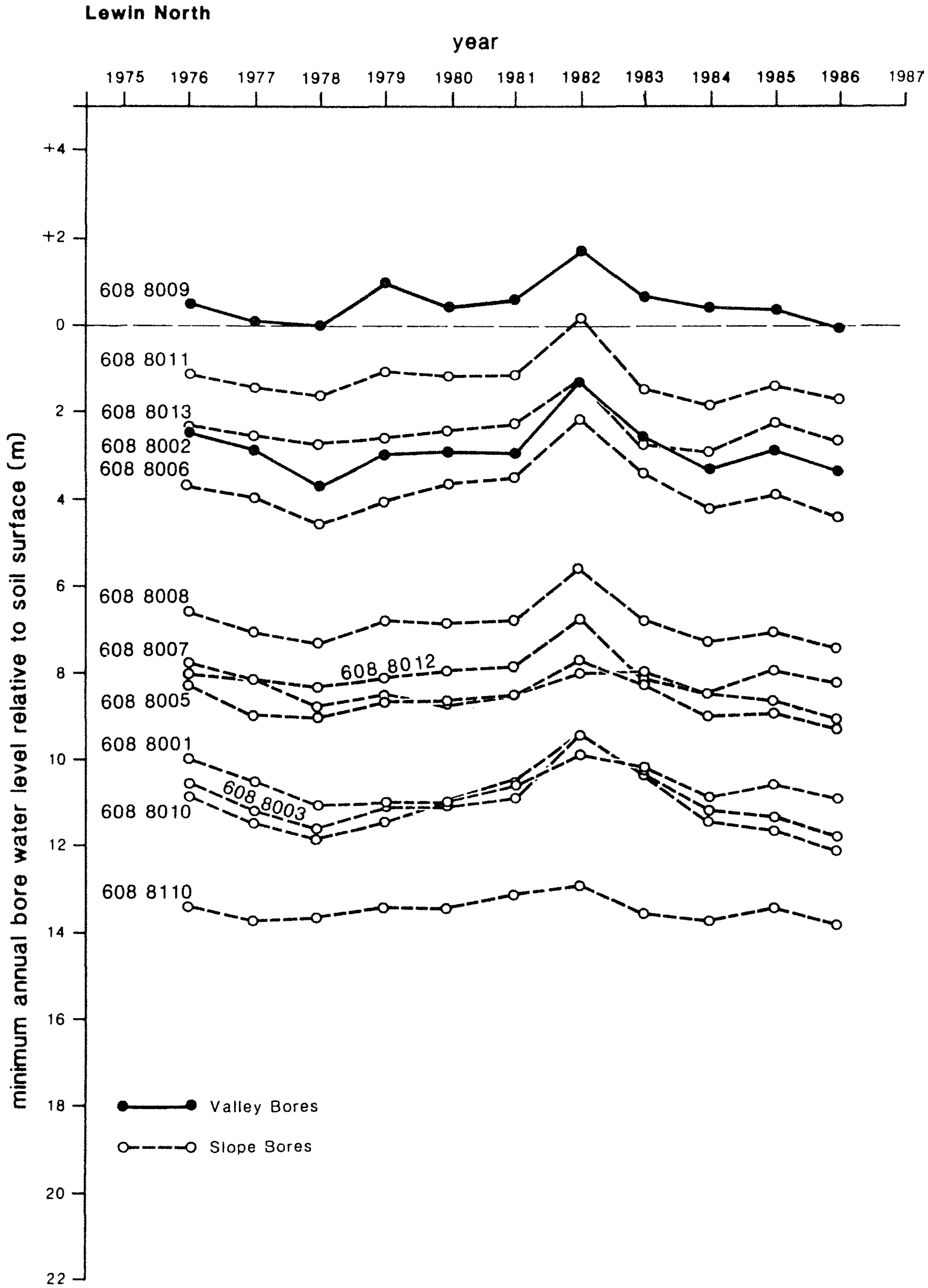
Appendix M

Minimum annual water level for individual bores in the seven research catchments from 1975 to 1986.

(All values given as depth below the soil surface in m. Plus signs indicate the height of the bore water level above the soil surface.)

Lewin North

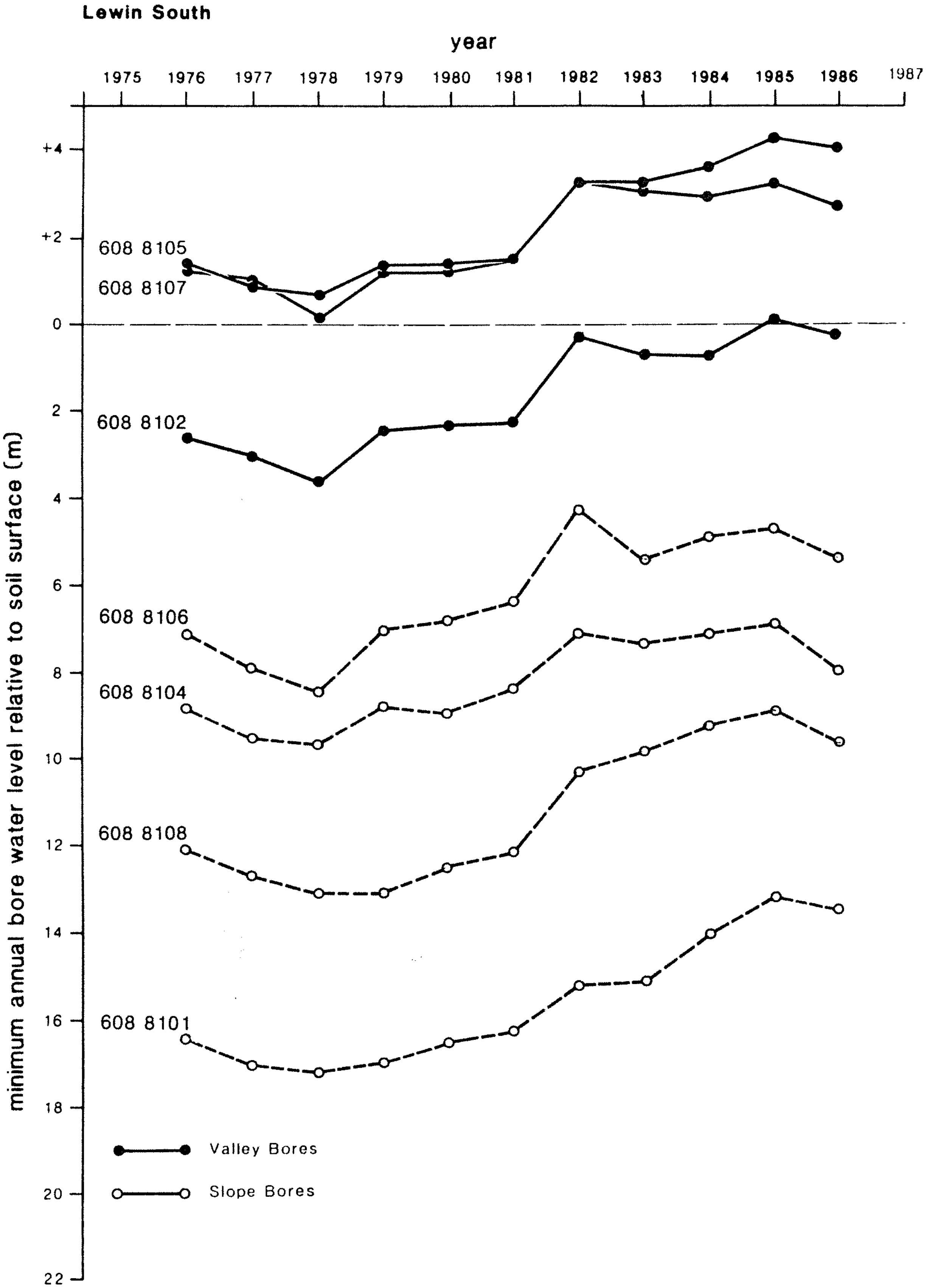
	valley bores		slope bores										
bore number	6088002	6088009	6088001	6088003	6088005	6088006	6088007	6088008	6088010	6088011	6088012	6088013	6088110
1975													
1976	2.46	+ 0.50	10.00	10.57	8.29	3.66	7.75	6.57	10.88	1.17	8.02	2.39	13.43
1977	2.83	+ 0.14	10.48	11.10	8.93	3.96	8.14	6.95	11.48	1.40	8.15	2.57	13.72
1978	3.61	0.03	11.05	11.58	8.98	4.59	8.76	7.29	11.88	1.60	8.34	2.72	13.64
1979	2.95	+ 1.02	10.92	11.04	8.69	4.06	8.49	6.79	11.45	1.09	8.10	2.62	13.41
1980	2.85	+ 0.50	10.92	11.00	8.60	3.62	8.68	6.88	11.07	1.16	7.98	2.42	13.46
1981	2.85	+ 0.70	10.57	10.85	8.41	3.46	8.48	6.74	10.53	1.10	7.87	2.27	13.19
1982	1.25	+ 1.82	9.82	9.40	7.61	2.16	8.03	5.59	9.43	+ 0.20	6.77	1.27	12.94
1983	2.50	+ 0.67	10.15	10.25	8.20	3.41	8.08	6.72	10.48	1.49	8.23	2.71	13.54
1984	3.28	+ 0.50	10.87	11.10	8.91	4.16	8.43	7.29	11.45	1.82	8.62	2.90	13.71
1985	2.80	+ 0.45	10.58	11.30	8.89	3.82	8.58	7.07	11.65	1.30	7.99	2.28	13.49
1986	3.26	+ 0.05	10.89	11.75	9.21	4.31	9.07	7.40	12.16	1.65	8.22	2.53	13.84
depth to bottom of bore (m)	11.08	25.10	12.11	16.98	12.29	9.09	14.23	27.53	24.80	13.58	13.47	9.54	23.89
soil surface elevation at bore (m)	182.01	199.70	189.19	193.00	196.77	195.90	212.36	212.62	208.79	221.45	228.82	221.07	233.18



Lewin North
year
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
+4
+2
0
2
4
6
8
10
12
14
16
18
20
22
minimum annual bore water level relative to soil surface (m)
608 8009
608 8011
608 8013
608 8002
608 8006
608 8008
608 8007
608 8012
608 8005
608 8001
608 8003
608 8010
608 8110
Valley Bores
Slope Bores

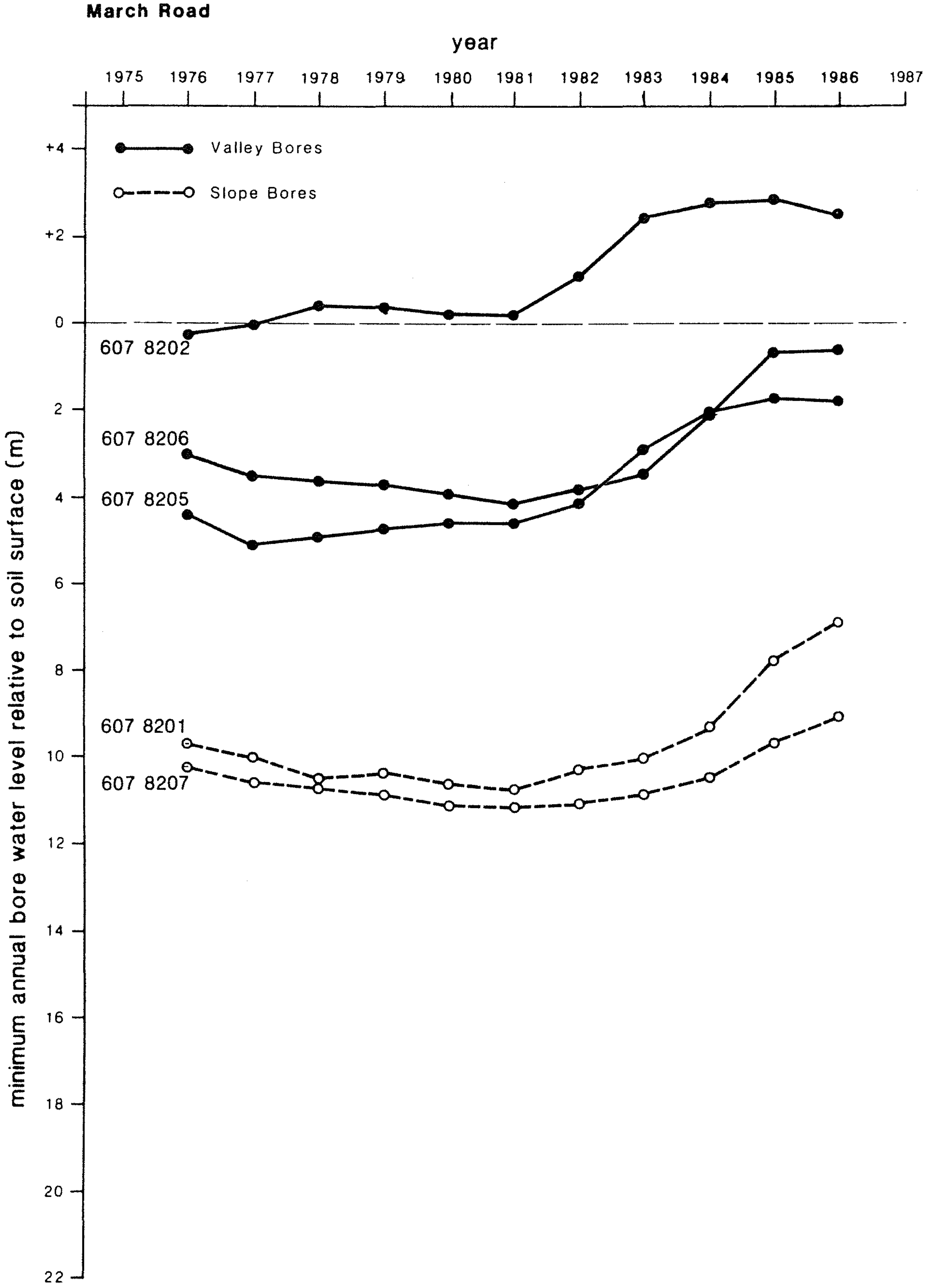
Lewin South

	valley bores			slope bores			
bore number	6088102	6088105	6088107	6088101	6088104	6088106	6088108
1975							
1976	2.60	+1.42	+1.27	16.43	8.84	7.14	12.10
1977	3.02	+.95	+1.03	17.03	9.59	7.90	12.74
1978	3.63	+.70	+.19	17.20	9.66	8.49	13.13
1979	2.41	+1.41	+1.21	17.02	8.79	7.07	13.16
1980	2.38	+1.48	+1.37	16.51	8.91	6.80	12.58
1981	2.26	+1.60	+1.63	16.24	8.34	6.32	12.11
1982	.21	+3.37	+3.30	15.24	7.19	4.22	10.36
1983	.66	+3.36	+3.11	15.19	7.38	5.47	9.89
1984	.45	+3.68	+3.00	14.09	7.10	4.87	9.27
1985	+.17	+4.35	+3.31	13.14	6.93	4.67	8.96
1986	.14	+4.18	+2.79	13.46	7.93	5.37	9.66
depth to bottom of bore (m)	14.36	15.08	23.45	33.30	24.62	20.59	20.72
soil surface elevation at bore (m)	189.50	194.46	203.01	211.63	220.15	217.20	218.40


Lewin South
year
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
+4
+2
0
2
4
6
8
10
12
14
16
18
20
22
minimum annual bore water level relative to soil surface (m)
608 8105
608 8107
608 8102
608 8106
608 8104
608 8108
608 8101
Valley Bores
Slope Bores

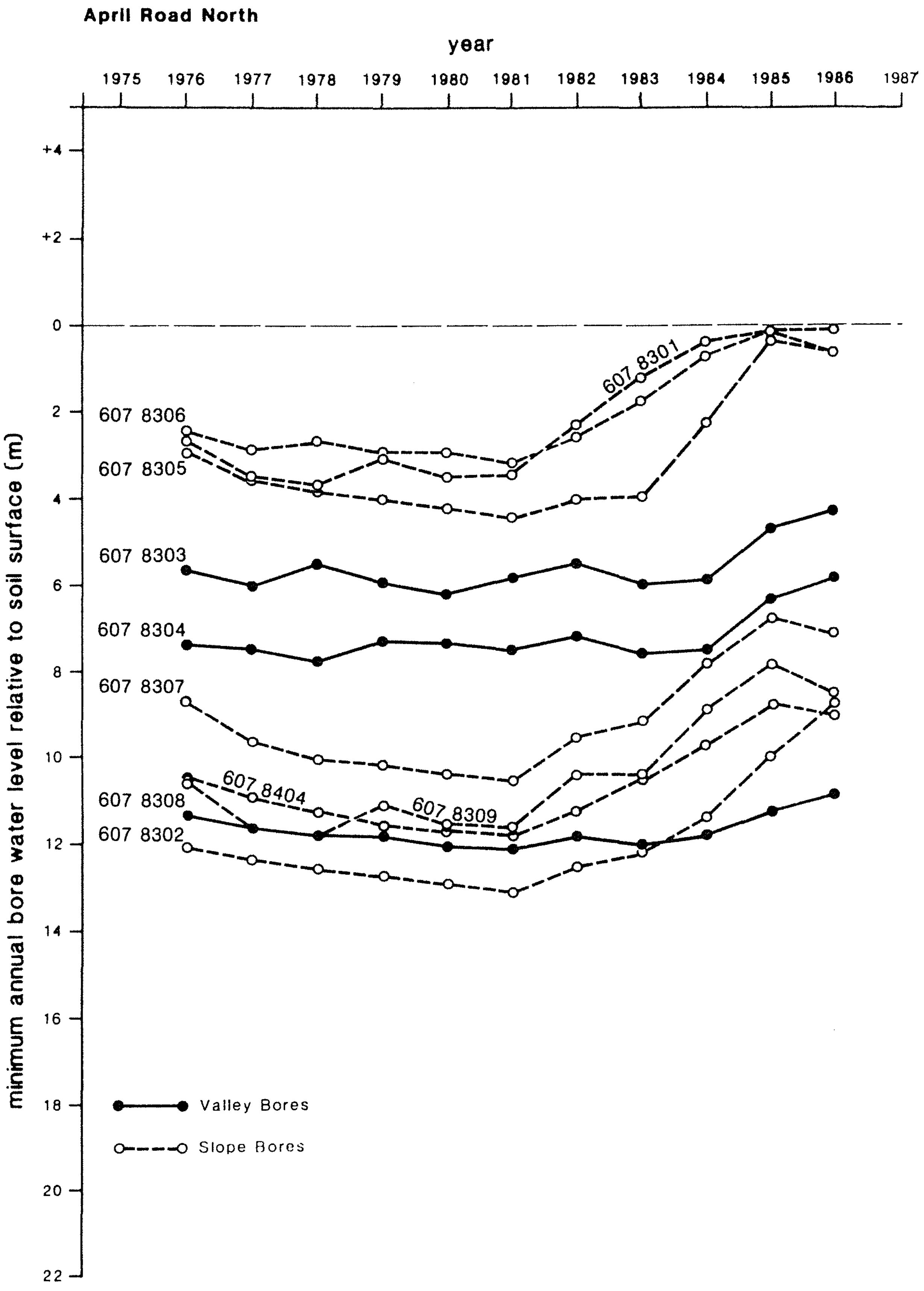
March Road

	valley bores		slope bores		
bore number	6078202	6078205	6078206	6078201	6078207
1975					
1976	.29	4.45	3.01	9.78	11.27
1977	.10	5.12	3.58	10.10	11.62
1978	+.42	4.99	3.67	10.52	11.78
1979	+.38	4.72	3.74	10.44	11.91
1980	+.19	4.65	3.94	10.64	12.16
1981	+.15	4.67	4.14	10.76	12.20
1982	+1.09	4.16	3.89	10.34	12.17
1983	+2.44	2.96	3.49	10.04	11.91
1984	+2.74	2.06	2.19	9.34	11.51
1985	+2.84	1.76	.69	7.84	9.71
1986	+2.44	1.86	.69	6.94	8.91
depth to bottom of bore (m)	21.77	13.20	13.22	18.70	15.82
soil surface elevation at bore (m)	177.44	184.17	199.11	201.05	213.77


March Road
year
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
Valley Bores
Slope Bores
+4
+2
0
2
4
6
8
10
12
14
16
18
20
22
607 8202
607 8206
607 8205
607 8201
607 8207
minimum annual bore water level relative to soil surface (m)

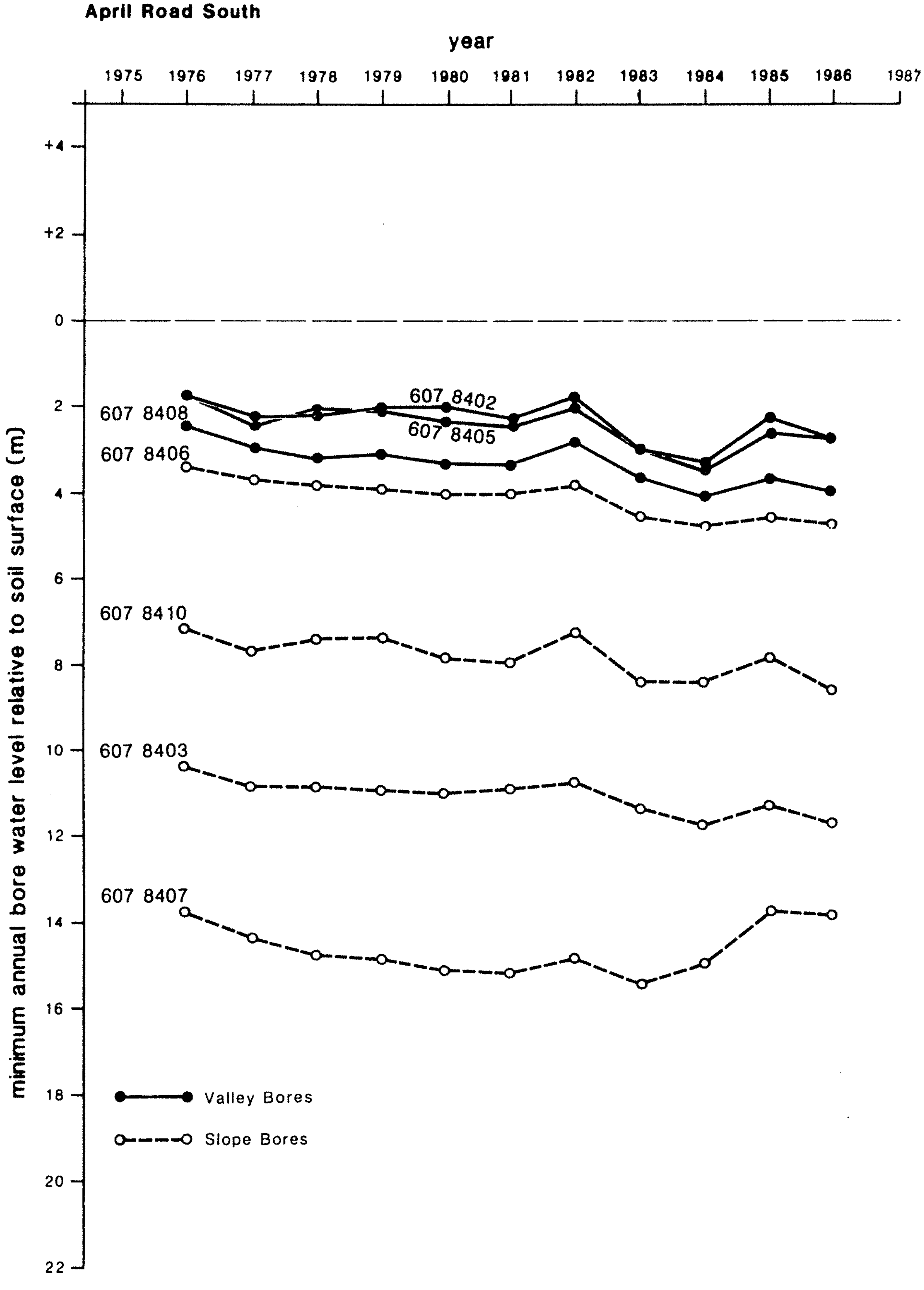
April Road North

	valley bores			slope bores						
bore number	6078303	6078304	6078308	6078301	6078302	6078305	6078306	6078307	6078309	6078404
1975										
1976	5.61	7.30	11.36	2.64	12.04	2.92	2.43	8.73	10.60	10.48
1977	5.94	7.47	11.64	3.48	12.38	3.54	2.84	9.65	11.54	10.95
1978	5.47	7.71	11.87	3.62	12.60	3.89	2.68	10.04	11.75	11.27
1979	5.93	7.26	11.88	3.06	12.55	4.13	2.90	10.14	11.14	11.60
1980	6.15	7.31	12.04	3.54	12.76	4.21	2.99	10.36	11.51	11.65
1981	5.78	7.41	12.13	3.43	12.91	4.44	3.11	10.59	11.61	11.84
1982	5.43	7.19	11.83	2.23	12.55	4.13	2.55	9.59	10.48	11.25
1983	5.93	7.59	12.03	1.16	12.25	3.93	1.70	9.19	10.41	10.55
1984	5.83	7.39	11.83	0.36	11.45	2.23	0.70	7.89	8.91	9.75
1985	4.63	6.39	11.33	0.16	10.05	0.38	+ 0.10	6.84	8.01	8.95
1986	4.23	5.84	10.73	0.61	8.85	0.63	0.10	7.19	8.76	9.05
depth to bottom of bore (m)	12.68	8.38	25.36	10.02	20.31	11.63	7.80	15.40	20.28	16.87
soil surface elevation at bore (m)	200.18	203.06	214.72	220.09	211.58	208.92	211.67	224.81	223.52	220.38


April Road North
year
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
+4
+2
0
2
4
6
8
10
12
14
16
18
20
22
minimum annual bore water level relative to soil surface (m)
607 8301
607 8306
607 8305
607 8303
607 8304
607 8307
607 8404
607 8309
607 8308
607 8302
Valley Bores
Slope Bores

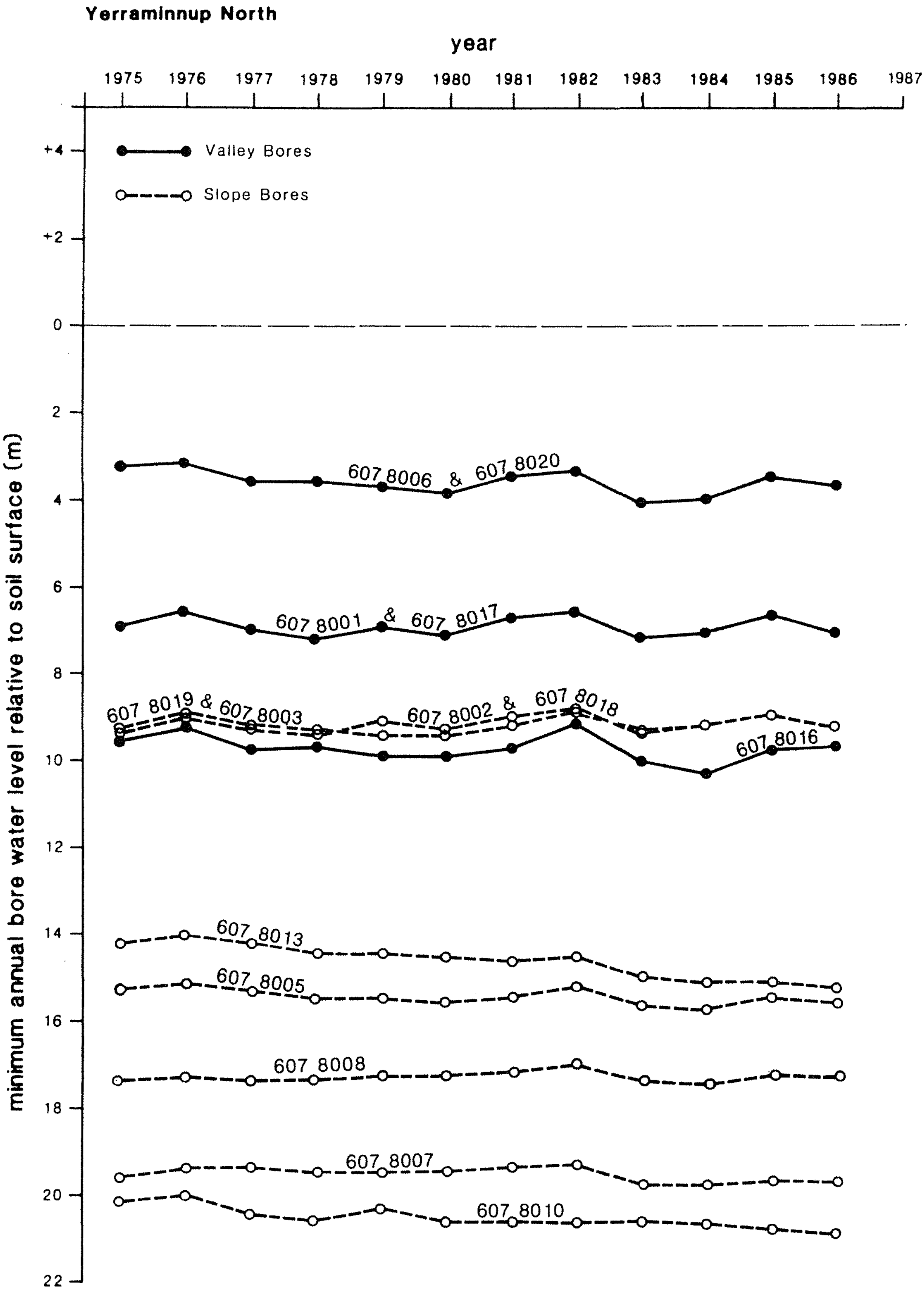
April Road South

	valley bores			slope bores			
bore number	6078402	6078405	6078408	6078403	6078406	6078407	6078410
1975							
1976	1.74	1.70	2.48	10.36	3.40	13.72	7.17
1977	2.28	2.46	2.94	10.86	3.71	14.35	7.70
1978	2.22	2.07	3.17	10.80	3.81	14.77	7.47
1979	2.01	2.14	3.07	10.90	3.96	14.85	7.37
1980	2.06	2.35	3.25	11.00	4.05	15.12	7.85
1981	2.21	2.42	3.35	10.93	4.09	15.16	7.91
1982	1.76	2.02	2.87	10.75	3.84	14.83	7.21
1983	2.96	3.02	3.67	11.35	4.59	15.43	8.41
1984	3.21	3.42	4.07	11.75	4.79	14.93	8.41
1985	2.21	2.62	3.67	11.30	4.59	13.73	7.86
1986	2.71	2.72	3.97	11.70	4.79	13.88	8.56
depth to bottom of bore (m)	13.07	9.48	10.98	17.60	10.37	18.53	10.71
soil surface elevation at bore (m)	200.02	207.18	219.34	208.48	212.50	228.75	225.38


April Road South
year
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
+4
+2
0
2
4
6
8
10
12
14
16
18
20
22
minimum annual bore water level relative to soil surface (m)
607 8402
607 8408
607 8405
607 8406
607 8410
607 8403
607 8407
Valley Bores
Slope Bores

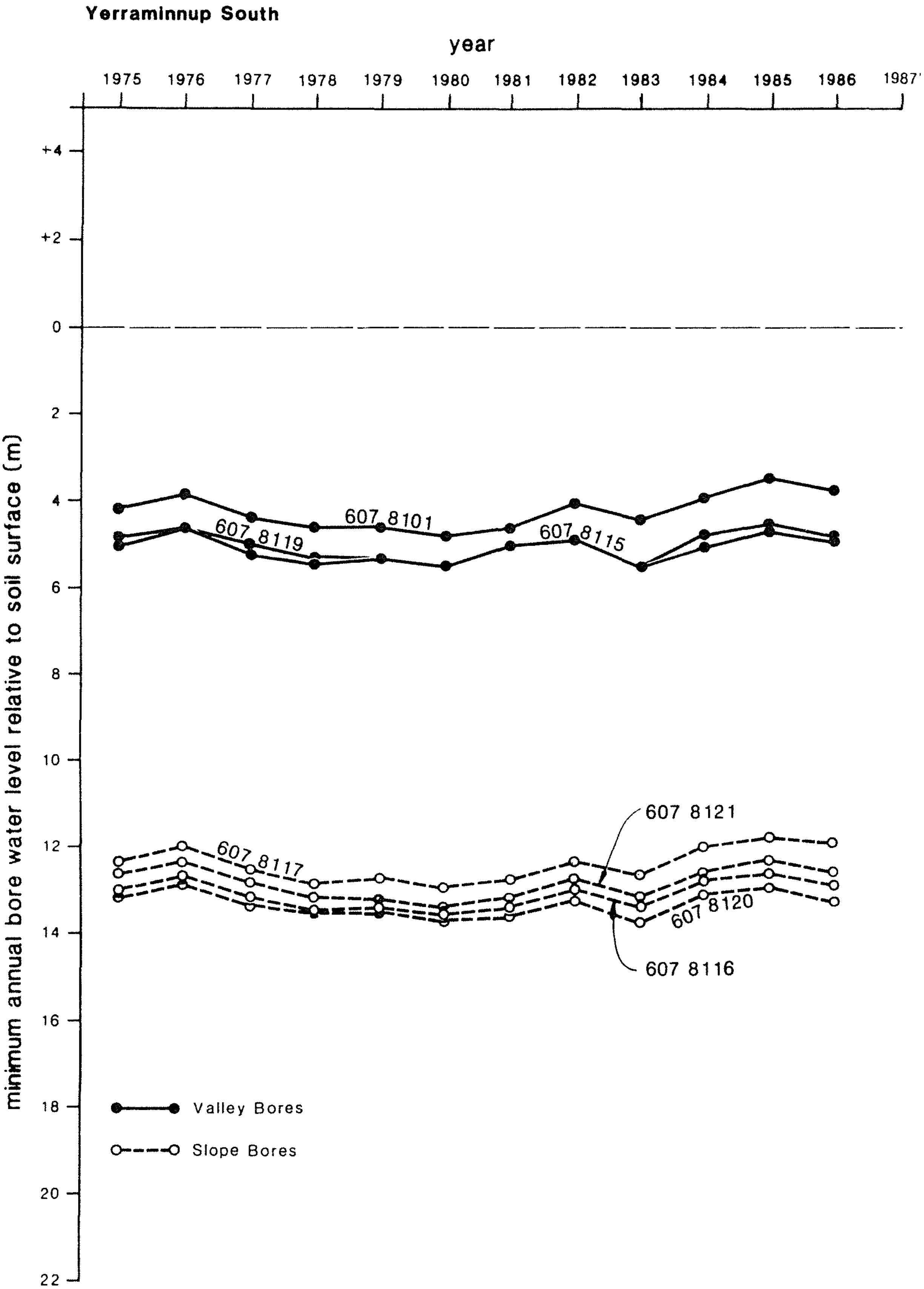
Yerrraminnup North

	valley bores					slope bores								
bore number	6078001	6078006	6078016	6078017	6078020	6078002	6078003	6078005	6078007	6078008	6078010	6078013	6078018	6078019
1975	6.90	3.24	9.54	6.86	3.23	9.31	9.22	15.29	19.60	17.34	20.04	14.21	9.26	9.32
1976	6.59	3.17	9.29	6.56	3.19	9.04	8.88	15.15	19.34	17.25	20.01	14.03	8.99	9.08
1977	6.96	3.55	9.65	6.98	3.86	9.23	9.14	15.28	19.34	17.26	20.36	14.20	9.20	9.35
1978	7.16	3.59	9.61	7.02	3.64	9.22	9.36	15.46	19.40	17.28	20.57	14.49	9.41	9.50
1979	6.89	3.66	9.84	6.86	3.79	9.34	9.07	15.40	19.46	17.17	20.31	14.49	9.27	9.36
1980	7.10	3.83	9.85	7.09	3.87	9.39	9.29	15.53	19.44	17.21	20.62	14.56	9.40	9.53
1981	6.76	3.41	9.70	6.74	3.45	9.11	8.93	15.40	19.35	17.11	20.56	14.62	9.13	9.30
1982	6.51	3.21	9.14	6.50	3.19	8.86	8.82	15.20	19.26	16.97	20.56	14.59	8.86	9.05
1983	7.11	4.01	10.04	7.20	4.09	9.26	9.32	15.68	19.76	17.37	20.56	15.09	9.36	9.55
1984	7.01	3.91	10.24	7.10	4.09	9.16	9.12	15.78	19.76	17.47	20.71	15.19	9.16	9.35
1985	6.66	3.41	9.74	6.60	3.49	8.96	8.92	15.48	19.66	17.27	20.76	15.19	8.96	9.15
1986	7.01	3.61	9.64	6.90	3.69	9.26	9.12	15.58	19.66	17.27	20.96	15.29	9.26	9.45
depth to bottom of bore (m)	29.67	6.95	11.87	50.88	16.18	28.09	18.95	28.37	22.46	19.62	22.04	16.73	39.43	45.56
soil surface elevation at bore (m)	263.57	263.69	267.31	263.67	263.76	266.24	266.64	280.25	300.05	291.59	317.71	291.83	266.24	266.94


Yerraminnup North
year
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
Valley Bores
Slope Bores
+4
+2
0
2
4
6
8
10
12
14
16
18
20
22
minimum annual bore water level relative to soil surface (m)
607 8006 & 607 8020
607 8001 & 607 8017
607 8019 & 607 8003
607 8002 & 607 8018
607 8016
607 8013
607 8005
607 8008
607 8007
607 8010

Yerraminnup South

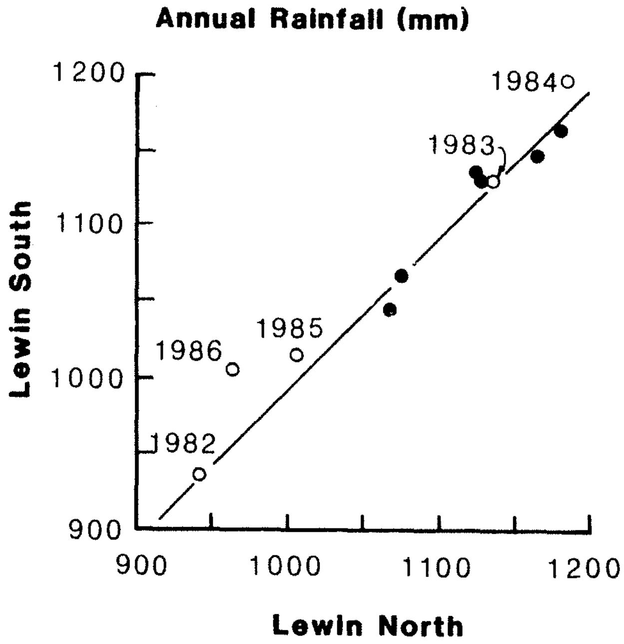
	valley bores			slope bores			
bore number	6078101	6078115	6078119	6078116	6078117	6081120	6078121
1975	4.12	5.02	4.80	12.97	12.35	13.15	12.67
1976	3.85	4.59	4.54	12.61	12.00	12.81	12.35
1977	4.39	5.27	4.98	13.10	12.55	13.33	12.89
1978	4.57	5.40	5.23	13.40	12.80	13.57	13.14
1979	4.57	5.27	5.23	13.32	12.78	13.58	13.24
1980	4.78	5.48	5.45	13.52	12.96	13.78	13.40
1981	4.53	5.08	5.11	13.33	12.78	13.71	13.18
1982	4.00	4.82	4.83	12.97	12.32	13.28	12.74
1983	4.40	5.42	5.33	13.37	12.62	13.78	13.14
1984	3.90	5.02	4.73	12.77	12.02	13.18	12.64
1985	3.40	4.62	4.43	12.57	11.72	12.98	12.34
1986	3.70	4.82	4.73	12.87	11.92	13.28	12.64
depth to bottom of bore (m)	9.26	9.19	24.85	17.58	25.11	43.49	39.75
soil surface elevation at bore (m)	248.53	245.67	245.55	253.89	253.83	254.01	254.04


Yerraminnup South
year
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
minimum annual bore water level relative to soil surface (m)
+4
+2
0
2
4
6
8
10
12
14
16
18
20
22
607 8101
607 8119
607 8115
607 8121
607 8117
607 8120
607 8116
Valley Bores
Slope Bores

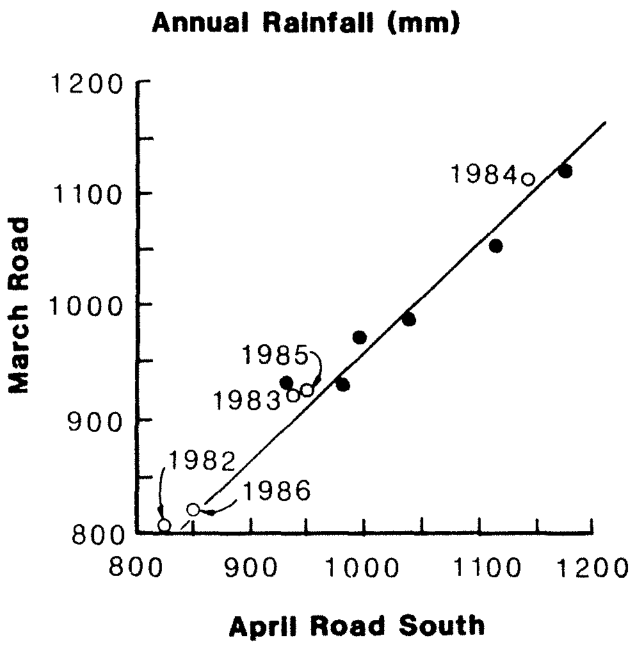
Appendix N

Annual rainfall in the logged catchments relative to that in the control catchments from 1975 to 1986.

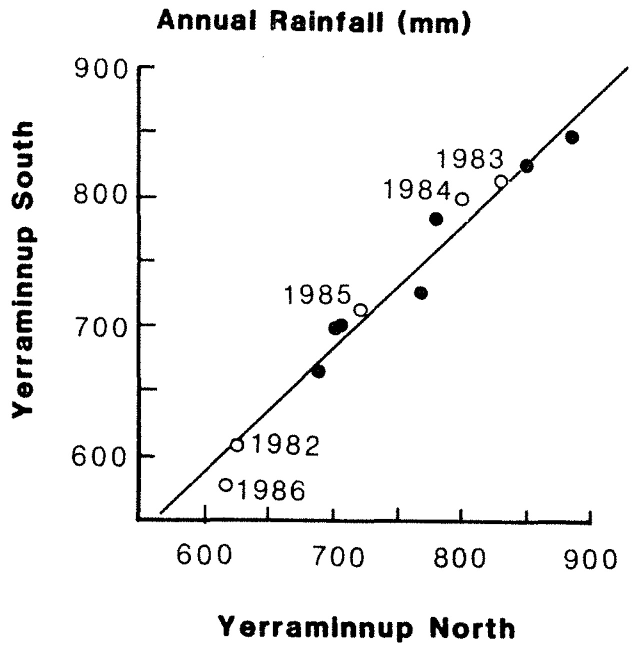
(All regressions are based on the data prior to 1982).



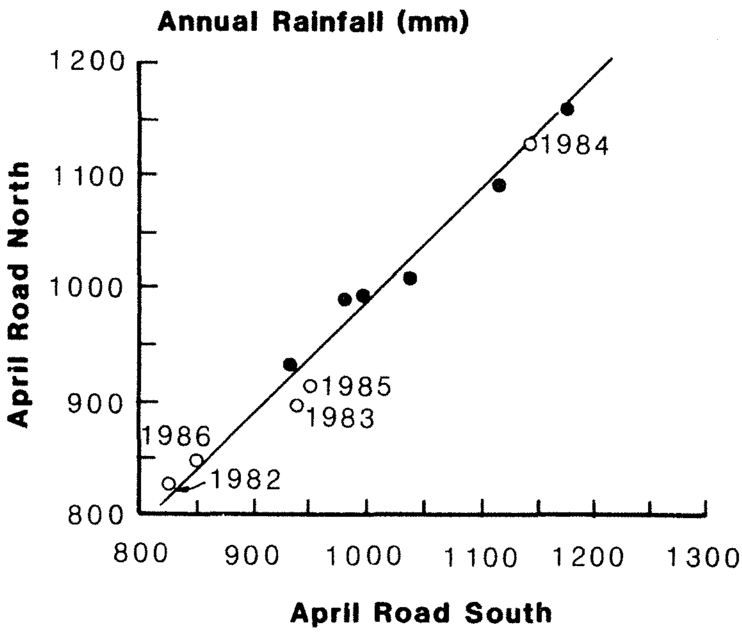
y = 0.993x
6 data points
R^2= 0.9999



y = 0.959x
6 data points
R^2= 0.9996



y = 0.977x
7 data points
R^2 = 0.9996



y = 0.988x
6 data points
R^2 = 0.9998

Changes in annual rainfall recorded in the four cut-over research catchments due to logging.

Catchment	year	observed rainfall (mm)	predicted rainfall[1] (mm)	absolute difference[2] (mm)	relative difference[3] (%)
Lewin South	1982	936	934	2	.2
	1983	1131	1129	2	.2
	1984	1198	1175	23	2
	1985	1015	1000	15	2
	1986	1006	958	48	5
March Road	1982	807	792	15	2
	1983	922	902	20	2
	1984	1114	1099	15	1
	1985	927	912	15	2
	1986	821	815	6	1
April Road North	1982	827	816	11	1
	1983	898	929	-31	-3
	1984	1129	1132	-3	-.2
	1985	914	940	-26	-3
	1986	848	840	8	1
Yerraminnup South	1982	607	614	-7	-1
	1983	816	812	4	.5
	1984	802	782	20	3
	1985	716	705	11	2
	1986	576	604	-28	-5

[1] rainfall that would have been recorded without logging, estimated by substituting the rainfall recorded in the respective control catchment given in Appendix A into the appropriate regression equation on the two previous pages

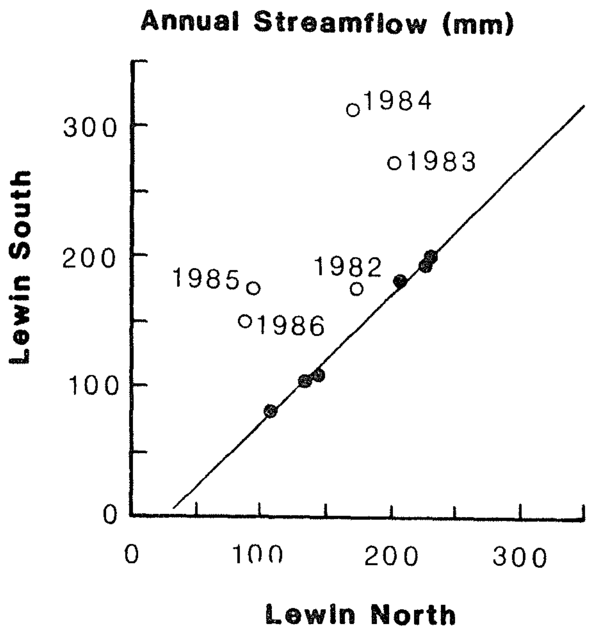
[2] observed value - predicted value

[3] (observed value - predicted value)/predicted value

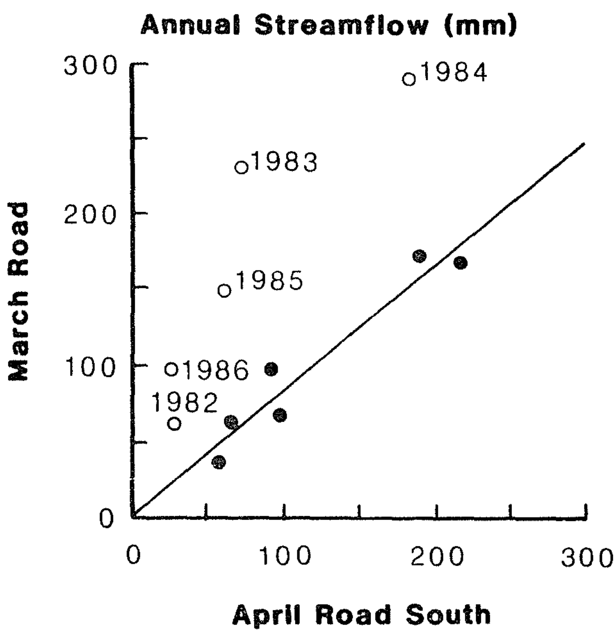
Appendix O

Annual streamflow in the logged catchments relative to that in the control catchments from 1975 to 1986.

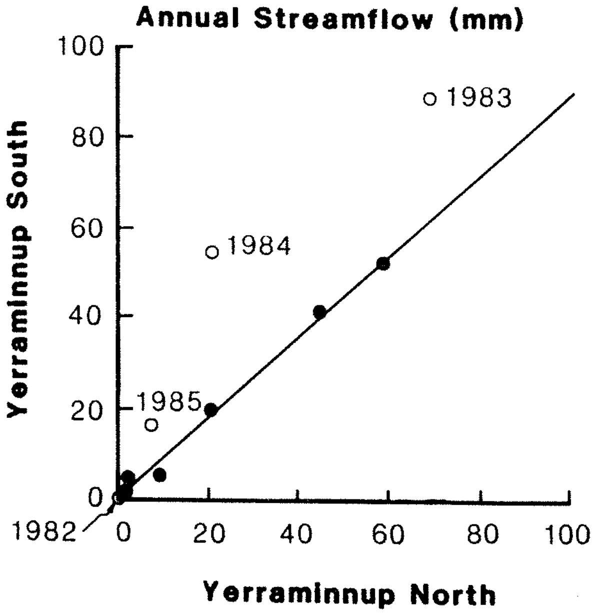
(All regressions are based on the data prior to 1982.)



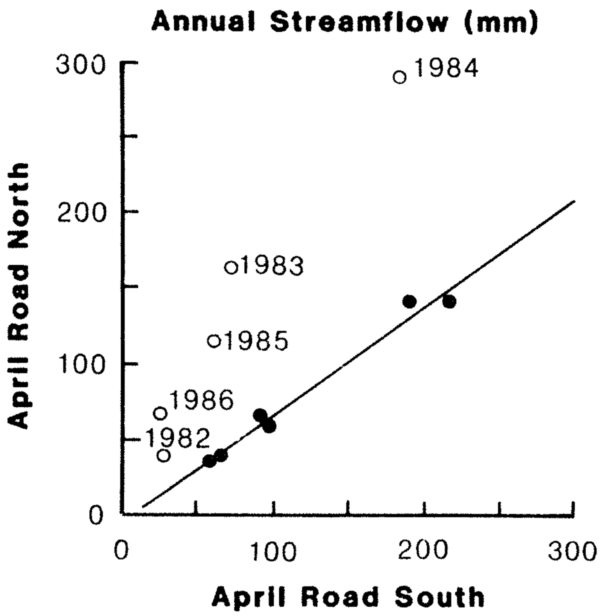
$y = -28.78 + 0.99x$
6 data points
$R^2 = 0.995$



$y = 2.10 + 0.82x$
6 data points
$R^2 = 0.931$



y = -0.25 + 0.91x
7 data points
R = 0.992



y = -5.10 + 0.71x
6 data points
R^2 = 0.979

Changes in annual streamflow in the four cut-over research catchments due to logging.

Catchment	year	flow observed (mm)	predicted flow[1] (mm)	absolute difference[2] (mm)	relative difference[3] (%)
Lewin South	1982	177	144	33	23
	1983	275	172	103	60
	1984	315	140	175	125
	1985	177	66	111	168
	1986	149	59	90	153
March Road	1982	61	26	35	135
	1983	230	62	168	271
	1984	290	155	135	87
	1985	149	53	96	181
	1986	98	23	75	326
April Road North	1982	41	16	25	156
	1983	165	47	118	251
	1984	291	127	164	129
	1985	114	39	75	192
	1986	67	14	53	379
Yerraminnup South	1982	.5	n/a[4]		
	1983	90	62	28	45
	1984	55	19	36	189
	1985	16	7	9	129
	1986	no flow	no flow		

[1] flow that would have occurred without logging, estimated by substituting the flow in the respective control catchment given in Appendix B into the appropriate regression equation on the two previous pages

[2] observed value - predicted value

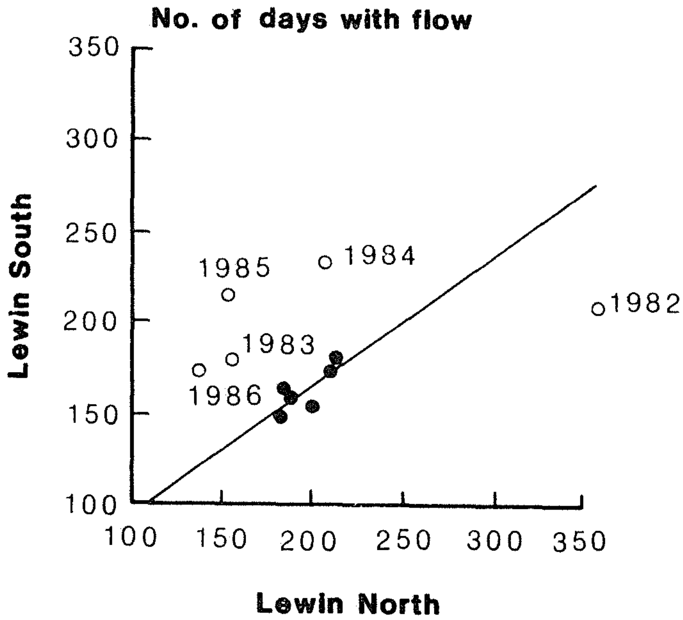
[3] (observed value - predicted value)/ predicted value

[4] not applicable, predicted value is negative

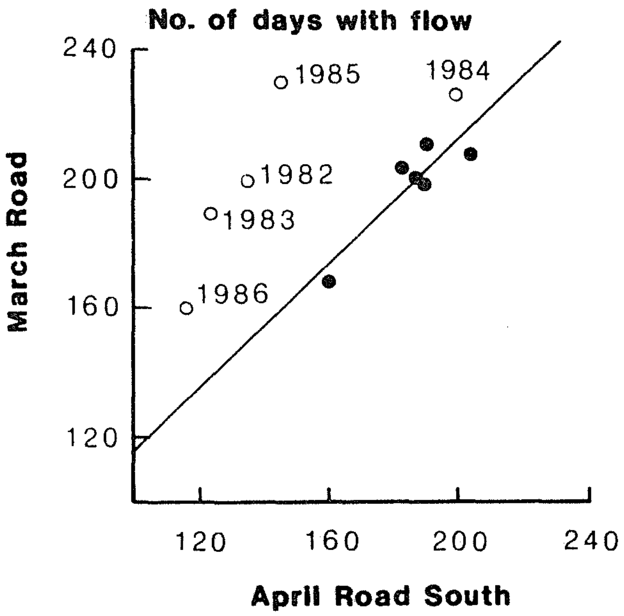
Appendix P

Number of days with streamflow per year in the logged catchments relative to that in the control catchments from 1975 to 1986.

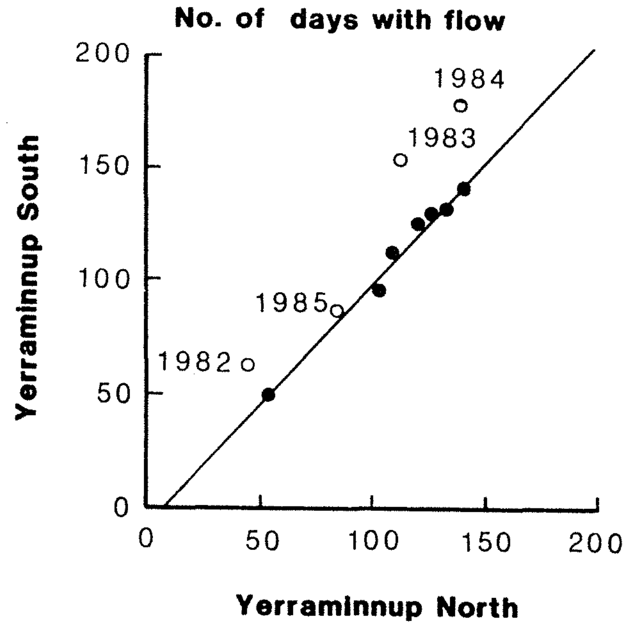
(All regressions are based on the data prior to 1982.)



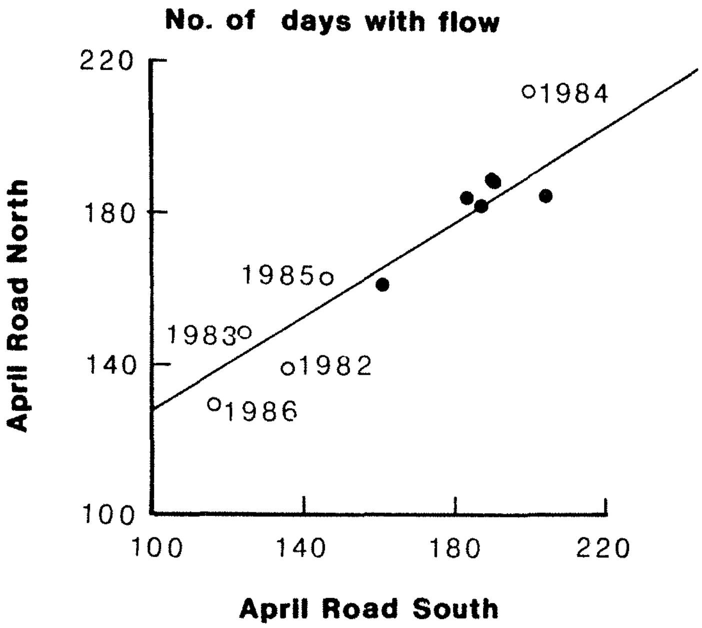
$y = 23 + 0.71x$
6 data points
$R^2 = 0.603$



$y = 21 + 0.95x$
6 data points
$R^2 = 0.797$



$y = -8 + 1.07x$
7 data points
$R^2 = 0.984$



$y = 65 + 0.62x$
6 data points
$R^2 = 0.744$

Changes in number of days with streamflow per year in the four cut-over research catchments due to logging.

Catchment	year	observed no. of days with flow	predicted no. of days with flow[1]	absolute difference[2] (days)	relative difference[3] (days)
Lewin South	1982	210	279	-69	-25
	1983	179	135	44	33
	1984	234	171	63	37
	1985	215	133	82	62
	1986	174	122	52	43
March Road	1982	199	150	49	33
	1983	189	139	50	36
	1984	226	211	15	7
	1985	229	160	69	43
	1986	160	132	28	21
April Road North	1982	139	150	-11	-7
	1983	148	143	5	3
	1984	212	191	21	11
	1985	163	157	6	4
	1986	129	138	-9	-7
Yerraminnup South	1982	62	40	22	55
	1983	154	114	40	35
	1984	178	142	36	25
	1985	86	83	3	4
	1986	no flow	no flow		

[1] no. of days with flow that would have occurred without logging, estimated by substituting the no. of days with flow in the respective control catchment given in Appendix C into the appropriate regression equation on the two previous pages

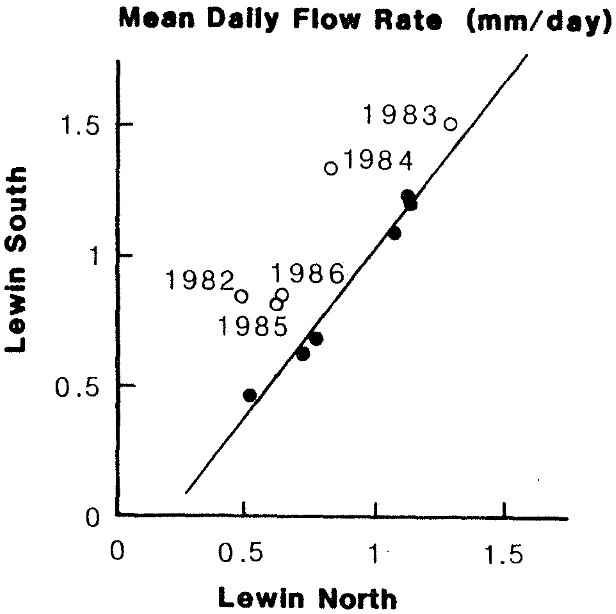
[2] observed value - predicted value

[3] (observed value - predicted value)/predicted value

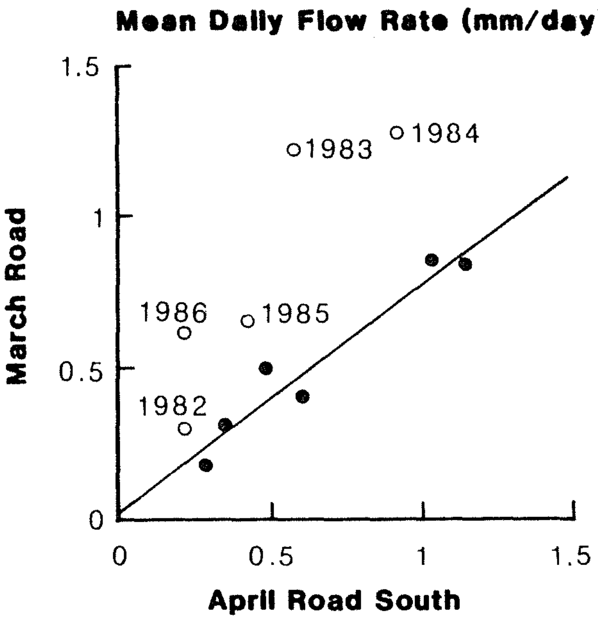
Appendix Q

Average daily streamflow rate in the logged catchments relative to that in the control catchments from 1975 to 1986.

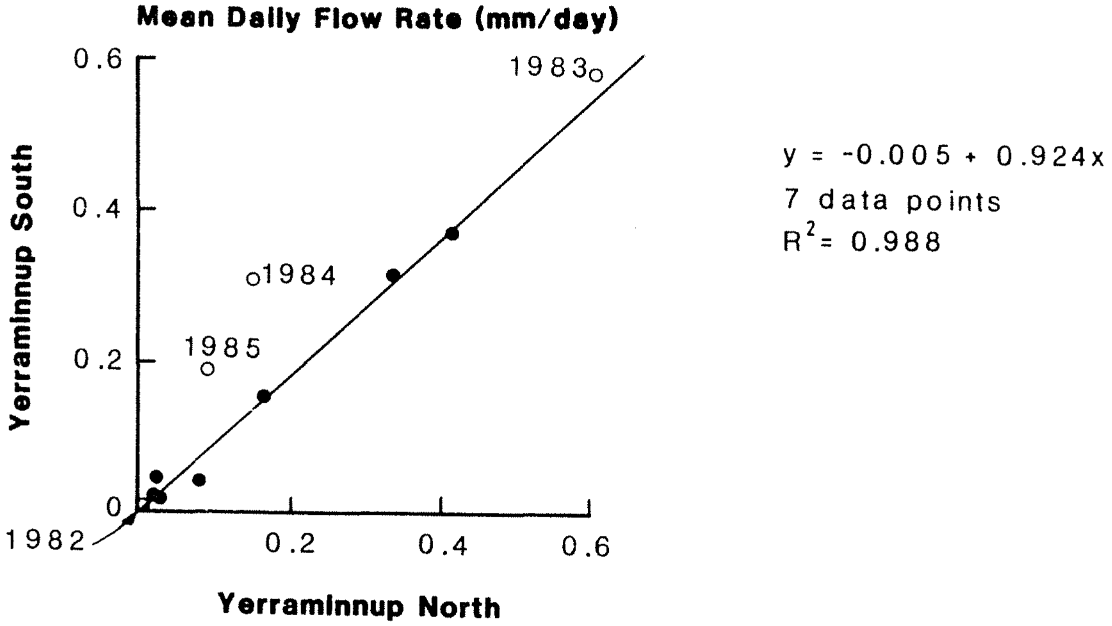
(All regressions are based on the data prior to 1982.)

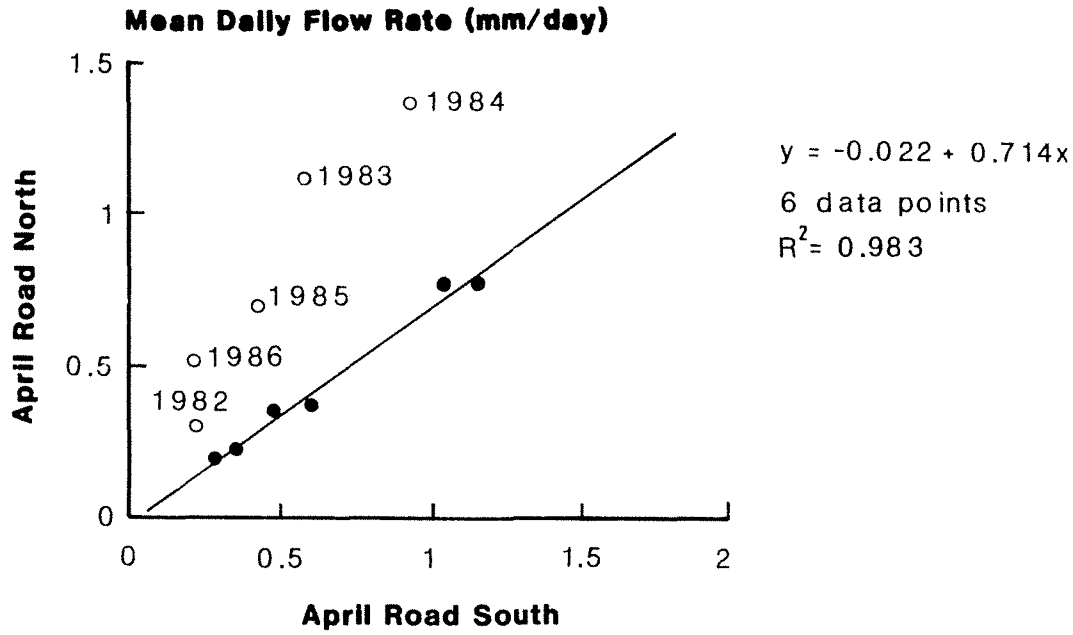


$y = -0.255 + 1.286x$
6 data points
$R^2 = 0.977$



$y = 0.026 + 0.741x$
6 data points
$R^2 = 0.936$


Mean Daily Flow Rate (mm/day)
0.6
0.4
0.2
0
1983
1984
1985
1982
0.2
0.4
0.6
Yerraminnup South
Yerraminnup North
y = -0.005 + 0.924x
7 data points
R² = 0.988


Mean Daily Flow Rate (mm/day)
1.5
1
0.5
0
1984
1983
1985
1986
1982
0
0.5
1
1.5
2
April Road North
April Road South
y = -0.022 + 0.714x
6 data points
R² = 0.983

Changes in average daily streamflow rate in the four cut-over research catchment due to logging.

Catchment	year	observed flow rate (mm/day)	predicted flow rate[1] (mm/day)	absolute difference[2] (mm/day)	relative difference[3] (%)
Lewin South	1982	.84	.37	.47	127
	1983	1.54	1.41	.13	9
	1984	1.35	.81	.54	67
	1985	.82	.55	.27	49
	1986	.86	.57	.29	51
March Road	1982	.31	.18	.13	72
	1983	1.22	.46	.76	165
	1984	1.28	.71	.57	80
	1985	.65	.34	.31	91
	1986	.61	.19	.42	221
April Road North	1982	.29	.13	.16	123
	1983	1.11	.40	.71	178
	1984	1.37	.64	.73	114
	1985	.70	.28	.42	150
	1986	.52	.14	.38	271
Yerraminnup South	1982	.01	n/a[4]		
	1983	.58	.55	.03	5
	1984	.31	.13	.18	138
	1985	.19	.08	.11	138
	1986	no flow	no flow		

[1] flow rate that would have occurred without logging, estimated by substituting the flow rate in the respective control catchment given in Appendix C into the appropriate regression equation on the two previous pages

[2] observed value - predicted value

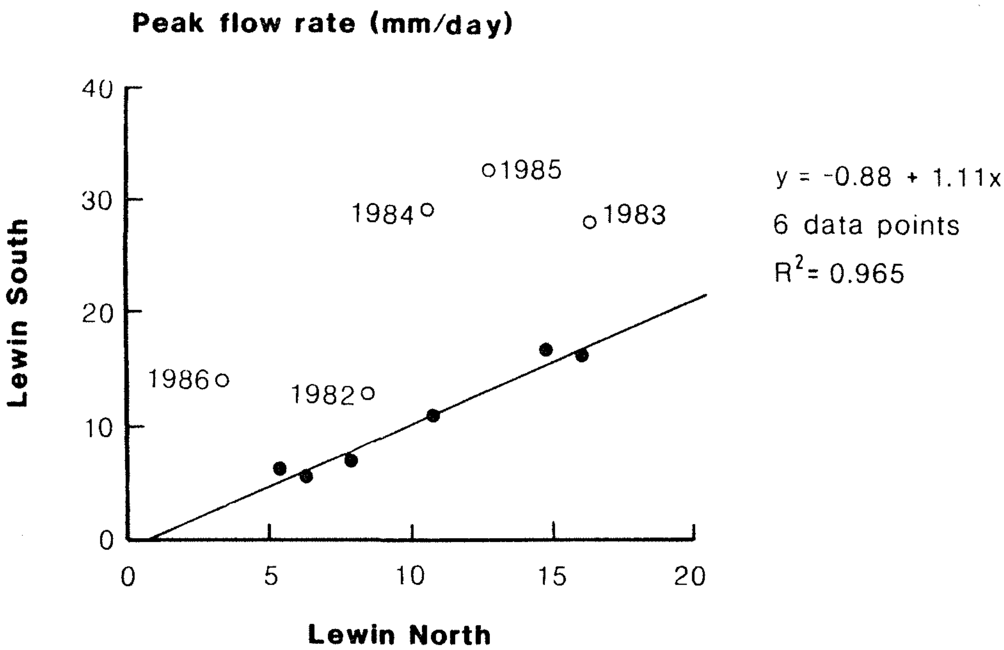
[3] (observed value - predicted value)/predicted value

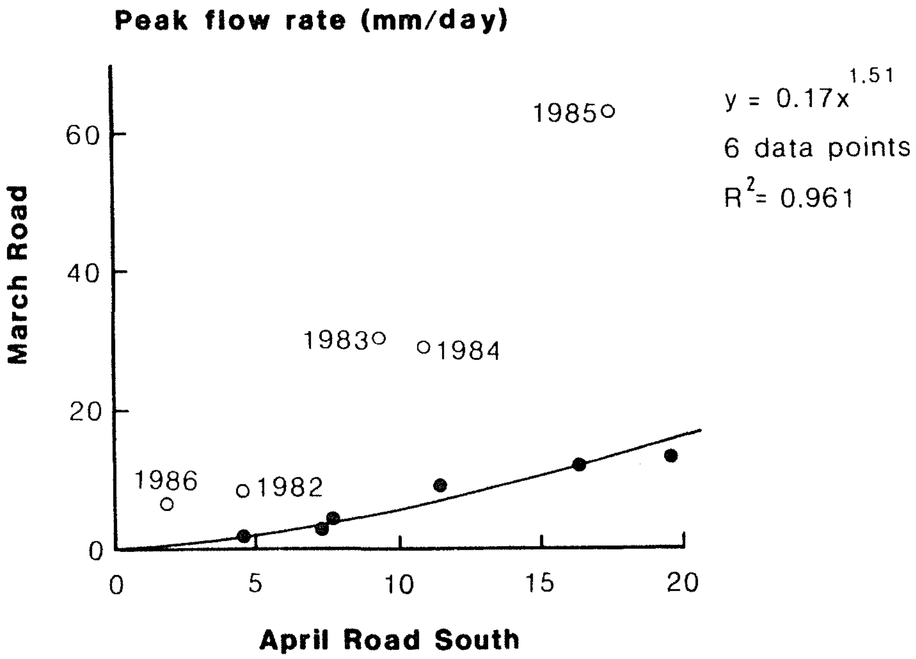
[4] not applicable, predicted value is negative

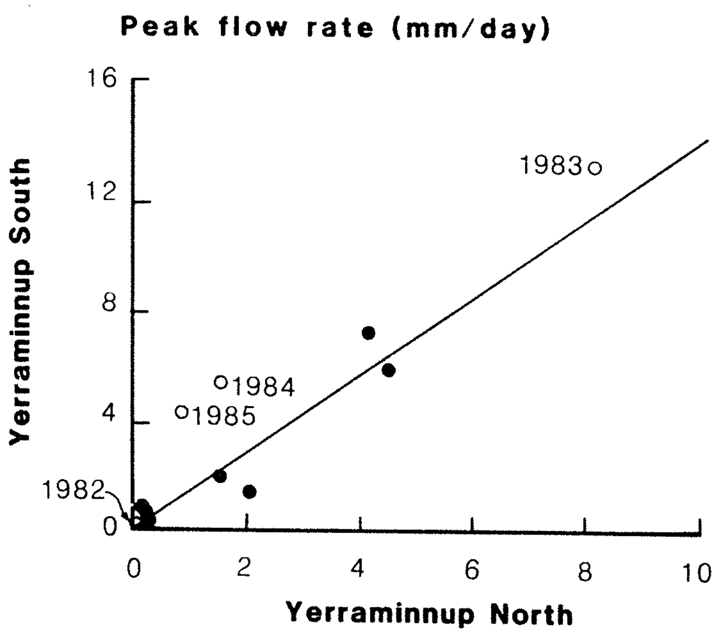
Appendix R

Peak streamflow rate in the logged catchments relative to that in the control catchments from 1975 to 1986.

(All regressions are based on the data prior to 1982.)


Peak flow rate (mm/day)
Lewin South
Lewin North
40
30
20
10
0
0
5
10
15
20
o1985
1984o
o1983
1986o
1982o
y = -0.88 + 1.11x
6 data points
R2= 0.965

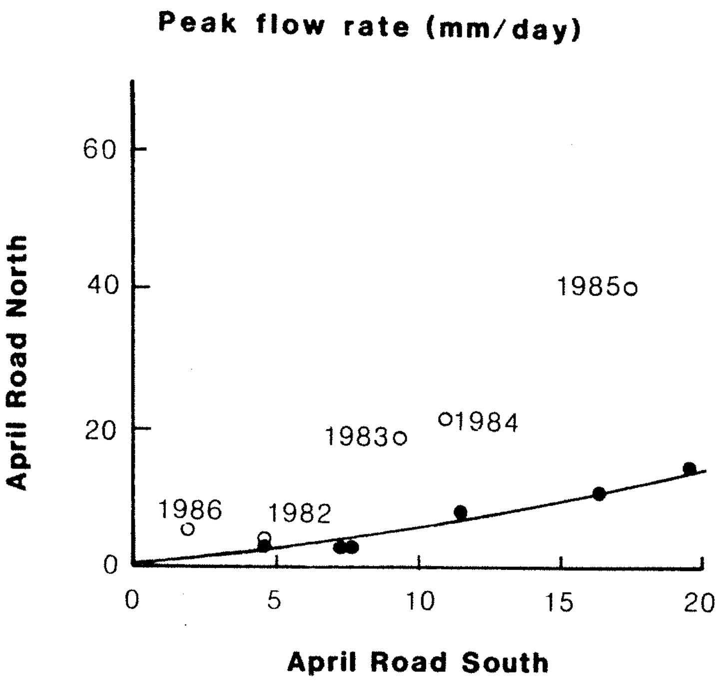

Peak flow rate (mm/day)
March Road
April Road South
60
40
20
0
0
5
10
15
20
1985o
1983o
o1984
1986
o1982
y = 0.17x1.51
6 data points
R2= 0.961



$y = -0.17 + 1.43x$

7 data points

$R^2 = 0.897$



$y = 0.32x^{1.25}$

6 data points

$R^2 = 0.887$

Changes in peak streamflow rate in the four cut-over research catchments due to logging.

Catchment	year	observed peak flow (mm/day)	predicted peak flow[1] (mm/day)	absolute difference[2] (mm/day)	relative difference[3] (%)
Lewin South	1982	12.9	8.6	4.3	50
	1983	28.3	17.3	11.0	64
	1984	29.2	10.8	18.4	170
	1985	32.8	13.3	19.5	147
	1986	14.1	2.9	11.2	386
March Road	1982	8.5	1.7	6.8	400
	1983	30.2	5.1	25.1	492
	1984	29.0	6.5	22.5	346
	1985	62.9	13.2	49.7	377
	1986	6.5	.5	6.0	1200
April Road North	1982	4.1	2.2	1.9	86
	1983	18.4	5.3	13.1	247
	1984	21.5	6.5	15.0	231
	1985	40.7	11.6	29.1	251
	1986	5.5	.7	4.8	686
Yerraminnup South	1982	.1	n/a[4]		
	1983	13.2	11.5	1.7	15
	1984	5.2	2.1	3.1	148
	1985	4.2	1.0	3.2	320
	1986	no flow	no flow		

[1] flow rate that would have occurred without logging, estimated by substituting the flow rate in the respective control catchment given in Appendix D into the appropriate regression equation on the two previous pages

[2] observed value - predicted value

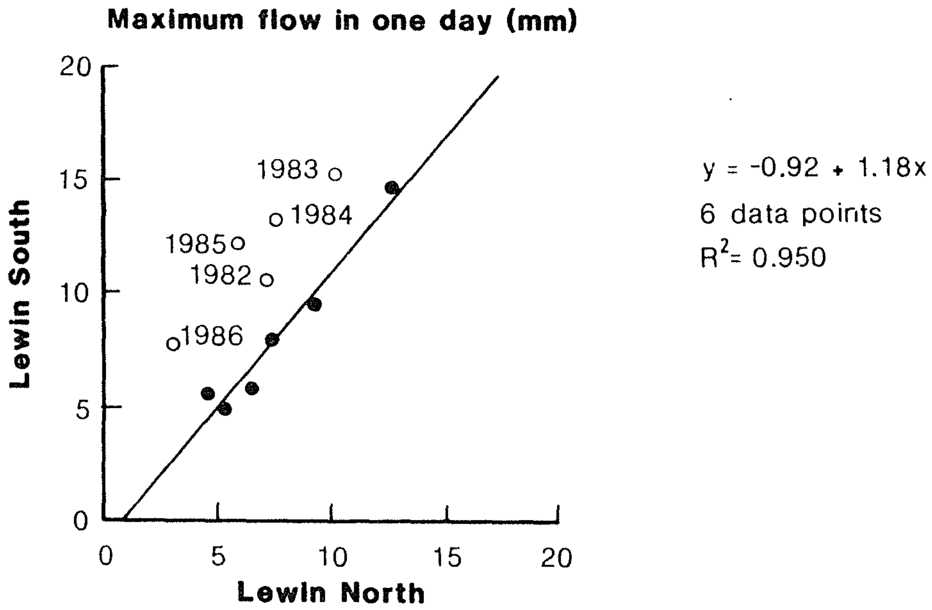
[3] (observed value - predicted value)/predicted value

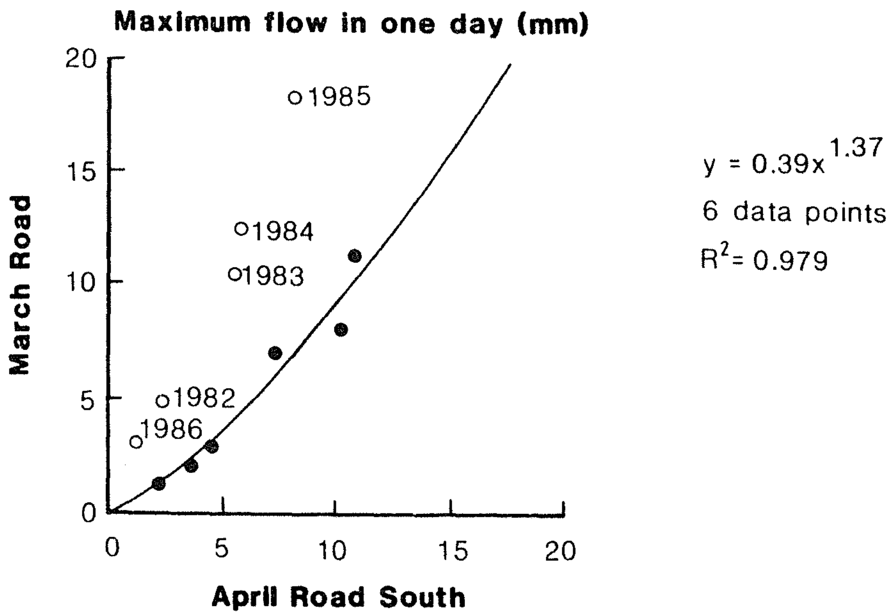
[4] not applicable, predicted value is negative

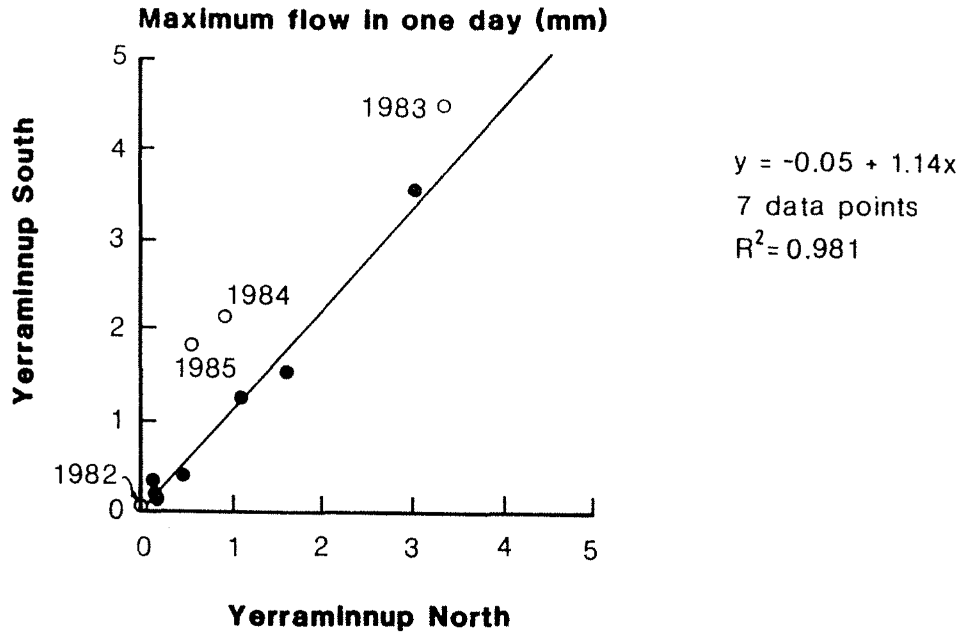
Appendix S

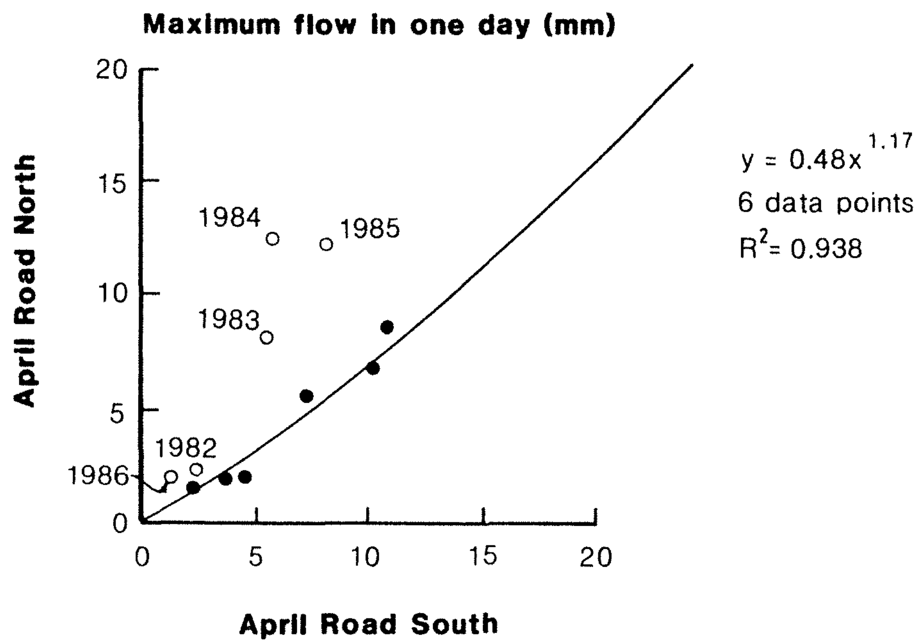
Maximum streamflow in one day in the logged catchments relative to that in the control catchments from 1975 to 1986.

(All regressions are based on the data prior to 1982.)


Maximum flow in one day (mm)
Lewin South
Lewin North
1983
1984
1985
1982
1986
0
5
10
15
20
y = -0.92 + 1.18x
6 data points
R²= 0.950


Maximum flow in one day (mm)
March Road
April Road South
1985
1984
1983
1982
1986
0
5
10
15
20
y = 0.39x^1.37
6 data points
R²= 0.979


Maximum flow in one day (mm)
Yerraminnup South
Yerraminnup North
1983
1984
1985
1982
0
1
2
3
4
5
y = -0.05 + 1.14x
7 data points
R²= 0.981


Maximum flow in one day (mm)
April Road North
April Road South
1984
1985
1983
1982
1986
0
5
10
15
20
y = 0.48x 1.17
6 data points
R²= 0.938

Changes in maximum streamflow in one day in the four cut-over research catchments due to logging.

Catchment	year	observed flow (mm)	predicted flow[1] (mm)	absolute difference[2] (mm)	relative difference[3] (%)
Lewin South	1982	10.6	7.6	3.0	39
	1983	15.3	11.2	4.1	37
	1984	13.3	8.2	5.1	62
	1985	12.3	6.2	6.1	98
	1986	7.8	2.8	5.0	35
March Road	1982	4.9	1.3	3.6	277
	1983	10.4	4.1	6.3	154
	1984	12.5	4.3	8.2	191
	1985	18.3	7.0	11.3	161
	1986	3.1	.6	2.5	417
April Road North	1982	2.4	1.4	1.0	71
	1983	8.1	3.5	4.6	131
	1984	12.4	3.7	8.7	235
	1985	12.3	5.6	6.7	120
	1986	2.1	.7	1.4	200
Yerraminnup South	1982	.04	n/a[4]		
	1983	.5	3.8	.7	18
	1984	2.1	1.0	1.1	110
	1985	1.8	.6	1.2	200
	1986	no flow	no flow		

[1] flow that would have occurred without logging, estimated by substituting the flow in the respective control catchment given in Appendix D into the appropriate regression equation on the two previous pages

[2] observed value - predicted value

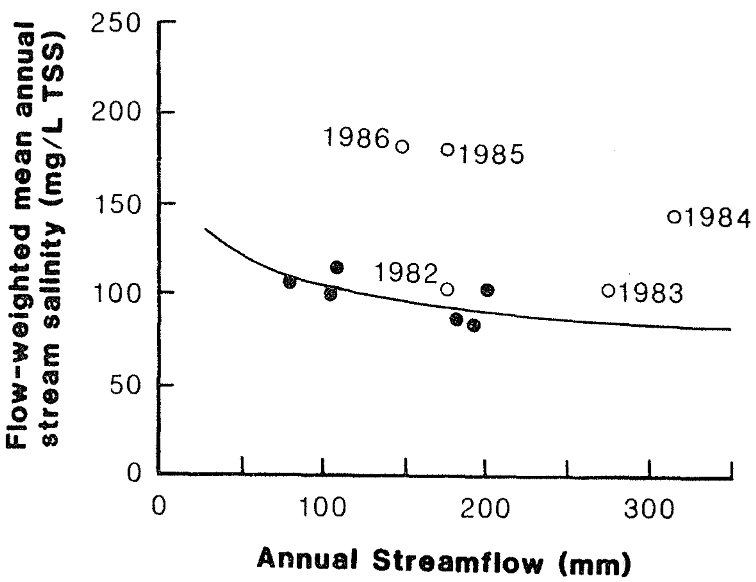
[3] (observed value - predicted value)/predicted value

[4] not applicable, predicted value is negative

Appendix T

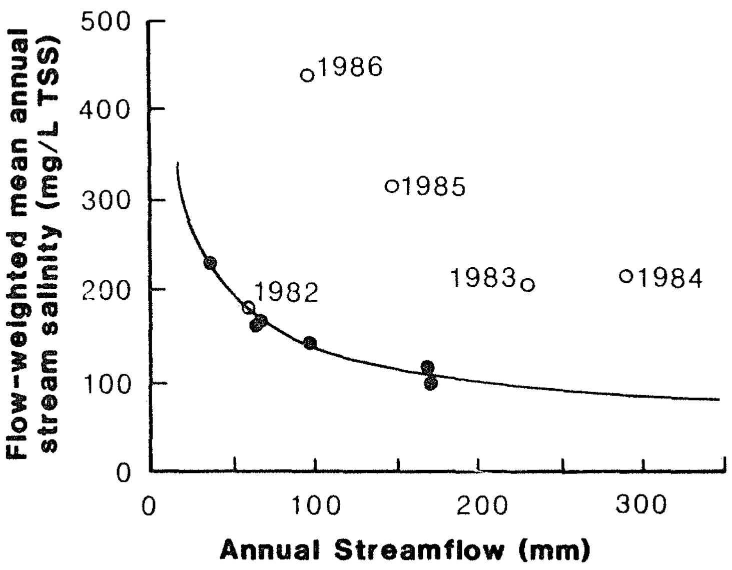
Flow-weighted mean annual stream salinity in relation to annual streamflow in the four logged catchment from 1975 to 1986.

(All regressions are based on the data prior to 1982.)



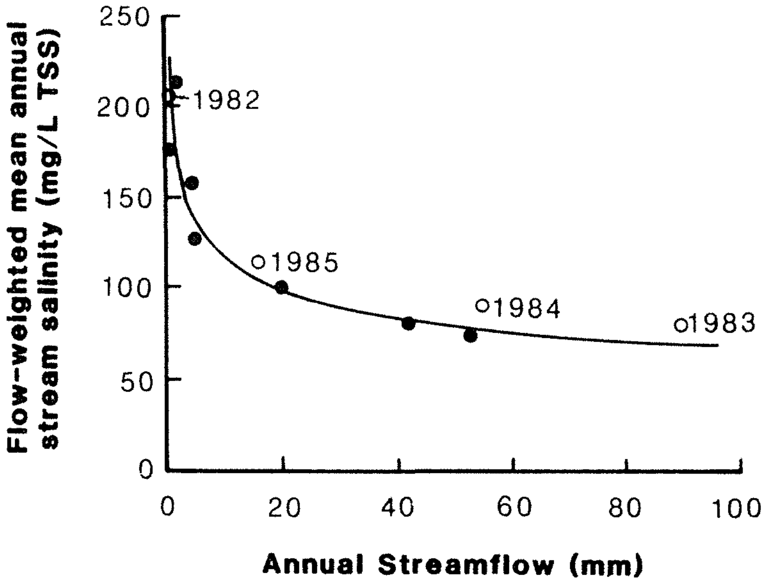
Lewin South

$y = 265x^{-0.20}$
6 data points
$R^2 = 0.445$



March Road

$y = 1217x^{-0.47}$
6 data points
$R^2 = 0.958$

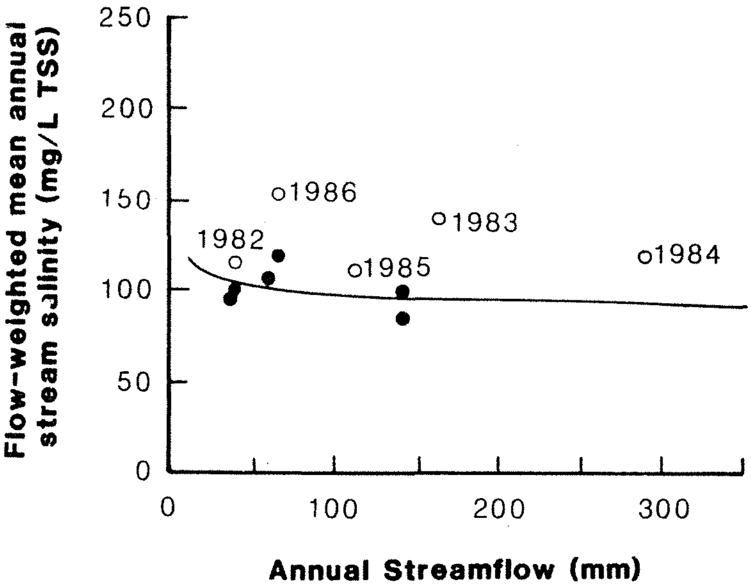


Yerraminnup South

$y = 198x^{-0.23}$

7 data points

$R^2 = 0.885$



April Road North

$y = 132x^{-0.064}$

6 data points

$R^2 = 0.117$

Changes in flow-weighted mean annual stream salinity in the four cut-over research catchments due to logging.

Catchment	year	observed salinity (mg/L)	predicted salinity[1] (mg/L)	absolute difference[2] (mg/L)	relative difference[3] (%)
Lewin South	1982	103	97	6	6
	1983	103	94	9	10
	1984	145	98	47	48
	1985	182	114	68	60
	1986	183	116	67	58
March Road	1982	181	263	-82	-31
	1983	208	174	34	20
	1984	218	114	104	91
	1985	314	188	126	67
	1986	439	275	164	60
April Road North	1982	116	111	5	5
	1986	140	103	37	36
	1984	119	97	22	23
	1985	111	105	6	6
	1986	154	113	41	36
Yerraminnup South	1982	207	239	-32	-13
	1983	82	76	6	8
	1984	91	100	-9	-9
	1985	114	128	-14	-11
	1986	no flow	no flow		

[1] salinity that would have occurred without logging, estimated by substituting the flow that would have occurred without logging, given in Appendix Y, into the appropriate regression equation on the two previous pages

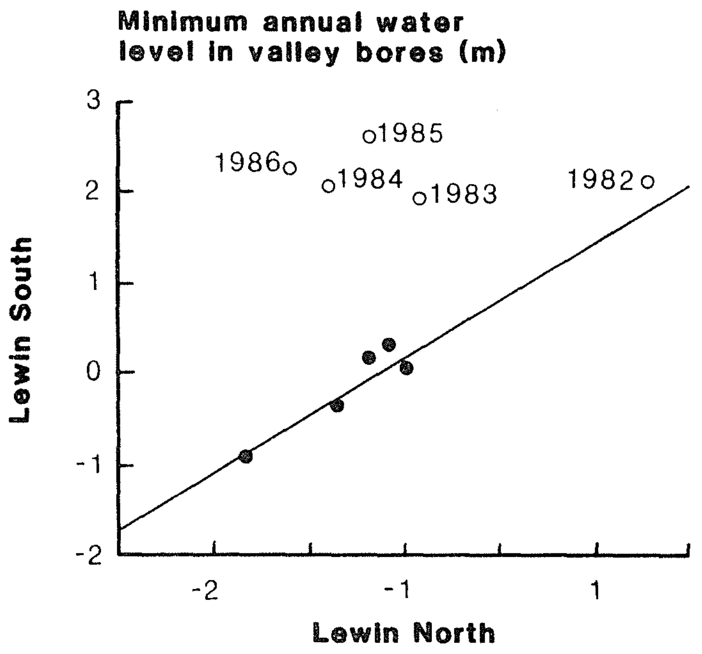
[2] measured value - predicted value

[3] (measured value - predicted value)/predicted value

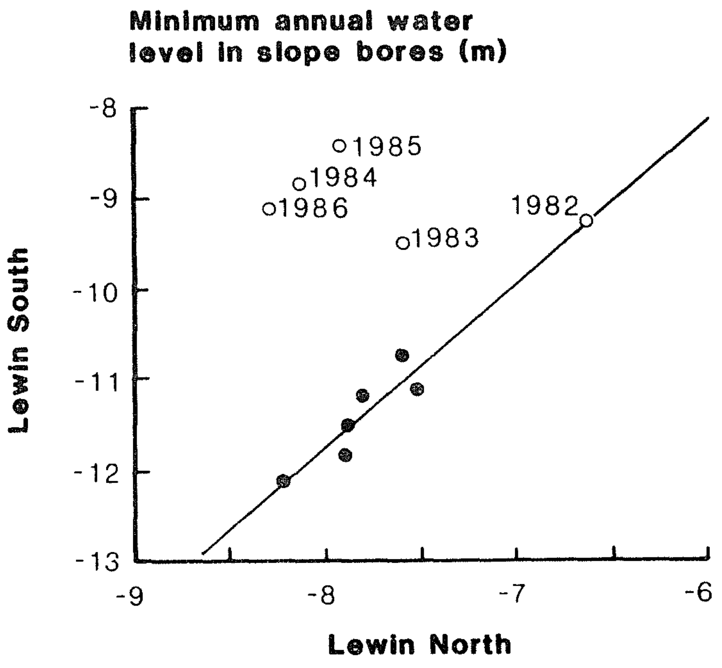
Appendix U

Minimum annual water level averaged for groups of bores in the logged catchments relative to that in the control catchments from 1975 to 1986.

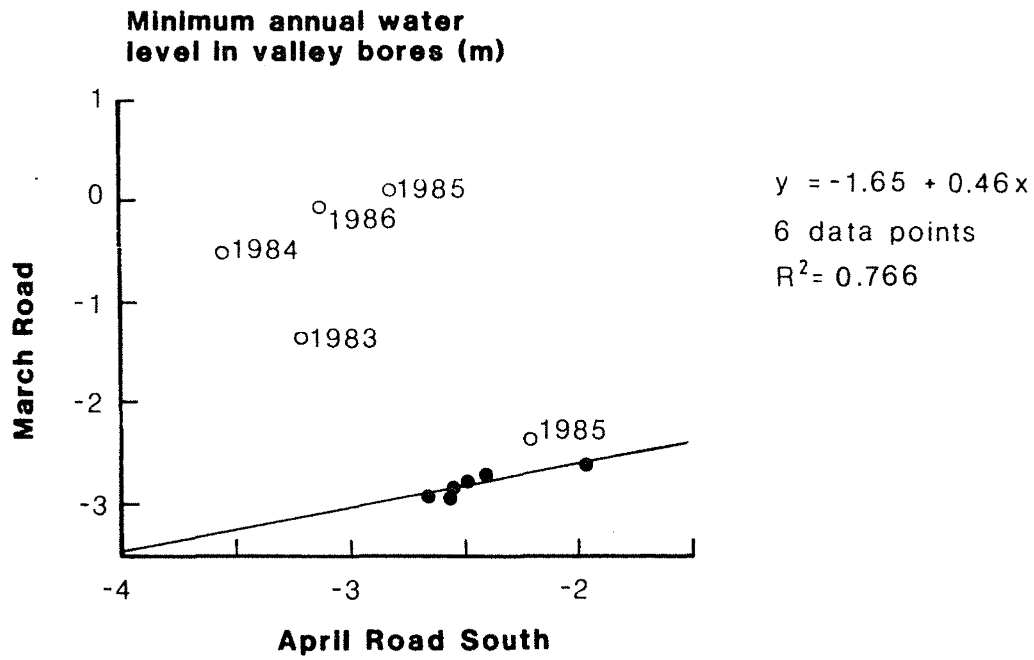
(All regressions are based on the data prior to 1982.)

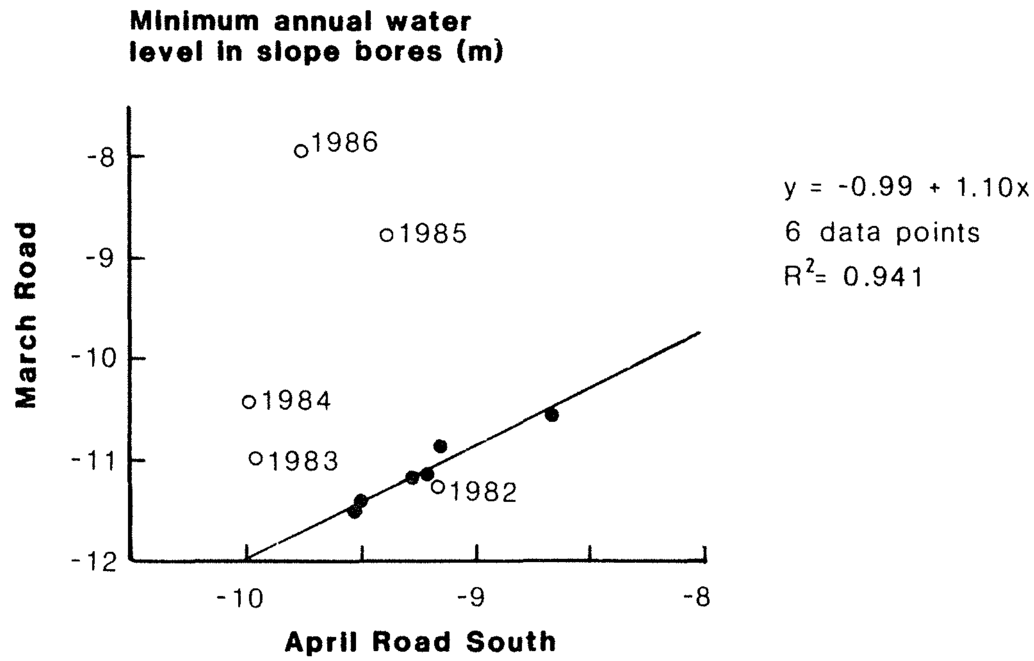


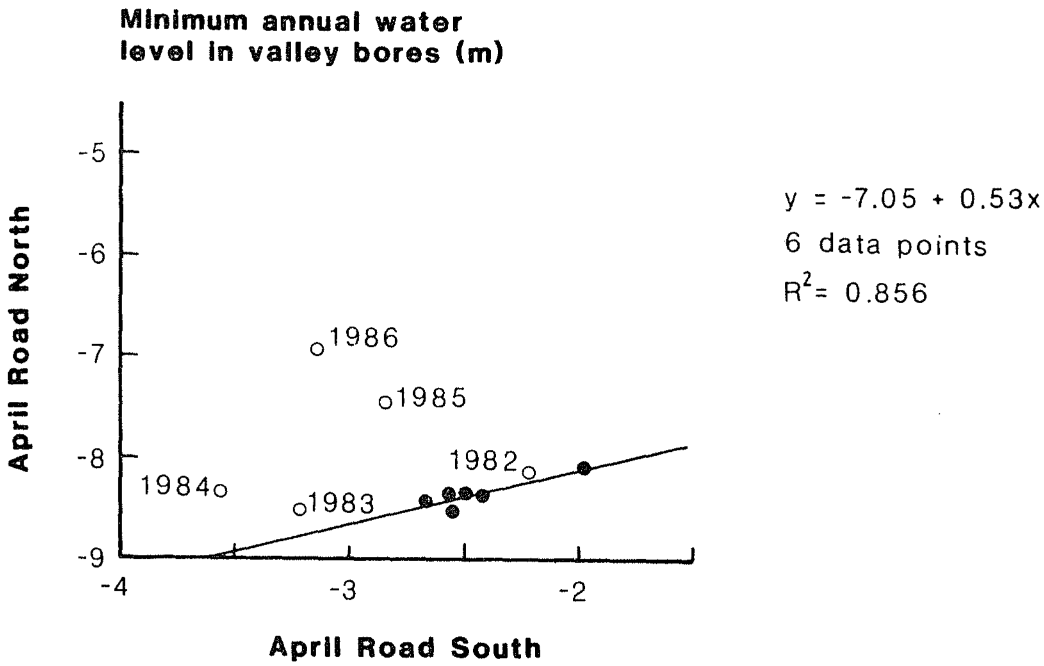
$y = 1.45 + 1.28x$
6 data points
$R^2 = 0.840$

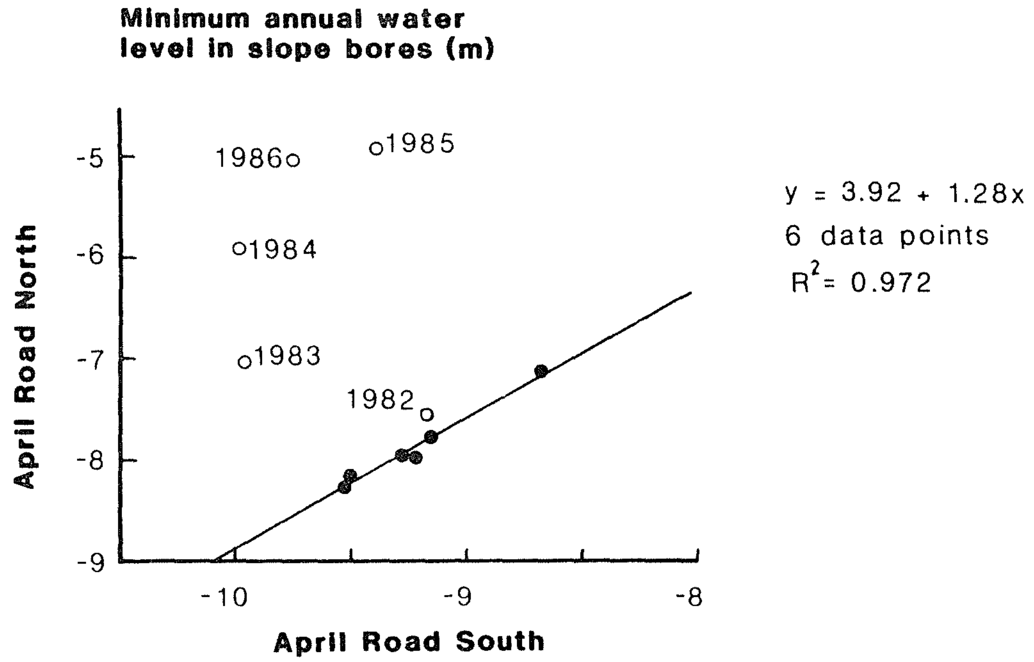


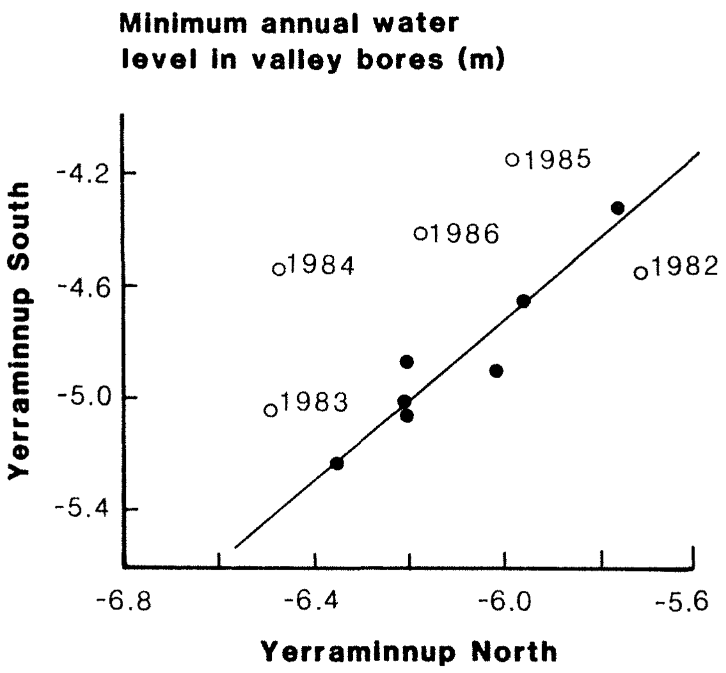
$y = 2.59 + 1.79x$
6 data points
$R^2 = 0.818$


Minimum annual water level in valley bores (m)
March Road
April Road South
1
0
-1
-2
-3
-4
-3
-2
o1985
o1986
o1984
o1983
o1985
y = -1.65 + 0.46x
6 data points
R²= 0.766

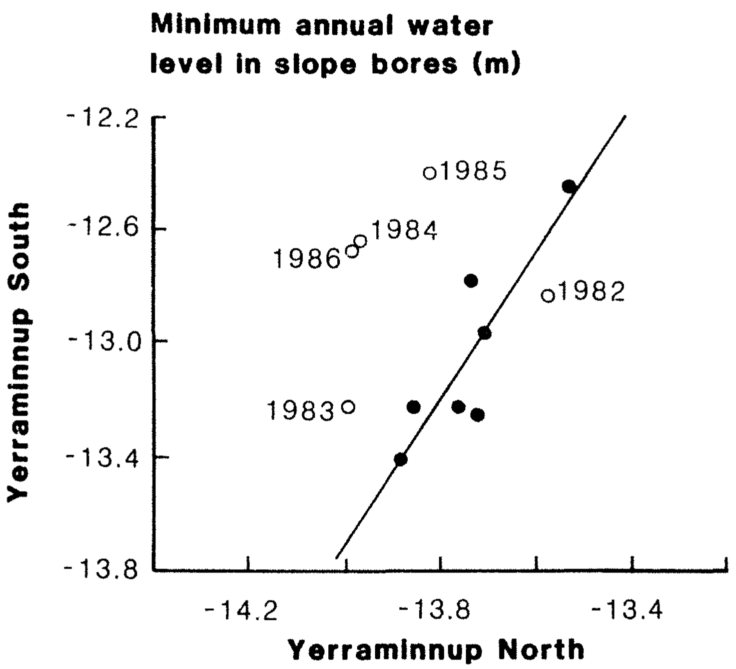

Minimum annual water level in slope bores (m)
March Road
April Road South
-8
-9
-10
-11
-12
-10
-9
-8
o1986
o1985
o1984
o1983
o1982
y = -0.99 + 1.10x
6 data points
R²= 0.941


Minimum annual water
level in valley bores (m)
April Road North
-5
-6
-7
-8
-9
1986
1985
1982
1984
1983
-4
-3
-2
April Road South
y = -7.05 + 0.53x
6 data points
R²= 0.856


Minimum annual water
level in slope bores (m)
April Road North
-5
-6
-7
-8
-9
1986
1985
1984
1983
1982
-10
-9
-8
April Road South
y = 3.92 + 1.28x
6 data points
R²= 0.972



y = 3.88 + 1.44x
7 data points
R^2 = 0.908



y = 22.35 + 2.58x
7 data points
R^2 = 0.780

Changes in the minimum annual water level averaged for groups of bores in the four cut-over research catchments due to logging.

Catchment	bore group	year	observed level (m)	predicted level[1] (m)	absolute difference[2] (m)	relative difference[3] (%)
Lewin South	valley bores	1982	+2.15	+1.82	.33	18
		1983	+1.94	+.28	1.66	593
		1984	+2.08	.32	2.40	750
		1985	+2.61	.05	2.66	5320
		1986	+2.28	.60	2.88	480
	slope bores	1982	9.25	9.27	.02	.2
		1983	9.48	10.98	1.50	14
		1984	8.83	11.95	3.12	26
		1985	8.43	11.58	3.15	27
		1986	9.11	12.24	3.13	26
March Road	valley bores	1982	2.32	2.67	.35	13
		1983	1.34	3.13	1.79	57
		1984	.50	3.29	2.79	85
		1985	+.13	2.96	3.09	104
		1986	.04	3.09	3.05	99
	slope bores	1982	11.26	11.03	-.23	-2
		1983	10.98	11.89	.91	8
		1984	10.43	11.92	1.49	13
		1985	8.78	11.26	2.48	22
		1986	7.93	11.66	3.73	32

April Road North	valley bores	1982	8.15	8.23	.08	1
		1983	8.52	8.76	.24	3
		1984	8.35	8.95	.60	7
		1985	7.45	8.56	1.11	13
		1986	6.93	8.72	1.79	21
	slope bores	1982	7.54	7.79	.25	3
		1983	7.03	8.80	1.77	20
		1984	5.90	8.83	2.93	33
		1985	4.90	8.06	3.16	39
		1986	5.03	8.52	3.49	41
Yerraminnup South	valley bores	1982	4.55	4.31	-.24	-6
		1983	5.05	5.43	.38	7
		1984	4.55	5.40	.85	16
		1985	4.15	4.70	.55	12
		1986	4.42	4.97	.55	11
	slope bores	1982	12.83	12.61	-.22	-2
		1983	13.23	13.70	.47	3
		1984	12.65	13.62	.97	7
		1985	12.40	13.24	.84	6
		1986	12.68	13.67	.99	7

[1] water level that would have occurred without logging, estimated by substituting the water level in the respective bore group in the respective control catchment given in Appendix F into the appropriate regression equation on the previous pages

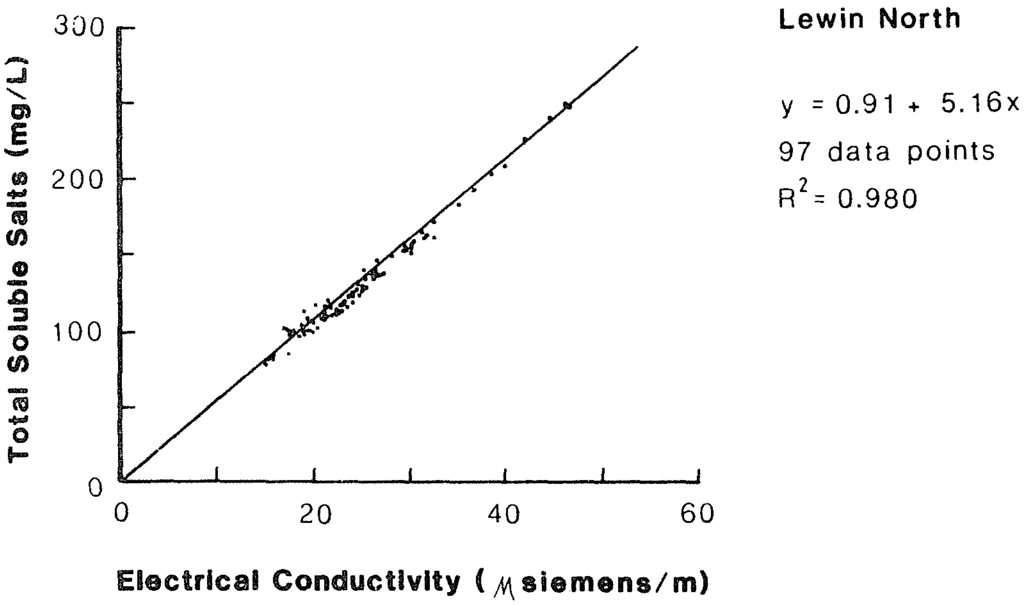
[2] observed value - predicted value

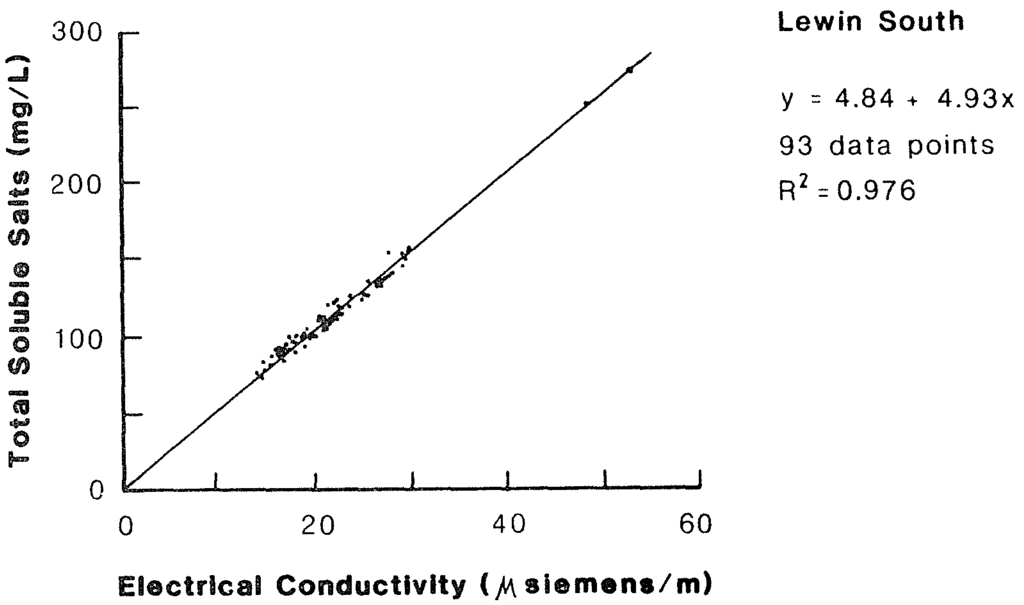
[3] (observed value - Predicted value)/predicted value

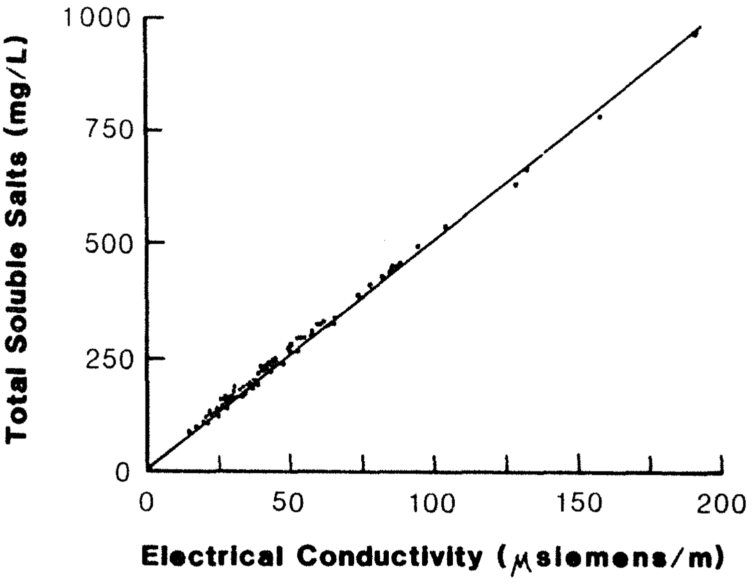
Appendix V

Correlations between electrical conductivity and the concentration of total soluble salts for the seven research catchments.

(All regressions are based on data from 1984 and 1985.)


300
200
100
0
Total Soluble Salts (mg/L)
0
20
40
60
Electrical Conductivity (μ siemens/m)
Lewin North
y = 0.91 + 5.16x
97 data points
R² = 0.980


300
200
100
0
Total Soluble Salts (mg/L)
0
20
40
60
Electrical Conductivity (μ siemens/m)
Lewin South
y = 4.84 + 4.93x
93 data points
R² = 0.976

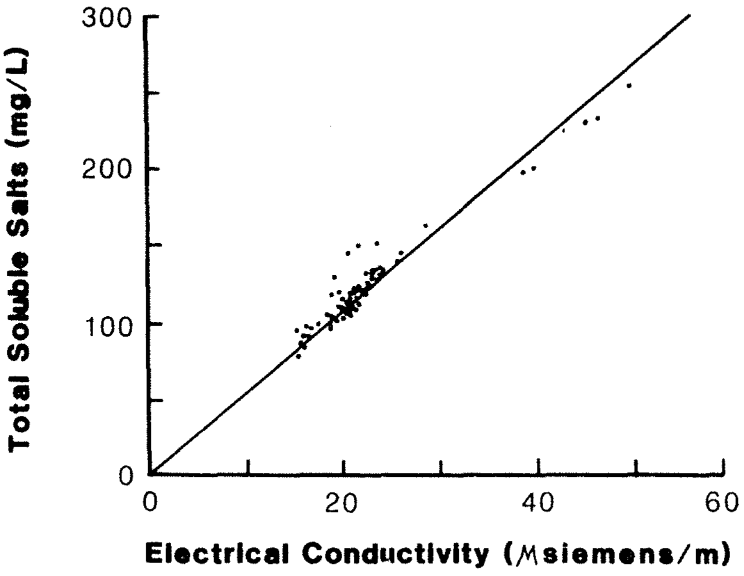


March Road

$y = 14.3 + 4.94x$

135 data points

$R^2 = 0.996$

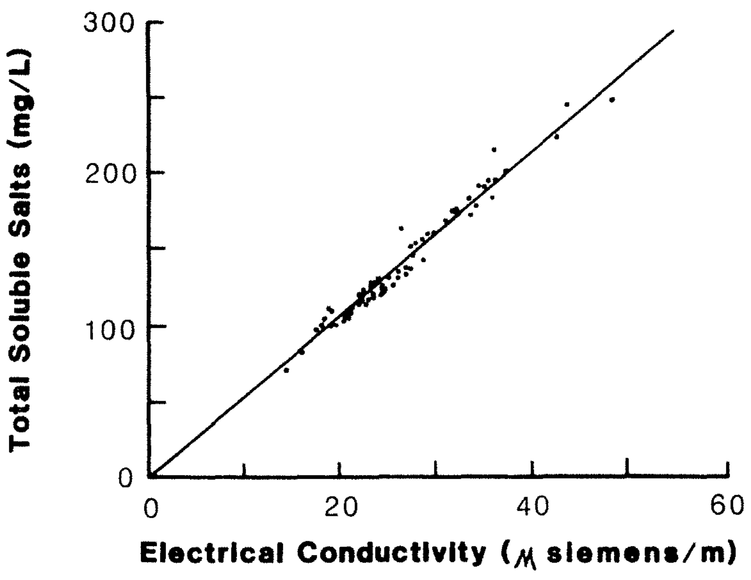


April Road North

$y = 13.4 + 4.82x$

93 data points

$R^2 = 0.9410$

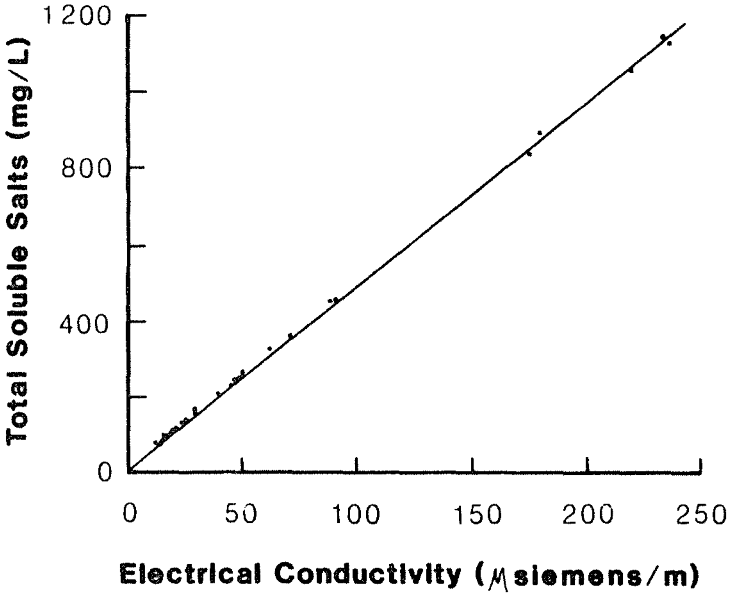


April Road South

$y = -4.53 + 5.52x$

77 data points

$R^2 = 0.969$

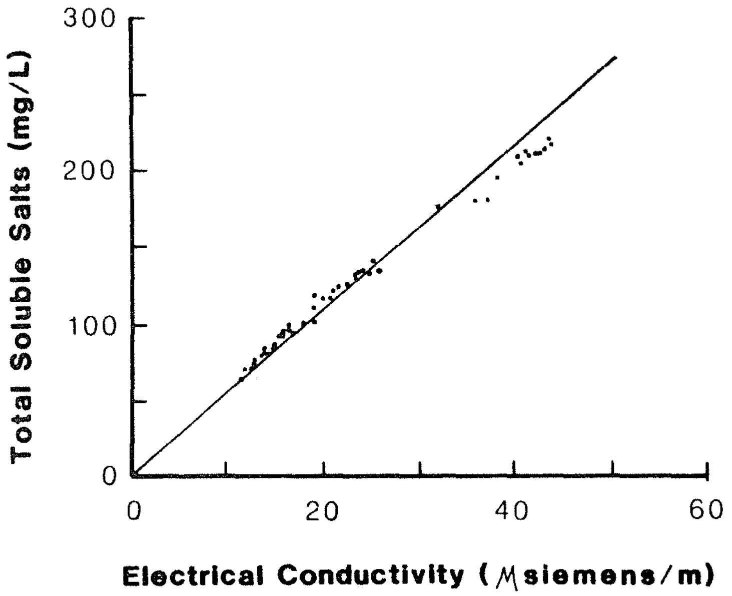


Yerraminnup North

y = 14.5 + 4.83x

35 data points

R^2 = 0.9996



Yerraminnup South

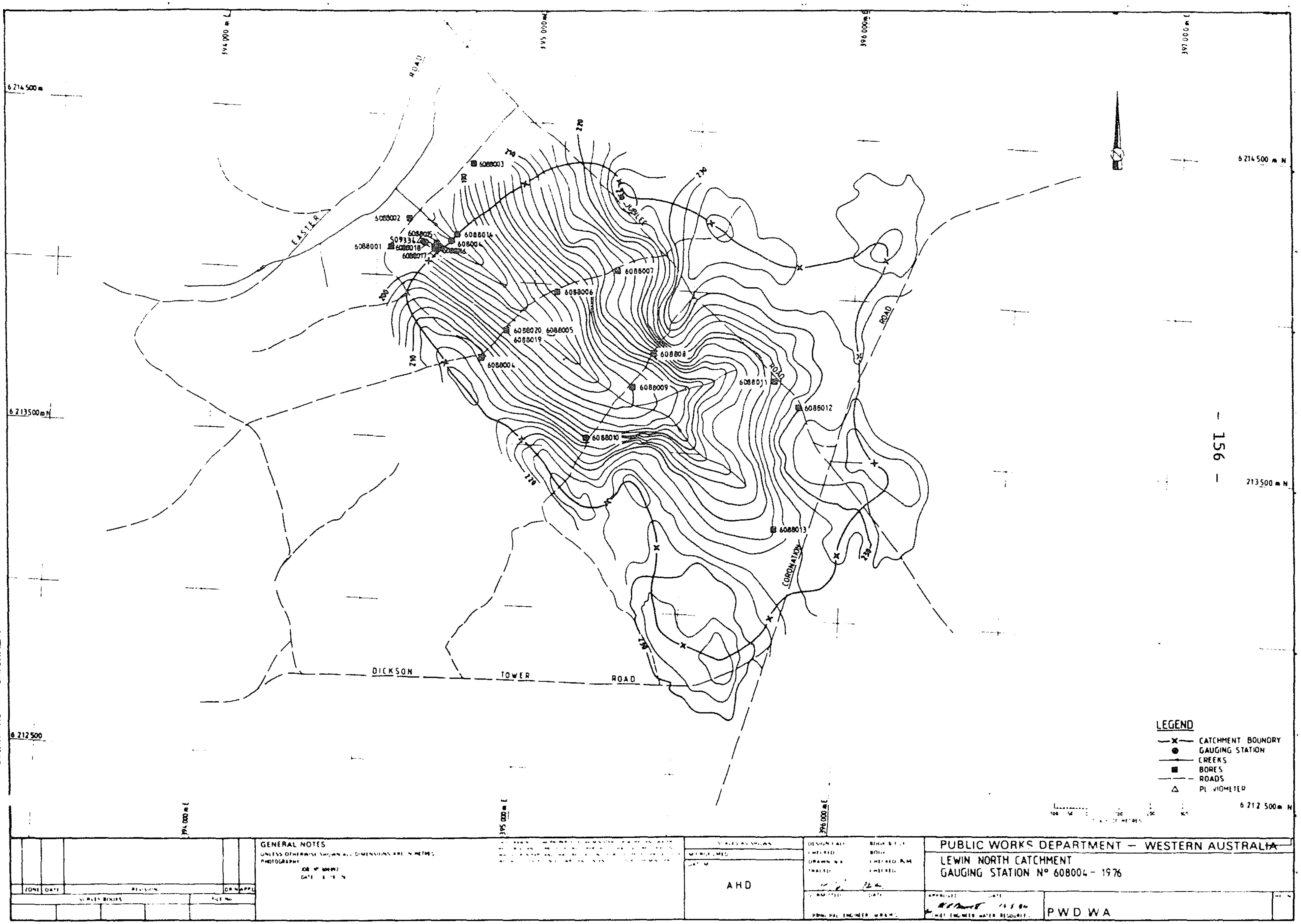
y = 15.0 + 4.75x

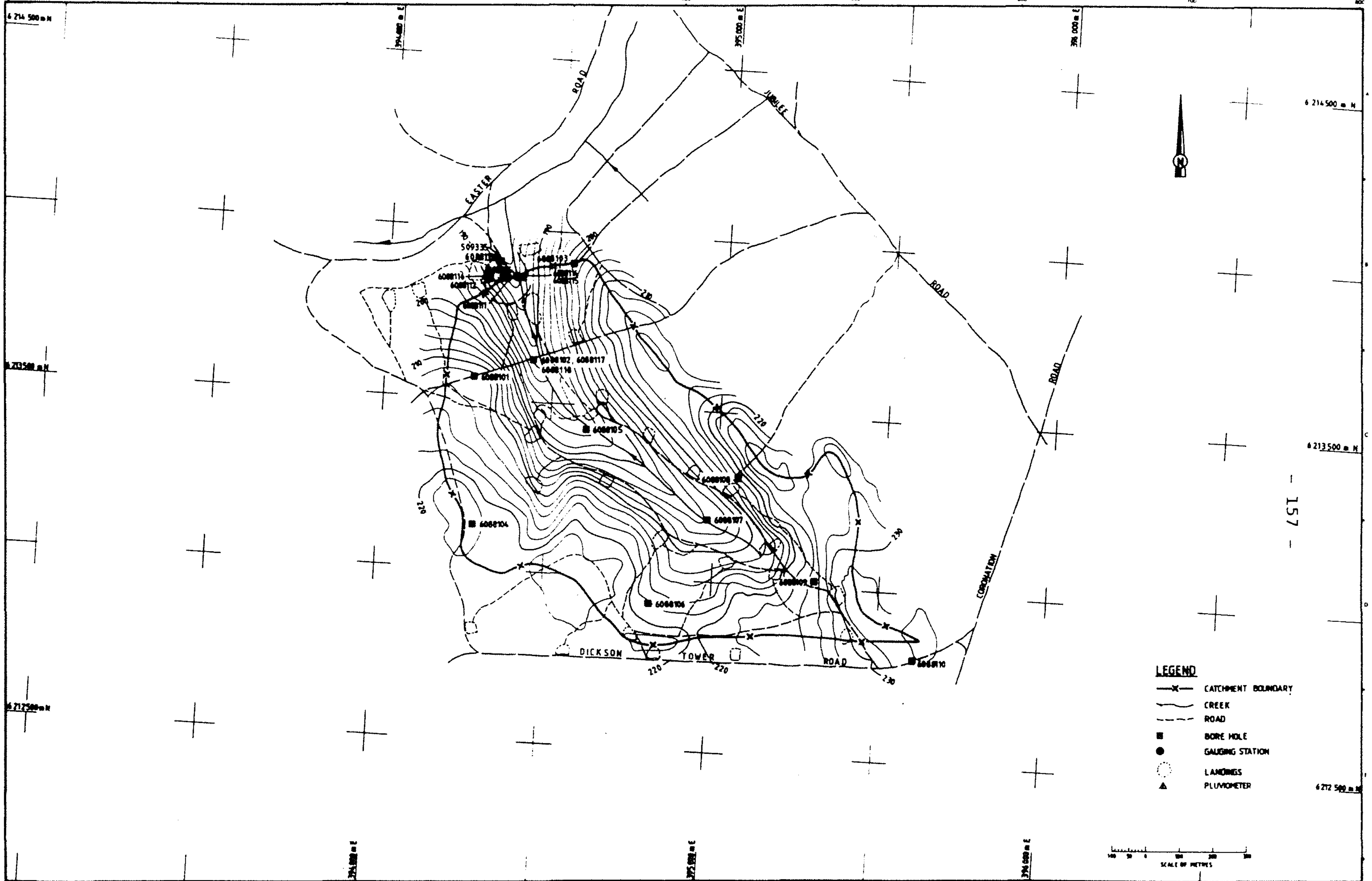
55 data points

R^2= 0.992

Appendix W

Topographic maps including the location of gauging stations and bores for the seven research catchments.


LEWIN NORTH CATCHMENT
394 000 m E
395 000 m E
396 000 m E
397 000 m E
6 214 500 m N
6 213 500 m N
6 212 500 m N
EASTER ROAD
JUBILEE
CORONATION ROAD
DICKSON TOWER ROAD
ROAD
210
220
230
6088001
6088002
6088003
6088004
6088005
6088006
6088007
6088008
6088009
6088010
6088011
6088012
6088013
6088014
6088016
6088017
6088018
6088019
6088020
509336
608004
LEGEND
CATCHMENT BOUNDRY
GAUGING STATION
CREEKS
BORES
ROADS
GENERAL NOTES
AHD
PUBLIC WORKS DEPARTMENT — WESTERN AUSTRALIA
LEWIN NORTH CATCHMENT
GAUGING STATION Nº 608004 - 1976
PWD WA



LEWIN SOUTH CATCHMENT

- 157 -

GENERAL NOTES
UNLESS OTHERWISE SHOWN ALL DIMENSIONS ARE IN METRES
PHOTOGRAPHY WA 2147(C)
DATE 30-4-83
PHOTO No. 5591

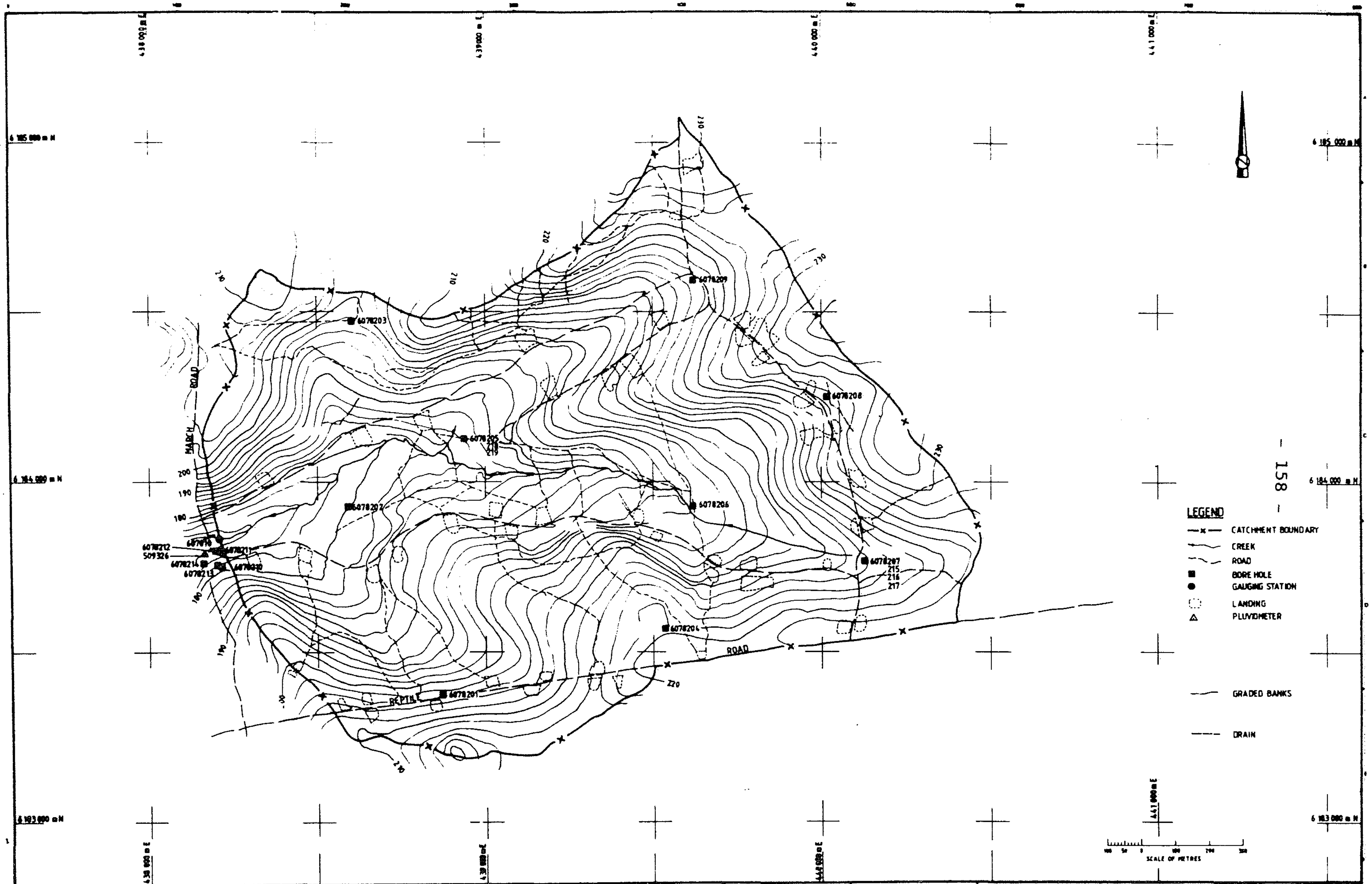
SCALES AS SHOWN
MICROFILMED
DATUM
A.H.D.

DESIGN CALC / BOOK & FILE
CHECKED / BOOK
DRAWN R BOZO / CHECKED R.M.
TRACED / CHECKED
SUBMITTED / DATE
APPROVED / DATE 16 5 84

PUBLIC WORKS DEPARTMENT — WESTERN AUSTRALIA
LEWIN SOUTH CATCHMENT
GAUGING STATION No 608005 - 1983 (POST-TREATMENT)
CONTOURS V I 2 m

P.W.D.,W.A.

MARCH ROAD CATCHMENT



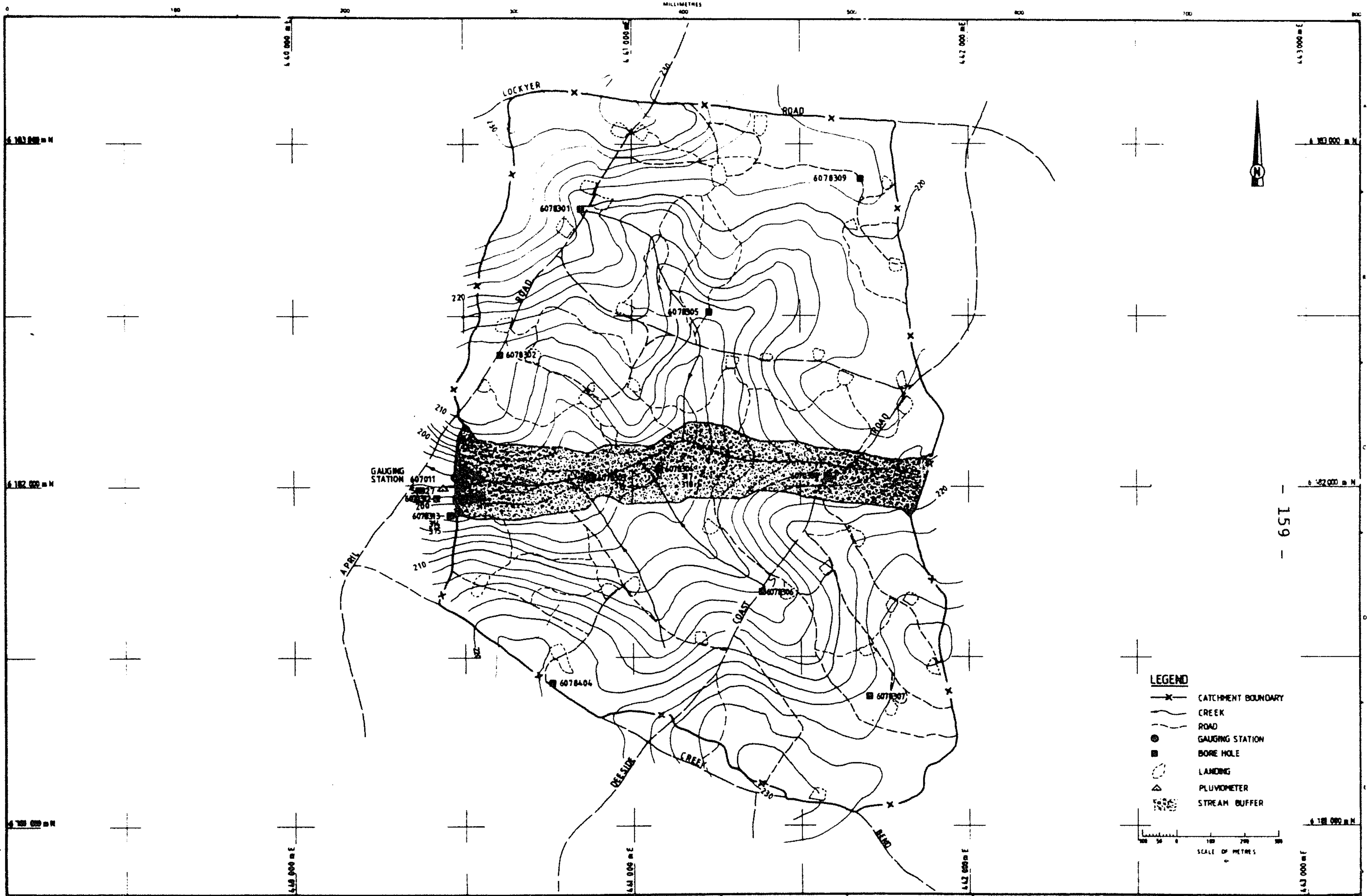
- 158 -

GENERAL NOTES
PHOTOGRAPHY WA 2471(C)
PHOTO No 5728

SCALES AS SHOWN
DATUM
A.H.D.

PUBLIC WORKS DEPARTMENT — WESTERN AUSTRALIA
MARCH ROAD CATCHMENT
GAUGING STATION Nº 607010 - 1983 (POST-TREATMENT)

P.W.D.,W.A.



APRIL ROAD NORTH CATCHMENT

- 159 -

GENERAL NOTES

UNLESS OTHERWISE SHOWN ALL DIMENSIONS ARE IN METRES

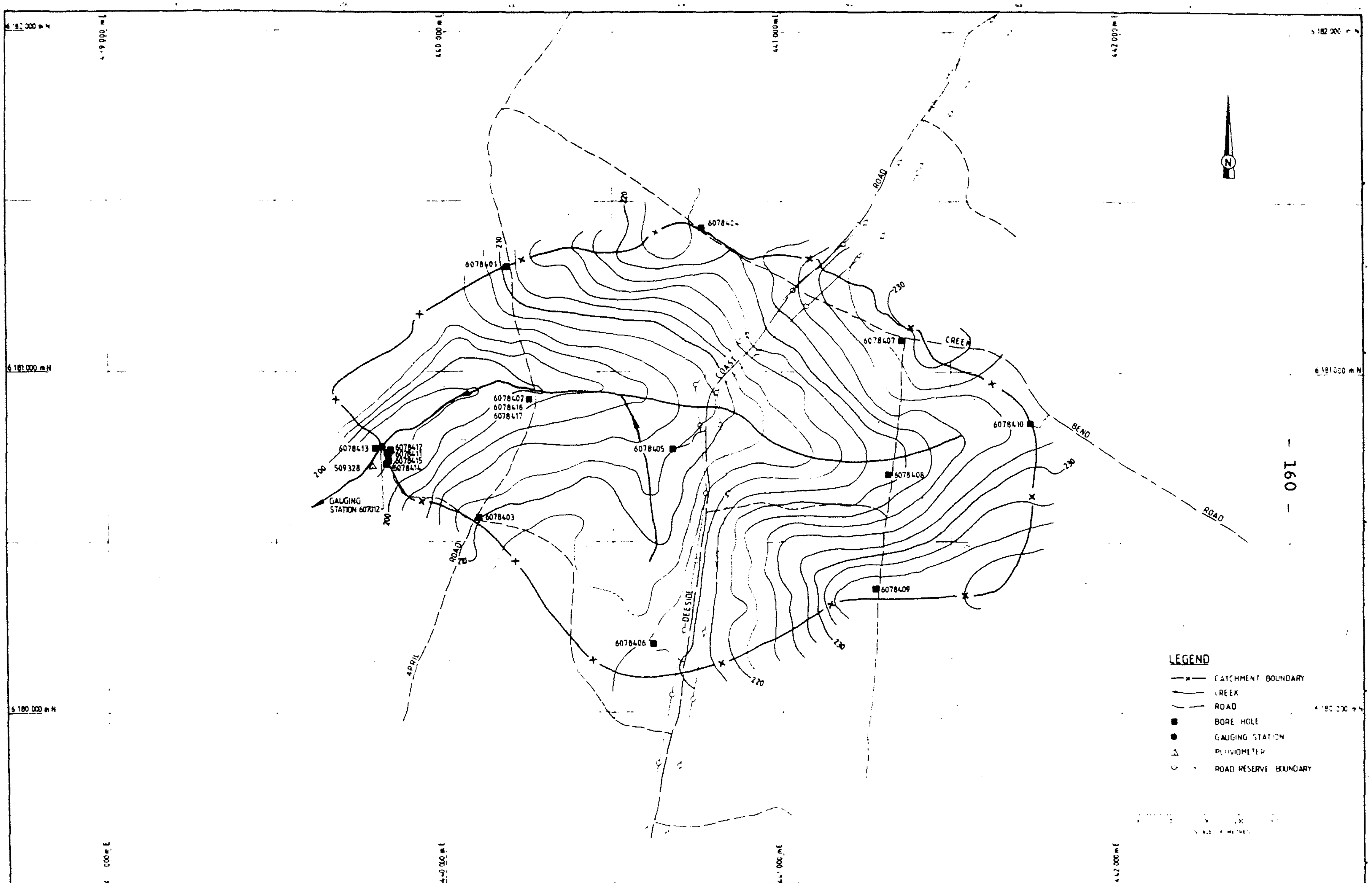
DATUM: A.H.D.

PUBLIC WORKS DEPARTMENT — WESTERN AUSTRALIA

APRIL ROAD NORTH CATCHMENT
GAUGING STATION No 607011 - 1983 (POST-TREATMENT)
CONTOURS VI 2m

P.W.D., W.A.

APRIL ROAD SOUTH CATCHMENT



GENERAL NOTES

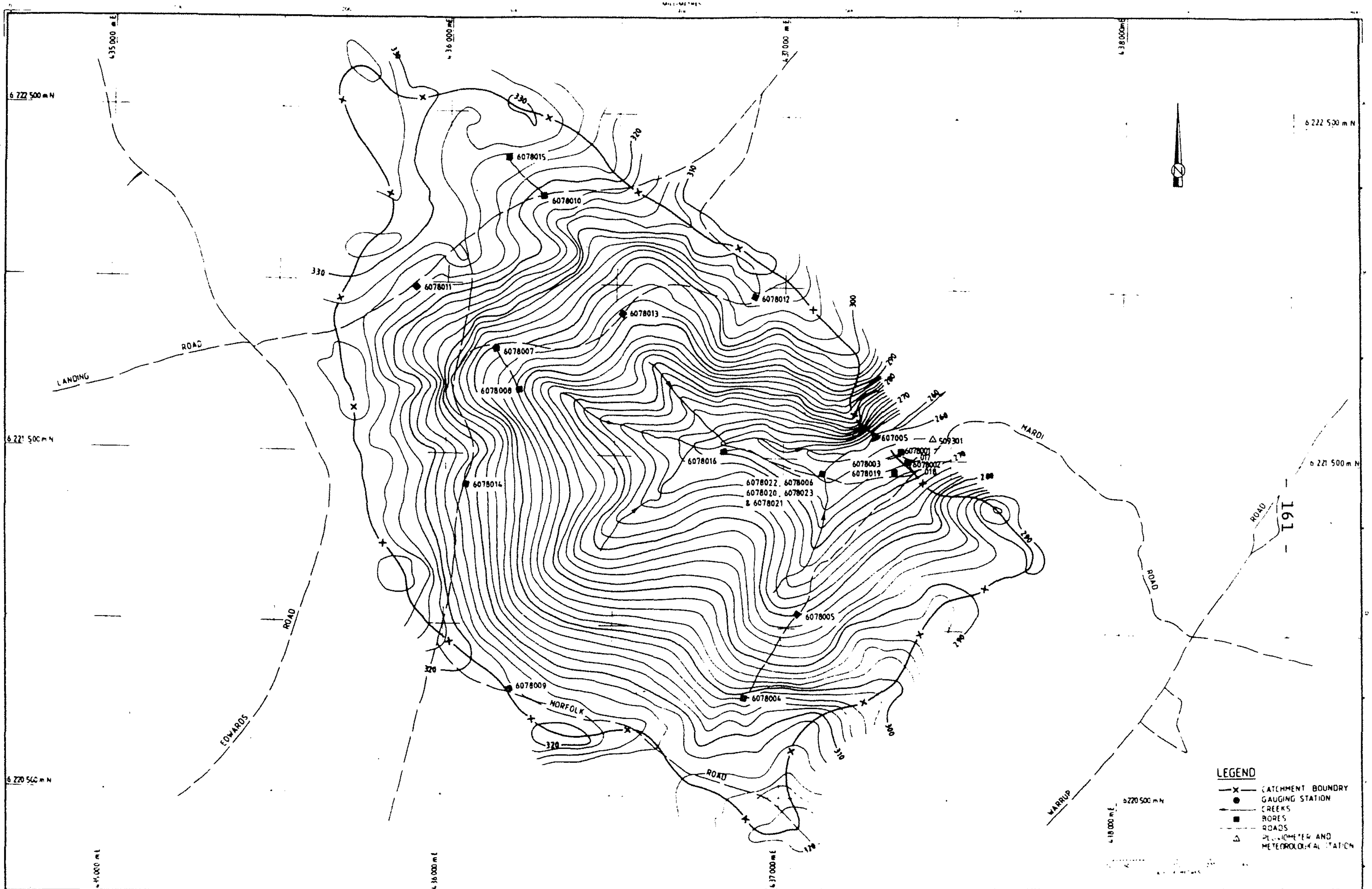
AHD

PUBLIC WORKS DEPARTMENT — WESTERN AUSTRALIA

APRIL ROAD SOUTH CATCHMENT
GAUGING STATION Nº 607012 - 1976
CONTOURS V.I. 2m

PWD.WA

YERRAMINNUP NORTH CATCHMENT



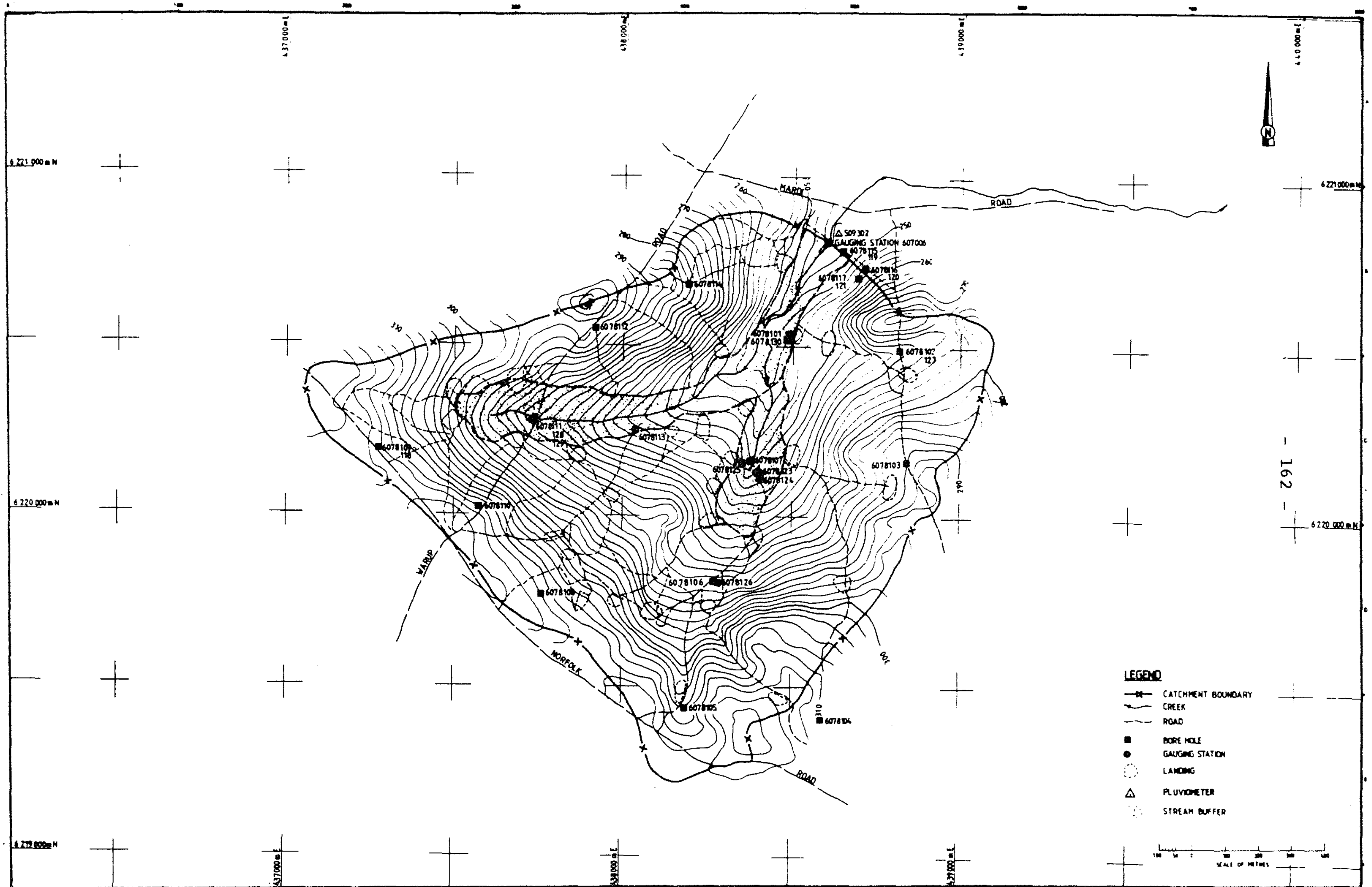
GENERAL NOTES

AHO

PUBLIC WORKS DEPARTMENT — WESTERN AUSTRALIA

YERRAMINNUP NORTH CATCHMENT
GAUGING STATION N° 607005 - 1976
CONTOURS V.I. 2m

PWD WA



GENERAL NOTES
PHOTOGRAPHY WA 2147(C) W
DATE 30-4-83
PHOTO No 5 1?2

DATUM
AHD

PUBLIC WORKS DEPARTMENT — WESTERN AUSTRALIA
YERRAMINUP SOUTH CATCHMENT
GAUGING STATION No 607006 - 1983 (POST-TREATMENT)
CONTOURS V I 2m

P.W.D.,W.A.

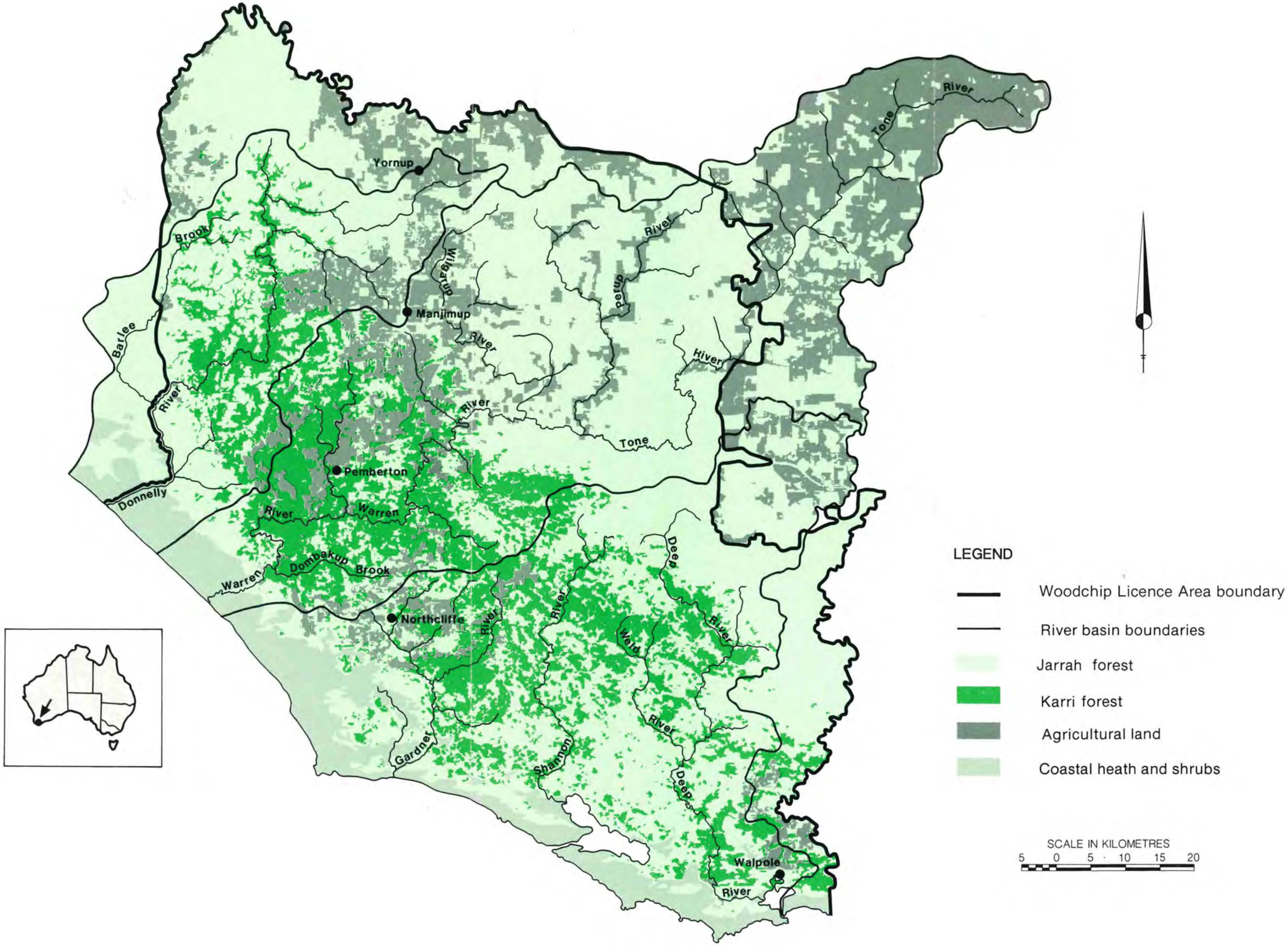


Figure 1

The Woodchip Licence Area in the southern forest of Western Australia. (Map based on data from the FMIS data base of the Department of Conservation and Land Management W.A., and Smith 1972.)