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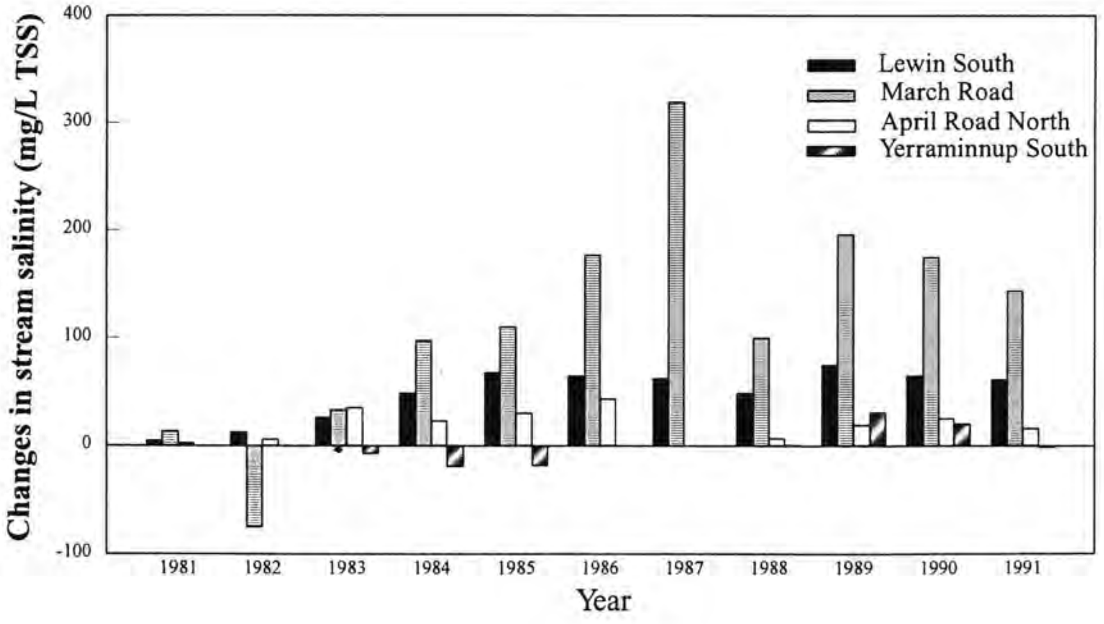

Report No. WS116
March 1993

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Water Resources Directorate
Surface Water Branch

STREAMFLOW AND SALINITY RESPONSE TO LOGGING AND REGENERATION IN THE SOUTHERN FOREST OF WESTERN AUSTRALIA

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SUMMARY

In the 1960s logging in the southern forest of Western Australia was changed from light selection cutting to heavy selection cutting and clear-felling. This raised the concern that changes in forest density could effect the hydrological balance and increase stream salinity.

In 1976, three sets of small experimental water resource catchments were established in the south-west of Western Australia. These catchments have been monitored to assess the effects of logging and subsequent regeneration on streamflow, stream salinity, groundwater levels and groundwater salinity. The set of Lewin North and South is located in the High Rainfall Zone (HRZ), the March Road, April Road North and South set is in the Intermediate Rainfall Zone (IRZ) and Yerraminnup North and South catchments in the Low Rainfall Zone (LRZ).

In 1982, four catchments were logged and three (one in each rainfall zone) were left untouched as control catchments. The forest management treatments applied were: heavy selection cutting at Lewin South, clear-felling at March Road, clear-felling with a 200 m stream buffer at April Road North, and heavy selection cutting with a 100 m stream buffer at Yerraminnup South. Vegetation regeneration began in 1983.

Vegetation cover of karri (*Eucalyptus diversicolor*) had regenerated to prelogging levels within 5 to 10 years after logging. Jarrah (*E. marginata*) and marri (*E. calophylla*) stands responded more slowly, reaching 90% of prelogging values in 10 years.

During the study period (1976-91), the average annual rainfall at the experimental catchments was 6% to 12% lower than the long term average. The lower rainfall may have influenced the magnitude and duration of hydrologic response to logging and regeneration, but not the general trend.

Relative to the control catchments, groundwater levels at the treated sites rose for the first

five years (1982-87) after logging and then began to decline as the forest regenerated. The largest rise of 4.5 m was at March Road (IRZ) and the lowest was 1 m was at Yerraminnup South (LRZ). By 1991, groundwater levels at the treated catchments exceeded relative control catchment levels by 0.5 to 3 m. Groundwater salinity at the treated catchments initially increased after logging and then fell as groundwater levels declined.

Annual streamflow at the treated catchments increased gradually for the first three years (1982-85) and began to decline systematically as the vegetation grew. Logging led to temporary increases in stream salinity. Flow-weighted average stream salinity increased for the first five (1982-87) years. The largest increase in stream salinity occurred at March Road (IRZ). Daily stream salinity, peaked in excess of 1000 mg L^{-1} TSS during low flows. However, annual stream salinity at March Road only exceeded 500 mg L^{-1} TSS in 1987. The annual stream salinity at Lewin South (HRZ) and April Road North (IRZ) peaked at less than 100 mg L^{-1} TSS above the prelogging levels. In most years the stream salinity was below 200 mg L^{-1} TSS. The increase in annual stream salinity at Yerraminnup South (LRZ) was not significant. Stream salinity did not exceed 200 mg L^{-1} TSS.

The trends in streamflow, stream salinity, groundwater level and groundwater salinity suggest, forest management methods, with the exception of clear-felling without a stream buffer, will not create salinity problems in the south-west of Western Australia. Regeneration is stabilising the initial disturbances to the hydrological regimes following logging operation. However, forest management needs to be refined to minimise the impact of temporary changes on the different hydrological settings within the southern forest.

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1 INTRODUCTION

The southern forest of Western Australia has been logged for about 100 years. Various methods of logging and subsequent regeneration have been practised (Borg, et. al, 1988). In the 1960s logging changed from light selection cutting to heavy selection cutting and clear-felling. This raised the concern that changes in forest management strategy may alter the hydrological balance and lead to substantial increase in stream salinity.

The increase in stream salinity following agricultural clearing in the south-west of Western Australia has long been recognised (Ruprecht and Schofield, 1991; Schofield and Ruprecht, 1989; Schofield, et al., 1988; Wood, 1924; Bleazby, 1917). Clearing leads to an increase in groundwater levels which results in salts previously "stored" in the unsaturated zone of the soil profile being mobilised and ultimately being discharged into streams (Williamson, 1986). Logging and subsequent regeneration of forest is a temporary and less severe hydrological disturbance than agricultural clearing. A review by Bosch and Hewlett (1982) shows the reduction in forest cover results in an increase in streamflow. Cheng (1989) found that clear felling 34% of a catchment area produced obvious and consistent streamflow increases. In the south-west of Western Australia, thinning of jarrah (*Eucalyptus marginata*) forest in the High Rainfall Zone (>1100 mm yr^{-1}) resulted in a considerable increase in streamflow (Ruprecht et al., 1991; Stoneman and Schofield, 1989). But in the Low Rainfall Zone (<900 mm yr^{-1}) of the jarrah forest, a selection cutting and regeneration treatment which reduced forest cover from 38% to 20% had negligible impact on streamflow yield (Stokes and Batini, 1985). In the southern forest region of Western Australia an increase in streamflow and stream salinity had been observed up to 8 years after logging and subsequent regeneration (Borg et al., 1988). However, very little is known about the long term (>20 years) effects of logging and subsequent regeneration on streamflow and salinity.

The southern forest region contains 39% of the State's surface water resources (Collins and Barrett, 1980). The effects of logging and regeneration on quality and quantity of these potential regional water supplies is very important. To understand the long term hydrological process related to logging and regeneration three sets of research catchments were established in the three rainfall zones of the southern forest. The main objectives of the research were to:

(i) determine the effects of logging and subsequent regeneration on streamflow;
(ii) quantify the magnitude and duration of stream salinity and stream salt load changes resulting from logging;
(iii) assess the spatial and temporal variations in groundwater levels and groundwater salinity.

Early hydrological data from these catchments were analysed and reported by Borg, et al., 1987). This report extends the analysis to present results for the first 10 years after logging and compares these results with the six year pretreatment calibration period.

2 SITE DESCRIPTION AND EXPERIMENTAL SET UP

2.1 Catchment Description

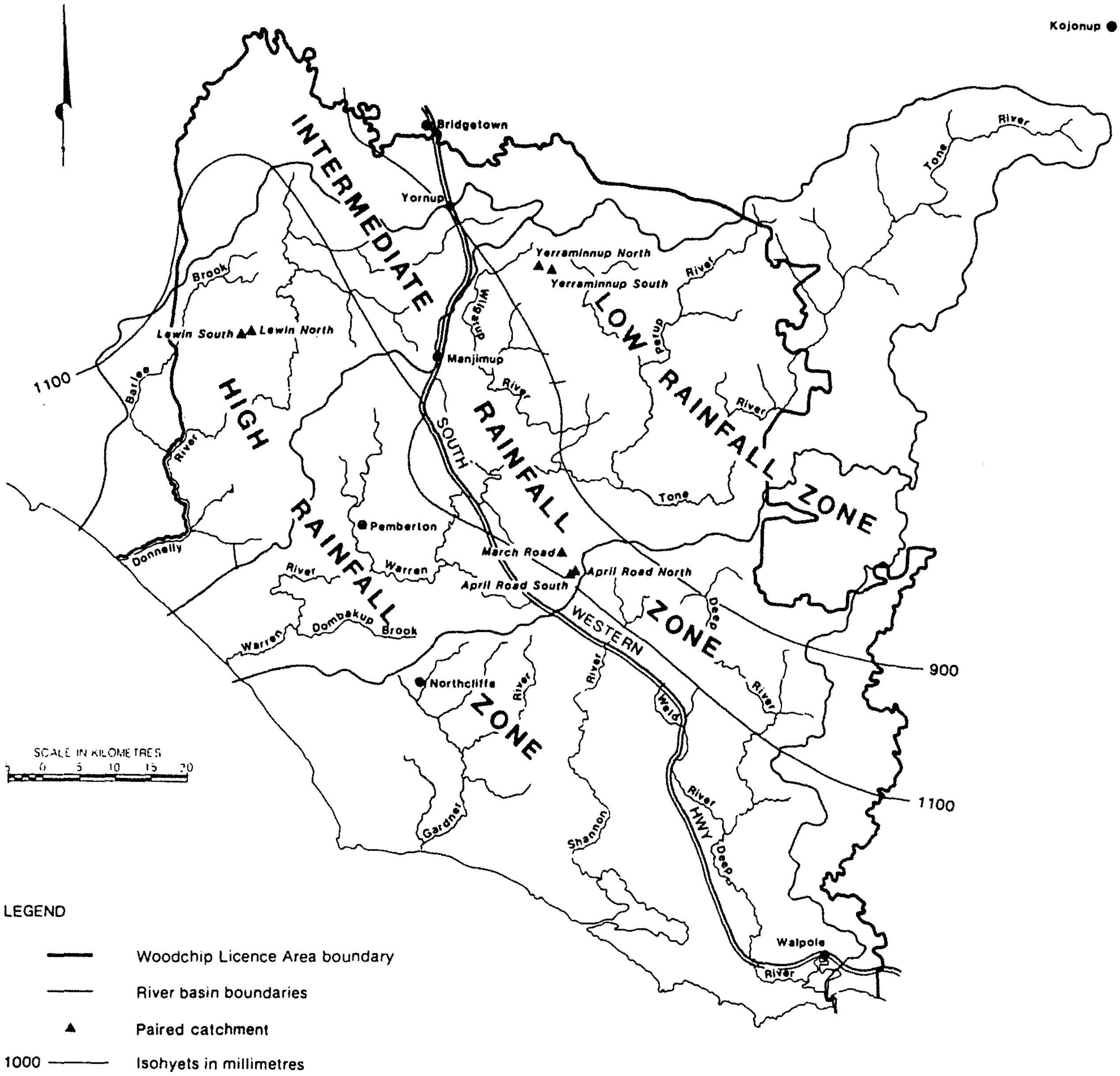
The experimental catchments are located in the south-west of Western Australia, about 320 km south of Perth (Fig. 1). The region has a Mediterranean climate, with cool, humid, wet winters and dry, hot summers. The long term average annual rainfall (1926-76) of the catchments ranges from 830 mm to 1240 mm (Loh and King, 1978) while the pan evaporation ranges from 1210 mm to 1370 mm (Table 1) (Luke et al., 1988). The soil types are typical of the south-west of Western Australia. The sites mainly consist of laterites, red and yellow duplex soils (Table 1). The native forest is dominated by jarrah (*Eucalyptus marginata*), marri (*E. calophylla*) and karri (*E. diversicolor*).

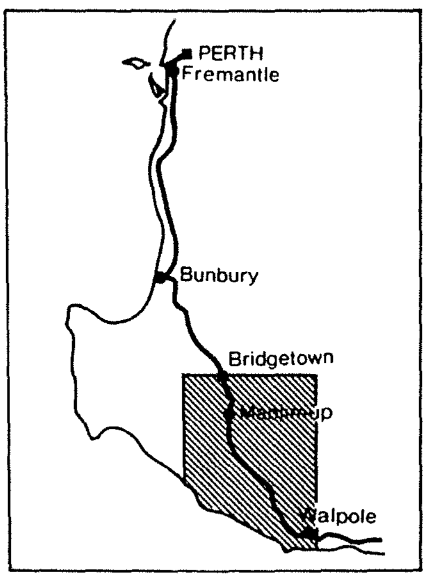
2.2 Instrumentation and Measurements

All catchments were instrumented in the same manner. Daily rainfalls were recorded with pluviometers installed at the catchment outlets. For the periods of missing record, rainfall data were interpolated from the nearest pluviometer using a correlation between the stations.

A network of bores were drilled to bedrock in each catchment to monitor groundwater level and salinity (Appendix A). Monitoring bores were installed in the valley and on the midslope and upslope areas. Groundwater level and salinity was measured once a month. Salinity samples were obtained from the screened area of the bores. The groundwater salinity (Total Soluble Salts, TSS) was determined using a derived relationship between TSS (mg L^{-1}) and electrical conductivity (mS m^{-1}).

A calibrated, sharp-crested V-notch weir and a stilling basin were constructed at the outlet of each catchment (Appendix A). A float well was connected to the stilling basin and attached to the chart recorder to supply a continuous record of stage (water level) in the





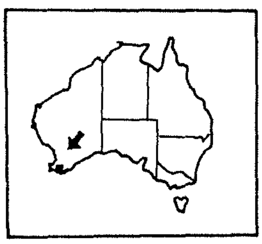


Figure 1 Location of the study area

Table 1 Characteristics of experimental catchments

Catchment name	Location	Area (ha)	Mean annual rainfall (mm)		Rainfall zone	Mean annual pan evaporation (mm)	Soil type	Forest type
			Long term	Study period				
Lewin South	115°51'30" E 34°13'6" S	90	1230	1092	High	1210	Laterites, red and yellow duplex soils	Jarrah
Lewin North (control)	115°51'54" E 34°12'48" S	113	1240	1094	High	1220	Laterites, red and yellow duplex soils	Jarrah, marri and karri
March Road	116°20'18" E 34°28'48" S	261	1040	975	Intermediate	1295	Laterites, red and yellow duplex soils	Jarrah, marri and karri
April Road North	116°21'36" E 34°20'12" S	248	1070	993	Intermediate	1295	Laterites and yellow duplex soils	Jarrah and marri, some karri on slopes
April Road South (control)	116°21'18" E 34°30'36" S	179	1080	1006	Intermediate	1290	Laterites and yellow duplex soils	Jarrah, marri and karri mixed
Yerraminnup South	116°19'42" E 34°9'24" S	183	830	758	Low	1370	Laterites and yellow duplex soils	Jarrah and marri
Yerraminnup North (control)	116°18'36" E 34°8'48" S	253	850	771	Low	1365	Laterites and yellow duplex soils	Jarrah and marri

stilling basin. The stage record was converted to discharge using a rating curve. Stream water quality samples were obtained using an automatic pumping sampler and were also manually collected during visits to the sites. Samples were routinely analysed for electrical conductivity and chloride ion concentration. Selected samples were analysed for major ions from which a relationship between stream salinity (Total Soluble Salts, TSS) and electrical conductivity (mS m^{-1}) was derived. The flow-weighted mean daily stream salinity (or simply stream salinity, S) was computed as:

$$S=(\Sigma S_i Q_i)/\Sigma Q_i$$

where Q_i is the streamflow volume measured every 15 minutes. The corresponding TSS concentration (S_i) of the flow volume was interpolated from the quality samples collected by automatic pumping sampler. From the daily stream salinity and flow, annual stream salinity was calculated in the same way.

2.3 Experimental Method

The paired catchment experimental method was used where treated sites were compared with untreated control sites. In 1976, two pairs (Lewin South, Lewin North; Yerraminnup South, Yerraminnup North) and a group of three (March Road, April Road North and April Road South) were selected to represent different combinations of annual rainfall, pan evaporation, forest type, geology and topography found in the southern forest of Western Australia (Fig. 1). Lewin South and North are located in the High Rainfall Zone (HRZ), March Road, April Road North and South catchments in the Intermediate Rainfall Zone (IRZ), and Yerraminnup South and North in the Low Rainfall Zone (LRZ). Lewin South, March Road, April Road North and Yerraminnup South catchments were logged under different forest management treatments. The other catchments were used as controls (Table 2). Lewin North was control for Lewin South. April Road South was control for March Road and April Road North. Yerraminnup North was control for Yerraminnup South. Logging commenced in January 1982 and was completed in April 1983. Streamflow, stream salinity, groundwater level and groundwater salinity were monitored before, during and after logging.

Table 2 Logging and regeneration details at the treated catchments

Catchment Name	Logging Method	Volumes of Wood Removed (m^3)	Stream Buffer Retained	Management method	
				Logging	Regeneration
Lewin South	Heavy selection cutting in jarrah/marri with 11% overstorey retention; clear-felling of karri stands	Karri sawlog :330 Jarrah sawlog :3610 Chipwood :6700	No	Jan. 1982 to Dec. 1982	Jarrah areas: waste disposal burn in Nov. 1983, left to regenerate naturally; Karri areas: waste disposal burn in Feb. 1984, then hand planted with karri seedlings
March Road	Clear-felling	Karri sawlog :18772 Jarrah sawlog :8448 Chipwood :47436	No	Jan. 1982 to March 1983	Waste disposal burn in March 1983, then hand planted with karri seedlings
April Road North	Clear-felling	Karri sawlog :9703 Jarrah sawlog :6776 Chipwood :29410	100 m along each side of the stream line	Jan. 1982 to March 1983	Waste disposal burn in March 1983, then hand planted with karri seedlings
Yerraminnup South	Heavy selection cutting in jarrah/marri with 10% overstorey retention	Jarrah sawlog :2740 Chipwood :4380	50 m along each side of the stream line	Jan. 1982 to April 1983	Waste disposal burn in Oct. 1983, then left to regenerate naturally

3 CATCHMENT TREATMENT AND REGENERATION

3.1 Logging Method

Since 1967 the forest management method for logging the southern forest of Western Australia has been to undertake clear-felling of the karri (*Eucalyptus diversicolor*) and heavy-selection cutting of the stands dominated by jarrah (*E. marginata*) and marri (*E. calophylla*).

In 1982, karri stands were clear-felled and replanted with karri at Lewin South catchment. The jarrah stands were subjected to heavy-selection cutting, but trees with potential to grow into good quality timber were retained. The remaining average tree basal area was 11 m^2 ha^{-1}. March Road and April Road North catchments were clear-felled. A 100 m wide strip of forest on each side of the stream was left uncut at April Road North to observe how this would influence the groundwater level, streamflow, and stream salinity. At Yerraminnup South catchment, heavy selection cutting was undertaken leaving an average tree basal area of 5 m^2 ha^{-1}. A 50 m wide strip of forest was retained as a stream buffer on each side of the stream. In 1983, waste at all treated catchments was burnt allowing regeneration to begin. A summary of logging and regeneration at the four treated catchments is given in Table 2.

3.2 Vegetation Regeneration

Before logging, the total vegetation cover at Lewin South, March Road and April Road North was 95% while at Yerraminnup North it was 75% (Table 3). Clear-felling and controlled burning after logging reduced vegetation cover to nil at March Road and April Road North catchments. At Lewin South and Yerraminnup South, heavy selection cutting reduced the vegetation cover to 11% and 10% respectively. In all rainfall zones, vegetation recovered quickly after logging. Considerable regeneration has occurred since 1983. By 1986, the recovery of total vegetation cover ranged from 85% to 100% of the prelogging values. The overstorey vegetation cover increased considerably during 1986-92. In 1992, the overstorey vegetation cover ranged from 77% to 122% of prelogging levels. The percentage of catchment covered during various phases of the logging and regeneration process is given in Table 3.

Table 3 Vegetation cover at the treated catchments

Year	Lewin South		March Road		April Road North		Yerraminnup South	
	Total vegetation cover (%)	Over storey vegetation cover (%)	Total vegetation cover (%)	Over storey vegetation cover (%)	Total vegetation cover (%)	Over storey vegetation cover (%)	Total vegetation cover (%)	Over storey vegetation cover (%)
1976	90	65	90	65	90	65	75	70
1983	11	11	0	0	0	0	10	10
1986	86	53	91	31	87	38	69	52
1992	★	★	91	79	93	58	69	54

★ Data not available

4 ANNUAL RAINFALL

The long term average annual rainfall (1926-76) in the southern forest region ranges from 830 to 1240 mm (Table 1). During the study period (1976-1991), the average annual rainfall at the study sites was 6% to 12% lower than the long term average. Similar trends were also observed at the other rainfall gauging stations in the region. Years with low rainfall are not unusual, but such a long period of below average rainfall has not been previously recorded in this region (Fig. 2). Annual rainfall at all treated catchments was considerably higher than long term average in only two years, 1981 and 1988. Annual rainfall was below the long term mean on an average of 7 years during the study period. However, rainfall records for the region are too short to determine whether the current sequence of low rainfall is abnormal or whether the average recorded so far is a true representation of the long term mean.

Annual rainfall during the pretreatment period (1976-81), at all treated catchments was slightly higher than for the post treatment period (Table 4). This was also the case at the control catchments.

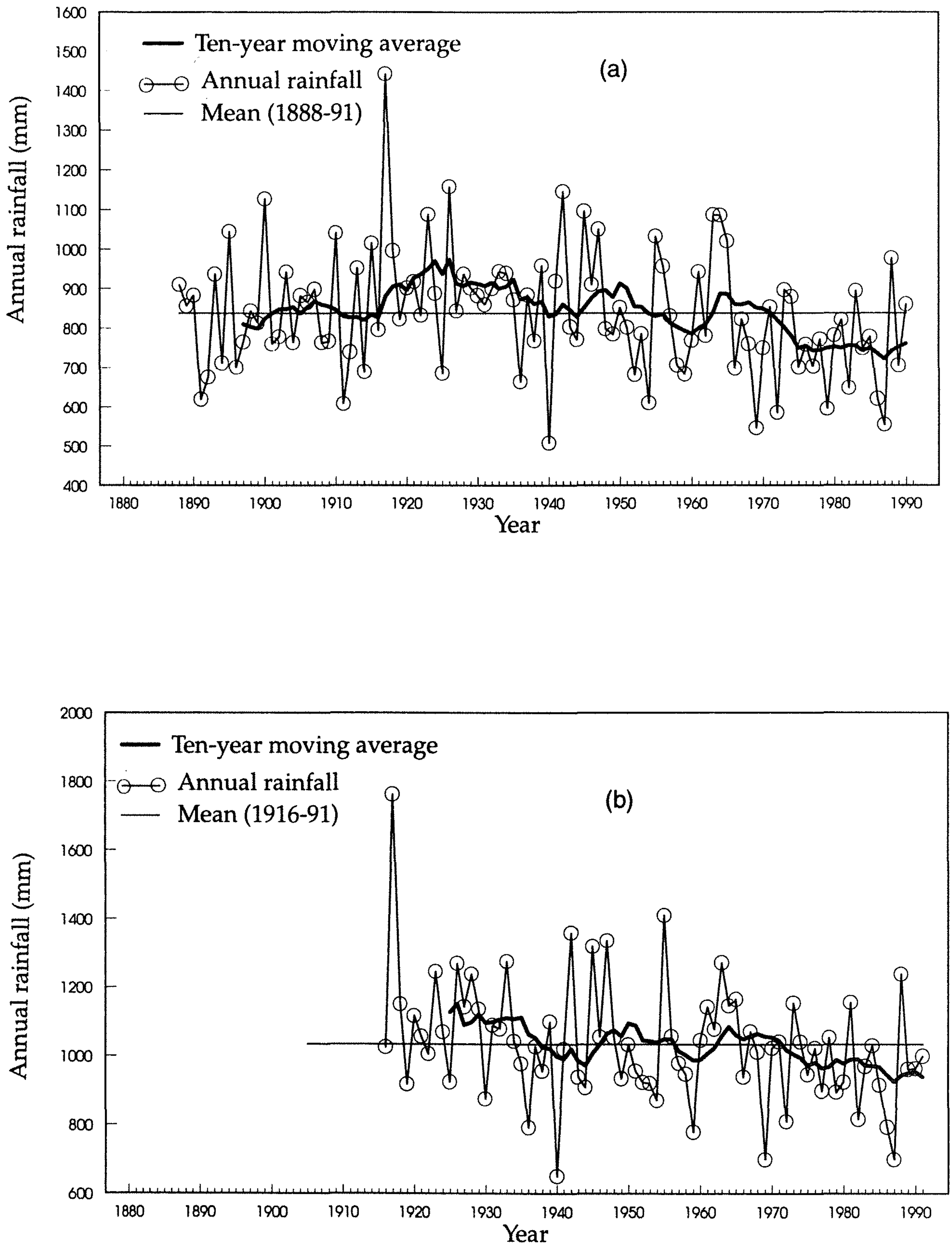


Figure 2 Annual rainfall at (a) Bridgetown and (b) Manjimup

5 RESPONSE OF GROUNDWATER LEVEL AND SALINITY

5.1 Groundwater Discharge Area

Prior to logging, the depth to groundwater at all treated catchments was about 10-15 m in the upslope areas. Groundwater discharge areas were evident in the valleys at both Lewin and March Road catchments (Table 4). The groundwater discharge area was defined as where the water table was at or above natural surface. There were no discharge areas at April Road or Yerraminnup catchments. Following logging, the groundwater discharge areas increased at Lewin South and March Road, and then decreased as vegetation grew.

5.2 Groundwater Level

Groundwater levels and salinity were monitored in a network of observation bores installed in each catchment (Appendix A). The bores were evaluated in two groups. The first group (valley bores) consisted of bores near the stream which were used to assess the value of retaining stream buffers. The second group (slope bores) consisted of remaining bores and were used to assess general response. At April Road North and Yerraminnup South catchments only bores in the uncut forest strips along the streamlines were classified as valley bores. For the other five catchments, bores located within 100 m of the stream channel were considered as valley bores.

The annual minimum groundwater levels (or simply groundwater levels) for each of the bore groups at the treated catchments were compared to levels in their respective control catchment bores (Fig. 3). After logging, the groundwater levels rose in all four treated catchments. But the magnitude of groundwater level rise varied from one catchment to another, depending upon the annual rainfall and vegetation cover.

5.2.1 High Rainfall Zone

Groundwater levels at Lewin South and North catchments have declined since the start of

Table 4 Summary of the effects of treatment on streamflow and salinity

Catchment	Average annual Rainfall (mm)		Average salt [a]		Average annual streamflow (mm)		Depth (m) to groundwater in valley			Groundwatrer discharge area present (?)
	1976-81	1982-91	storage (kg/ha)	concentration (mg/L TSS)	1976-81	1982-91	1981	1986	1991	
Lewin South	1097	1089	11.7	2090 [c]	144.1	209.1	+1.0 [b]	+3.5	+2.0	Yes, increased considerably following logging
March Road	991	965	12.8	2480	100.6	156.6	+0.5	+4.0	+3.0	Yes, maximum increase among all treated catchments
April Road North	1022	976	11.3	2560	81.0	134.6	6.0	3.0	2.5	No
Yerraminnup South	767	753	53.8	6960	17.8	31.1	5.0	5.0	5.0	No

[a] data from Johnston et al (1980).
[b] plus sign indicates water level above natural surface.
[c] average soil salt concentration in the unsaturated zone.

the study. But groundwater levels at Lewin South (treated catchment) increased relative to the control (Lewin North) after logging (Fig. 3a). The increase in groundwater level in the valley peaked in 1988 at 3.5 m above the control levels. The peak for slope bores was observed in 1985 at 3.0 m. In 1991, the increase had reduced to about 2.5 m above control in both valley and slope areas (Fig. 3a).

5.2.2 Intermediate Rainfall Zone

During the pretreatment period (1976-81), the relative groundwater level beneath March Road increased slightly while beneath April Road North it remained stable (Fig. 3). By 1988, the relative groundwater level in valley bores at March Road catchment had increased by about 4.5 m (Fig. 3b). The relative groundwater level in the valley at April Road North had increased about 3.5 m (Fig. 3c). In 1991, groundwater levels were still above pretreatment levels, about 3 m at both March Road and April Road North catchments.

5.2.3 Low Rainfall Zone

At Yerraminnup South, the groundwater level response was the least of all treated catchments. During the pretreatment period, groundwater levels in the valley and upslope areas declined by about 0.5 m (Fig. 3d). The relative groundwater level at Yerraminnup South increased by 0.5 m in 1983 and has remained practically stable since (Fig. 3d).

5.3 Groundwater Salinity

The soil salt storage at all treated catchments was measured before logging (Johnston, 1980). The average soil salt concentration in the unsaturated zone across the catchment at Lewin South (HRZ) was 2090 mg L^{-1} TSS (Table 4). At March Road and April Road North (IRZ), the average soil salt concentration was slightly higher, about 2500 mg L^{-1} TSS. The salt concentration was 6960 mg L^{-1} TSS at Yerraminnup South catchment (LRZ).

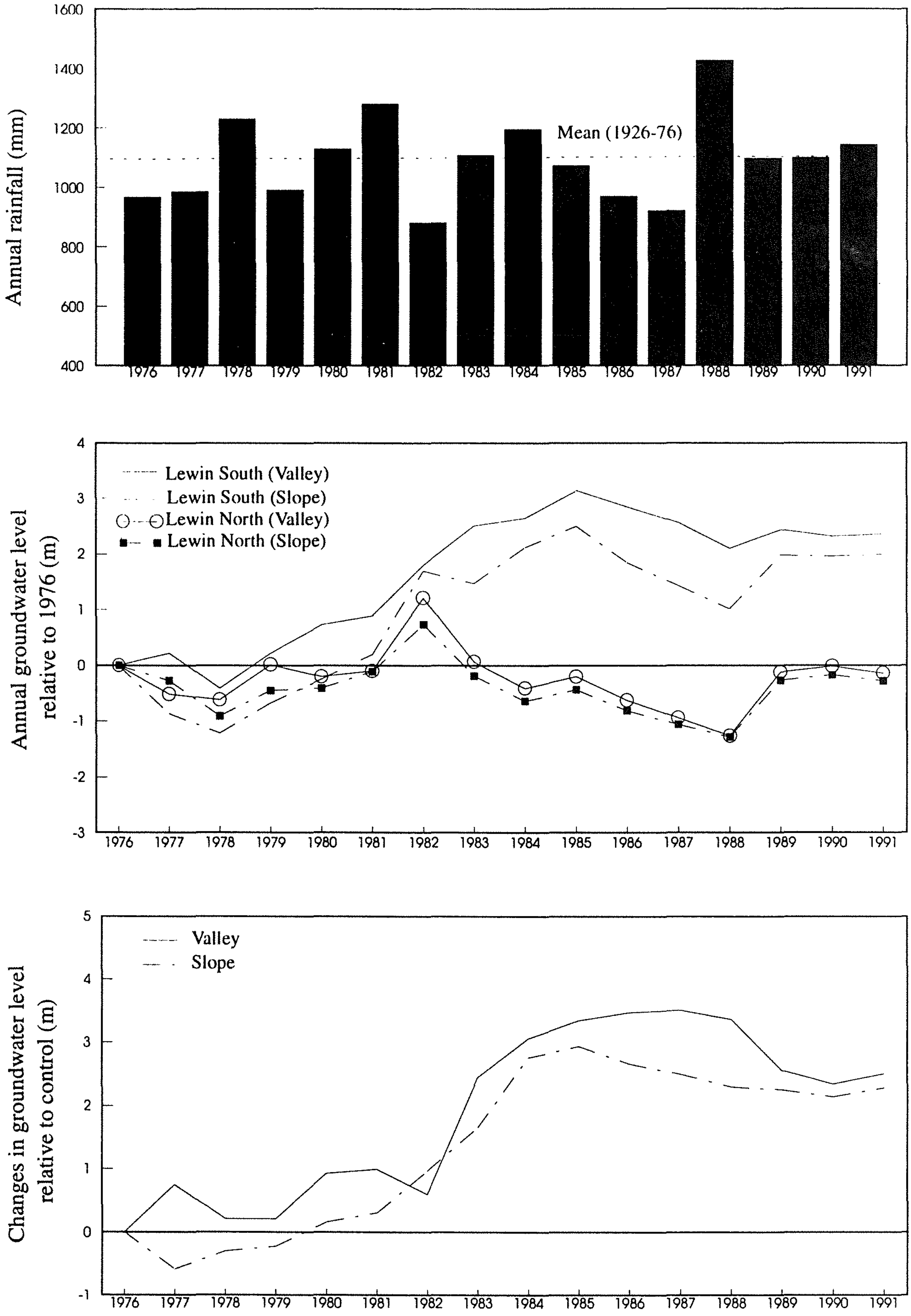
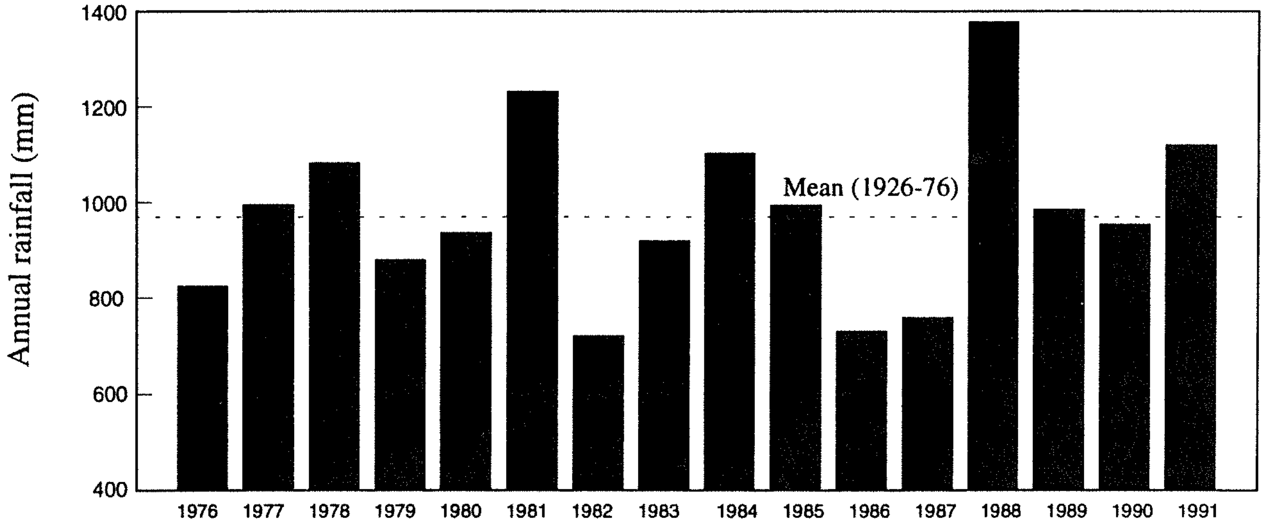
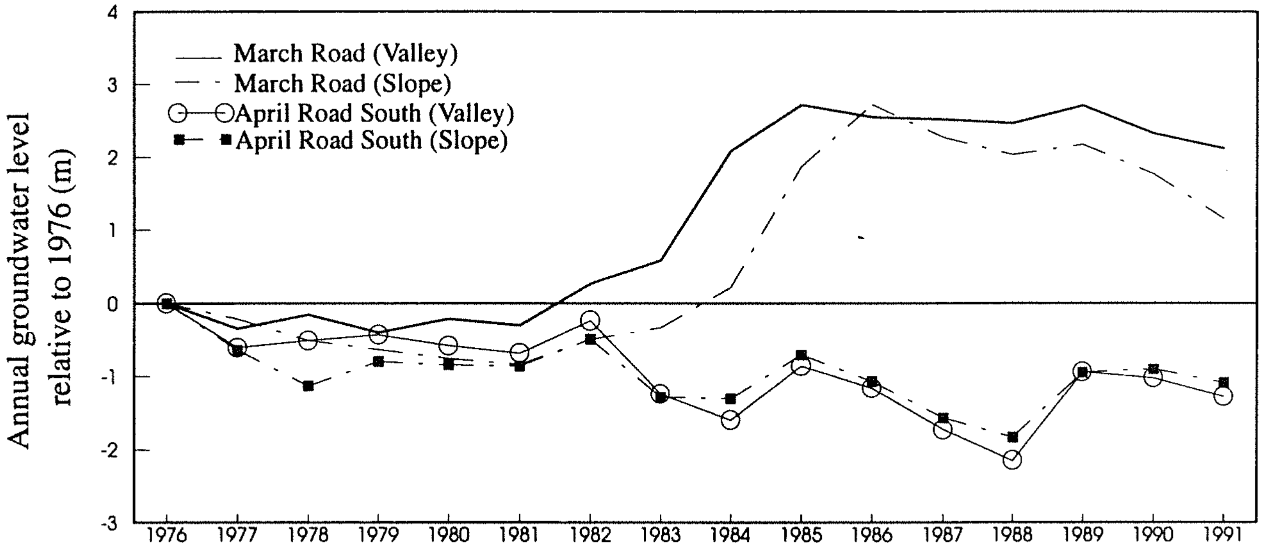


Figure 3(a) Response of groundwater levels at Lewin South





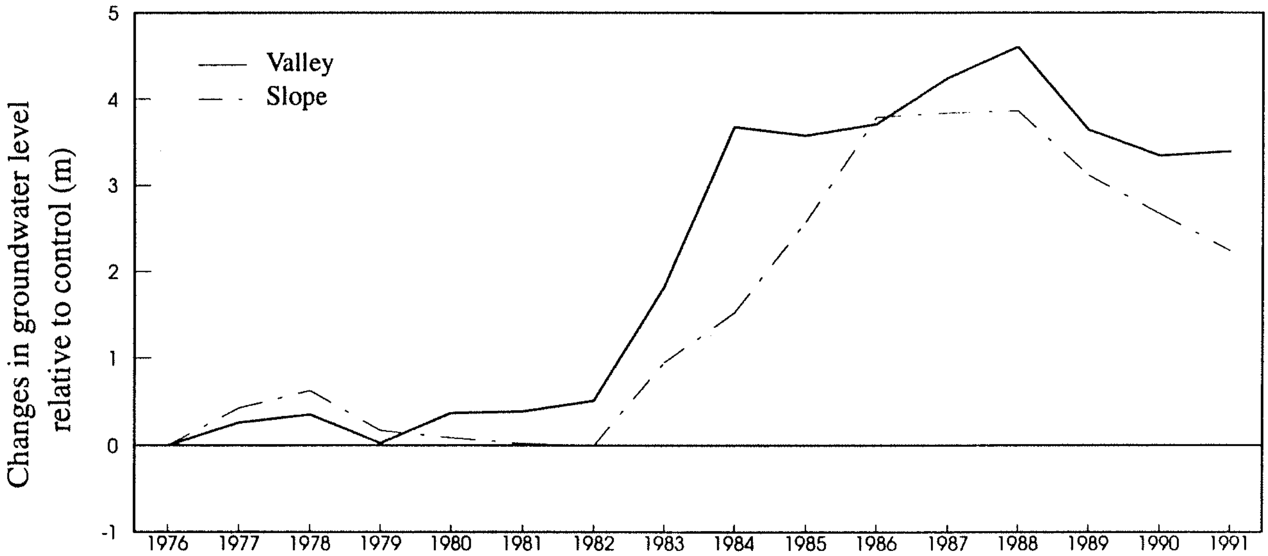


Figure 3(b) Respnse of groundwater levels at March Road

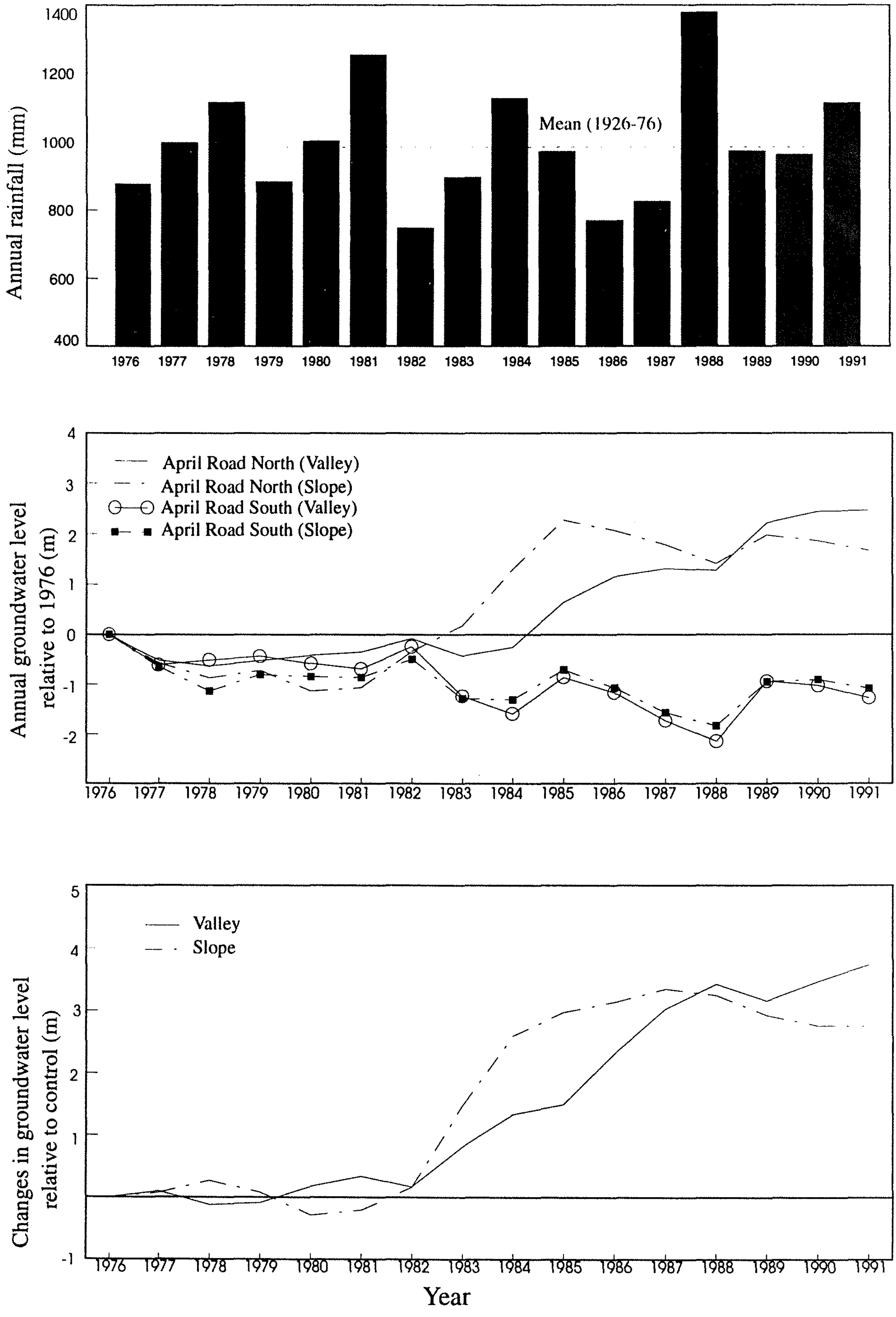


Figure 3(c) Response of groundwater levels at April Road North

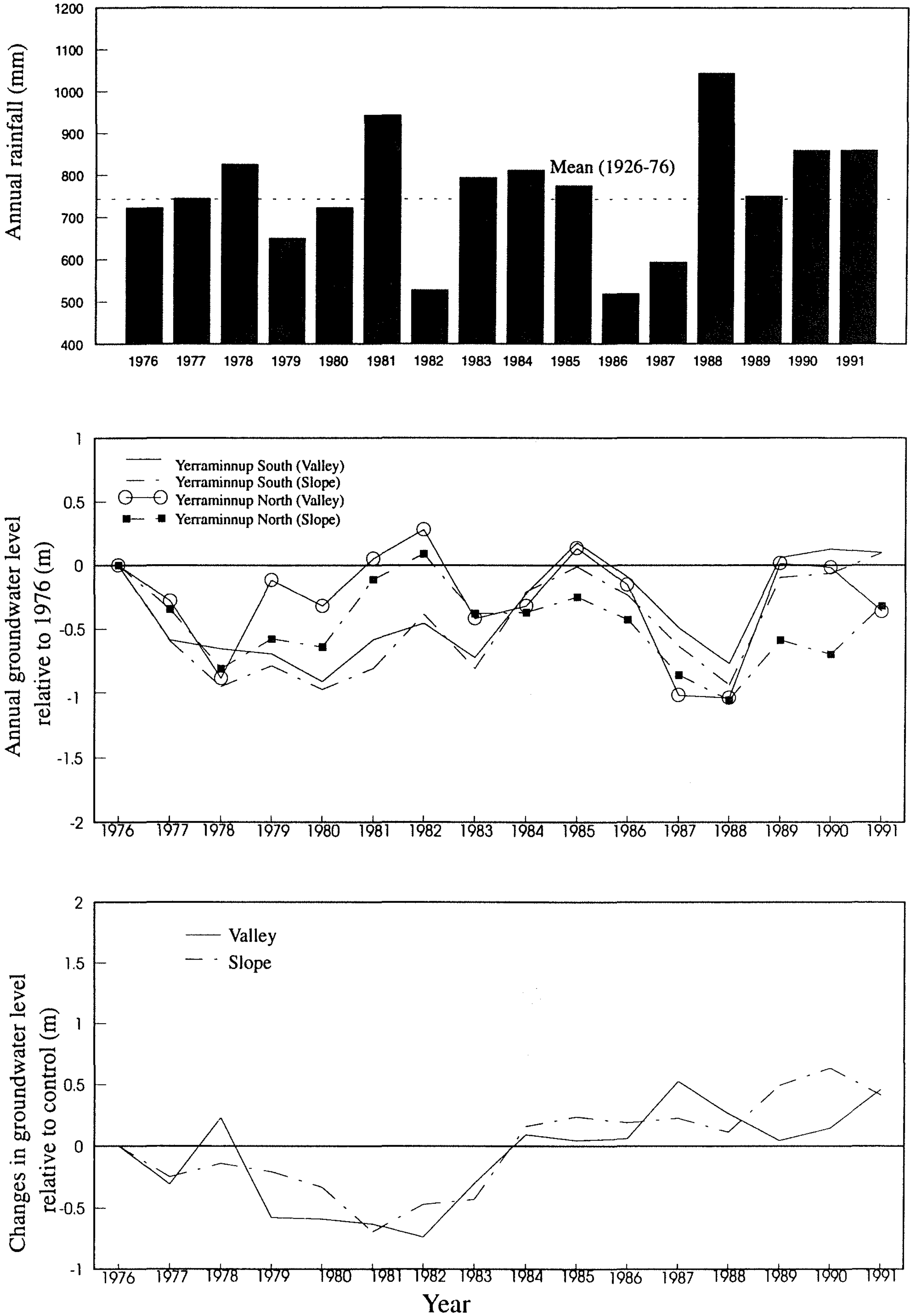


Figure 3(d) Response of groundwater levels at Yerraminnup south

During the pretreatment period, the groundwater salinity was about 500 mg L^{-1} TSS at catchments located in the High and Intermediate Rainfall Zones. On the other hand, groundwater salinity was significantly higher, approximately 5000 mg L^{-1} TSS, at Yerraminnup South catchment, in the Low Rainfall Zone. In all treated catchments, the spatial variation in groundwater salinity was considerable (Appendix B).

The average annual groundwater salinity for each catchment has increased following logging (Fig. 4). At Lewin South and March Road catchments, groundwater salinity increased until 1985 and then began to decrease. By 1991 groundwater salinity at both catchments had returned to prelogging levels. At April Road North, groundwater salinity increased after logging to about 700 mg L^{-1} TSS and has remained steady at this level since. At Yerraminnup South catchment, no significant changes in groundwater salinity were observed.

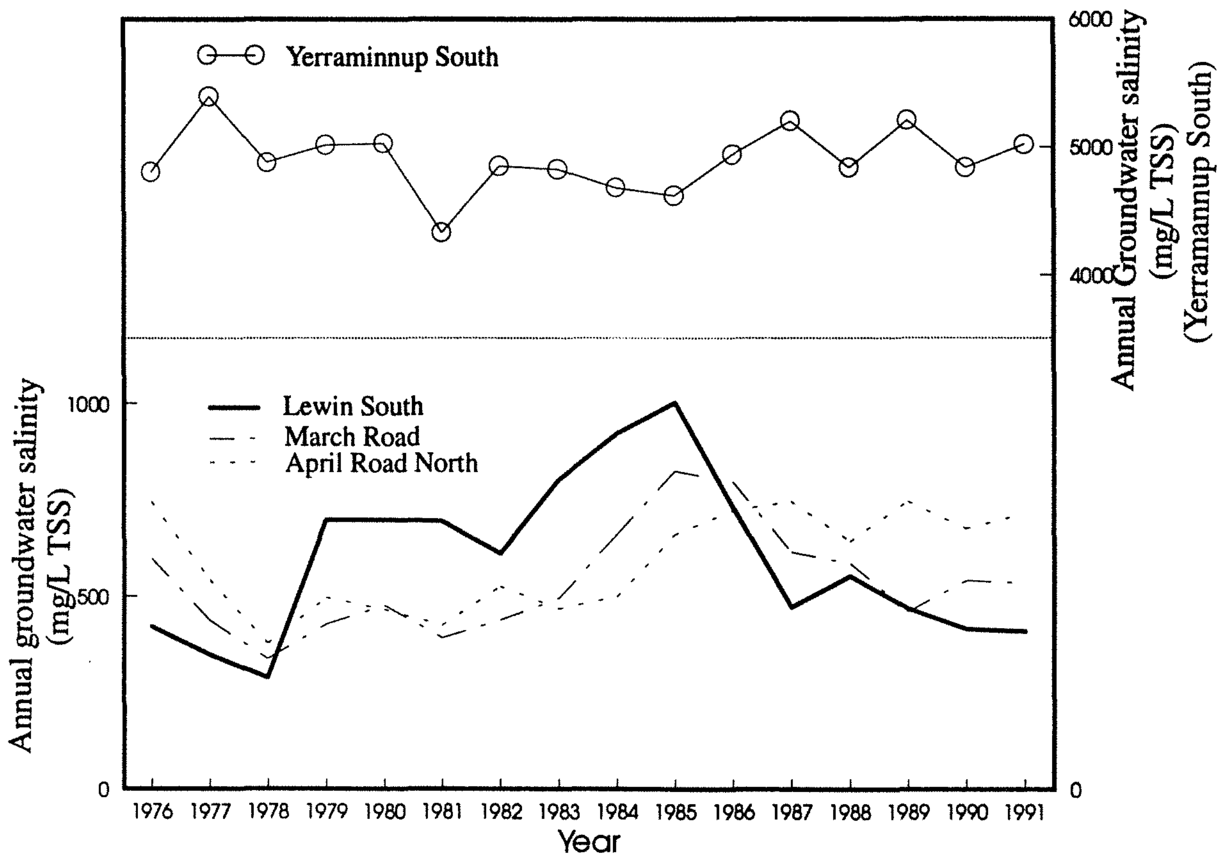


Figure 4 Annual groundwater salinity at the treated cacthments

6 STREAMFLOW AND STREAM SALINITY RESPONSE

6.1 Streamflow

6.1.1 Seasonal variations

Historically, catchments in the southern forest start to flow in April/May, following a significant rainfall event and cease in November or early December. A significant amount of the streamflow occurs in June/July, after considerable rainfall and catchment saturation (Fig. 5a). In response to logging, the treated catchments started flowing earlier than the control sites. Flows peaked earlier and higher than at the control catchments (Fig. 5b). Streamflow, with the exception of peak flow, returned to the historical pattern as the vegetation regenerated (Fig. 5c).

6.1.2 Streamflow yield

During the study period (1976-91), the annual streamflow was highest in High Rainfall Zone and lowest in Low Rainfall Zone. Fore example, streamflow at Lewin North catchment (control in HRZ) ranged from 56.3 mm to 337.2 mm (Table 5) and averaged 169.5 mm. The overall average streamflow at the other control catchments was 103.1 mm at April Road South (IRZ) and 22.2 mm at Yerraminnup North (LRZ).

Following logging, annual streamflow increased at all treated catchments and was considerably higher than their respective controls (Table 5). However, with regeneration of the vegetation, the variation was less significant.

6.1.3 Effects of treatment on streamflow

The relationships between streamflow and rainfall for all study catchments were developed from pretreatment data (1976-81) (Appendix C). The control catchments showed stable

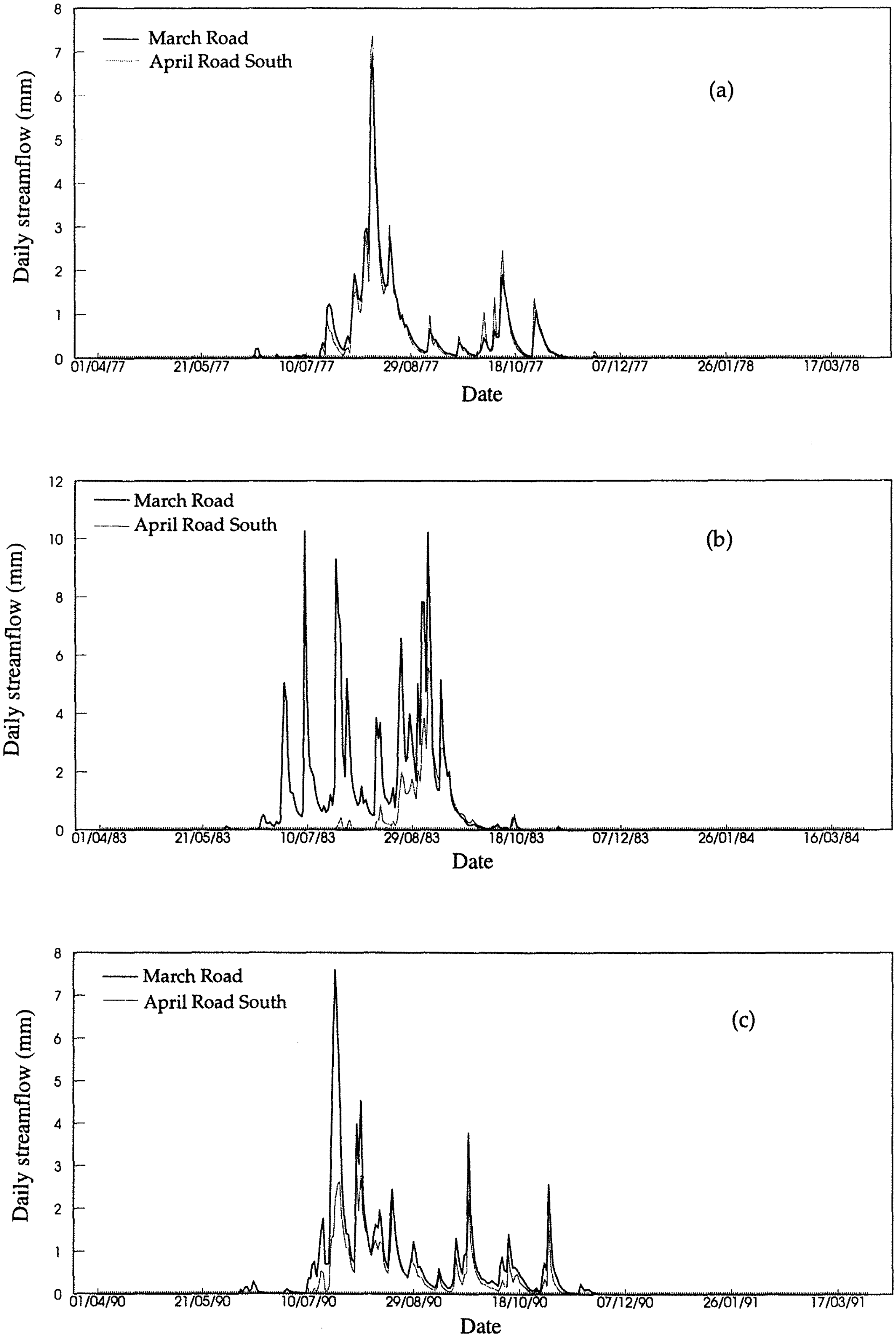


Figure 5 Typical daily streamflow hydrographs at treated and control catchments

Table 5 Annual streamflow (mm)

Year	High Rainfall Zone		Intermediate Rainfall Zone			Low Rainfall Zone	
	Lewin South	Lewin North (control)	March Road	April Road North	April Road South (control)	Yerraminnup South	Yerraminnup North (control)
1976	80.7	108.8	36.4	36.5	59.0	4.7	2.4
1977	108.1	144.2	97.7	66.2	92.4	1.8	2.5
1978	191.4	227.7	171.9	142.1	204.0	52.6	59.5
1979	105.7	136.2	63.9	40.4	67.5	0.7	1.6
1980	176.4	204.2	68.2	60.1	98.0	5.0	9.5
1981	202.3	240.9	165.7	140.8	218.1	41.8	45.2
1982	170.5	167.7	60.6	40.8	29.1	0.4	0.01
1983	270.0	202.8	230.1	165.0	73.2	89.0	69.1
1984	325.2	171.6	290.6	285.4	186.3	54.5	21.6
1985	172.0	95.9	149.1	113.8	51.2	15.8	7.7
1986	144.5	88.4	97.4	66.9	25.9	0.0	0.0
1987	78.1	56.3	34.8	23.7	4.0	0.0	0.0
1988	333.0	324.5	337.2	294.6	202.6	71.4	60.9
1989	175.7	145.6	131.5	97.1	93.9	13.0	9.1
1990	223.6	200.4	132.7	95.8	75.7	34.9	39.6
1991	198.6	196.7	102.4	163.4	168.1	32.4	26.5
Mean	184.7	169.5	135.6	114.5	103.1	26.1	22.2
Min.	78.1	56.3	34.8	23.7	4.0	0.0	0.0
Max.	333.0	324.5	337.2	294.6	218.1	89.0	69.1
CV	0.41	0.40	0.65	0.72	0.68	1.1	1.1

relationships over the entire study period, while the treated catchments had fundamental changes in the streamflow generation process following logging (Appendix C).

The regression equations between the treated and the control catchments were developed based on the pretreatment periods (Appendix D). The regression equations were used to derive annual streamflows for the treated catchments as if they had not been logged. The difference between the streamflows observed after logging and the derived untreated values were considered to be the changes in streamflow attributable to logging.

Annual streamflows at all treated catchments increased for two to three years after logging and then began to decline (Fig. 6). At Lewin South in HRZ, the maximum streamflow increase was about 15% of annual rainfall. In the IRZ, the maximum increases were 18% and 15% of annual rainfall for March Road and April Road North, respectively. Yerraminnup in the LRZ had the lowest increase, 5%. By 1991, streamflow exceeded pretreatment levels by 5% of annual rainfall at Lewin South. At April Road North streamflow excess was 5% while at March Road streamflow had reduced to below pretreatment levels (Fig. 6). The increase at Yerraminnup South was 2%.

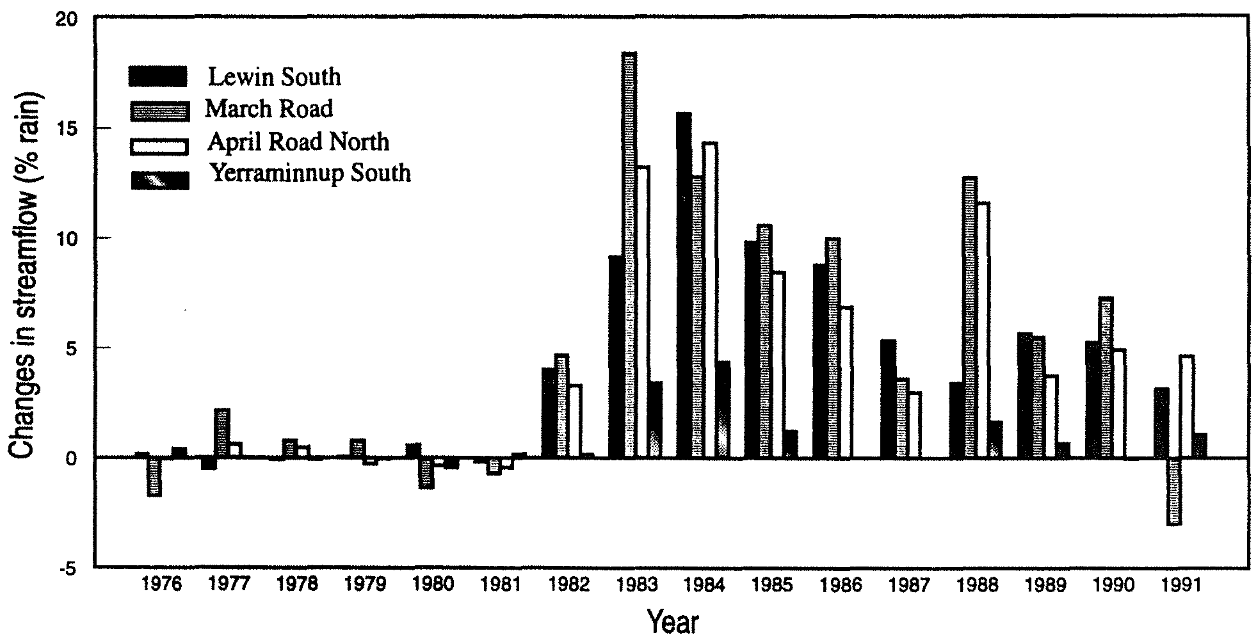


Figure 6 Changes in streamflow

The daily streamflow was separated into surface runoff and base flow using the numerical algorithm developed by Lynne and Hollick (1979). The relationships for surface runoff and base flow between the control and treated catchments were developed (Appendix E). The relationships were very strong for all treated catchments. Similar to streamflow, the effects of logging and subsequent regeneration on surface runoff and base flow were calculated. Both the surface runoff and base flow increased at treated sites after logging had occurred (Fig. 7). The increase in base flow was about twice the increase in surface runoff. After logging, the trends in changes in surface runoff and base flow components were similar to the changes in streamflow yield (Fig. 7).

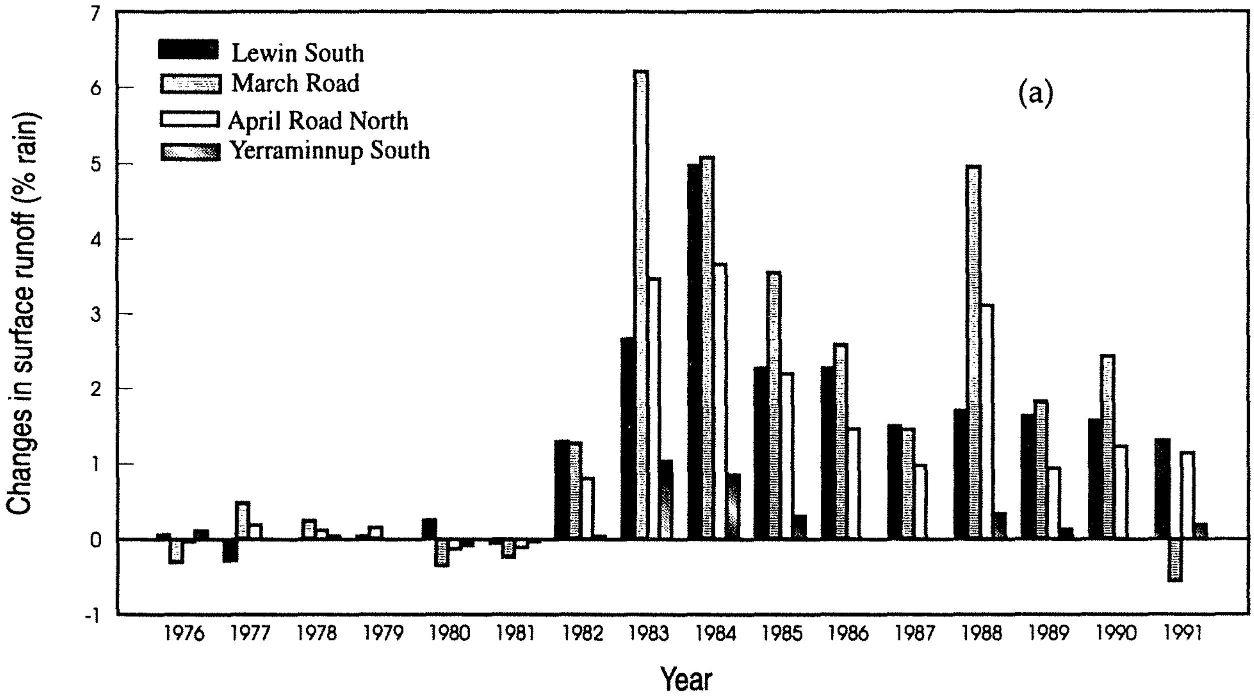
Logging also led to an increase in maximum daily flow. The greatest increase was for March Road, about 15 mm in 1985. The highest increase in maximum daily flow at Lewin South, April Road North and Yerraminnup South catchments was 11, 10 and 3 mm, respectively. There has been a declining trend in maximum daily flows since 1985 (Fig. 8). In 1991, the difference between treated and control sites was about 1 mm.

6.2 Stream Salinity and Salt Load

The relationships between streamflow, stream salinity and salt load were stable for all catchments during the pretreatment (1976-81) period. Logging resulted in an increase in stream salinity and salt load at all treated catchments (Appendix C).

6.2.1 Stream salinity

The changes in stream salinity and salt load were evaluated from the relationships between the streamflow, salinity and salt load at the treated catchments before and after logging. The procedure for calculating stream salinity changes is illustrated in Fig. 9. For example, the observed streamflow and stream salinity at March Road in 1984 was 291 mm (Table 5) and 218 mg L^{-1} TSS (Table 6), respectively. If there had been no logging, the streamflow and stream salinity in 1984 would have been 150 mm (from the regression equation between March Road and April Road South, given in Appendix D) and 121 mg L^{-1} TSS (from the pretreatment relationship between streamflow and salinity, given in



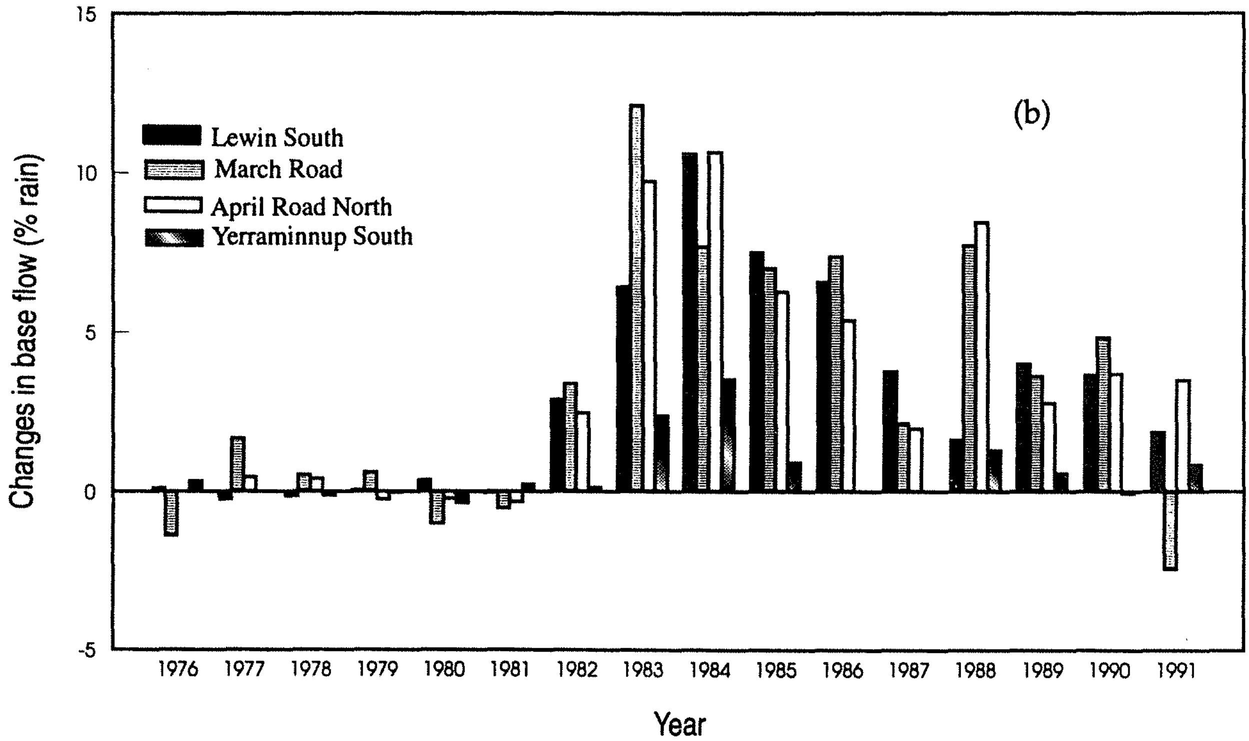


Figure 7 Changes in (a) surface runoff and (b) base flow

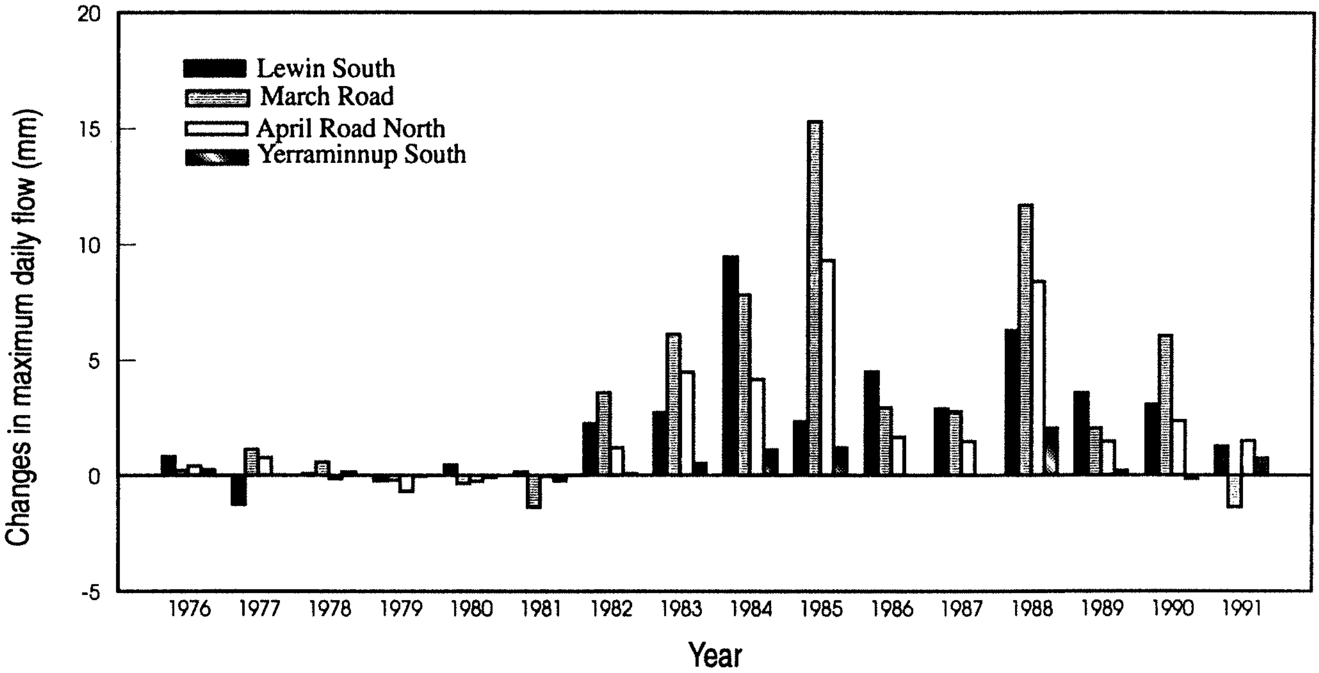


Figure 8 Changes in daily maximum flow

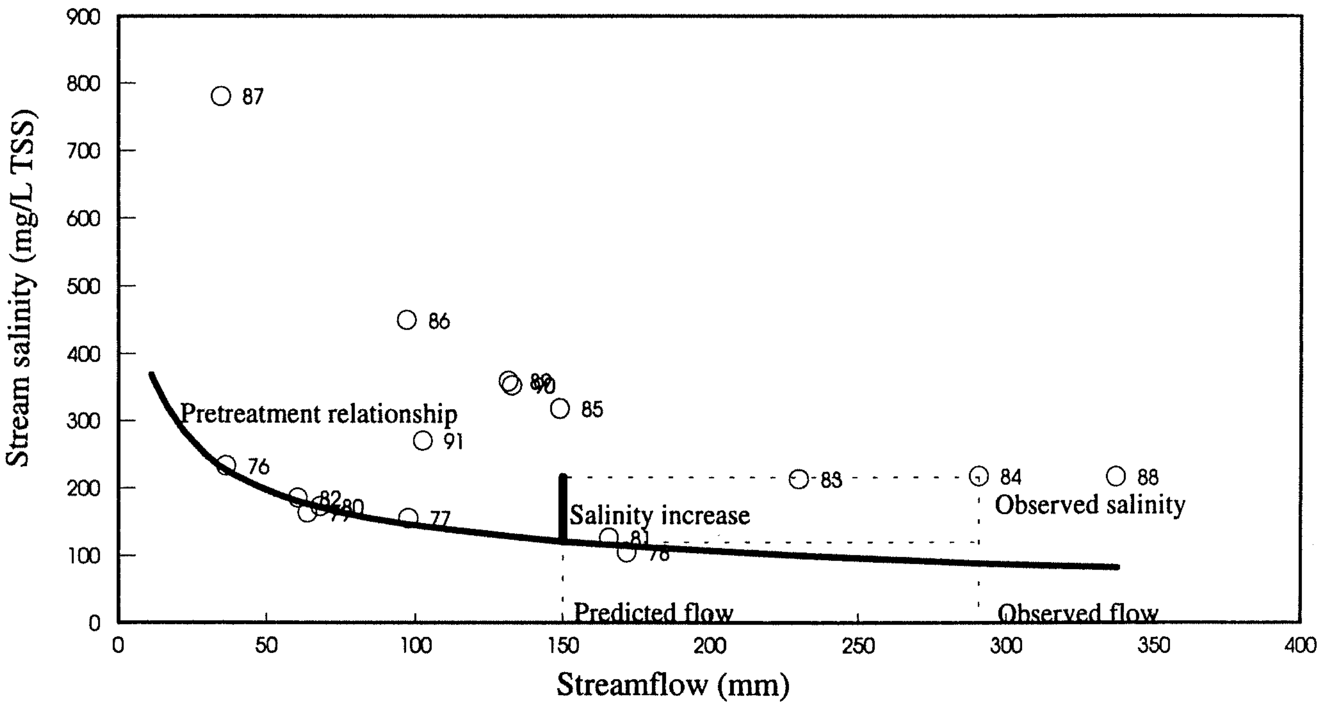


Figure 9 Calculation of stream salinity changes due to logging

Table 6 Annual stream salinity (mg L^{-1}, TSS)

Year	High Rainfall Zone		Intermediate Rainfall Zone			Low Rainfall Zone	
	Lewin South	Lewin North (control)	March Road	April Road North	April Road South (control)	Yerraminnup South	Yerraminnup North (control)
1976	107.8	116.9	233.3	100.3	150.9	150.7	335.4
1977	112.2	120.9	155.3	123.0	135.4	211.1	245.8
1978	81.1	87.6	105.1	89.6	98.2	76.7	92.0
1979	97.1	110.8	163.5	105.1	128.9	165.7	212.5
1980	87.9	100.7	172.2	109.1	123.9	129.1	162.0
1981	90.1	102.1	126.2	102.6	111.5	96.9	108.3
1982	108.4	129.4	185.1	120.1	143.5	180.3	980.8
1983	116.4	111.7	213.1	142.4	124.7	83.3	94.6
1984	143.6	105.2	218.4	124.2	108.8	91.6	112.4
1985	183.6	106.4	318.3	140.0	103.7	114.8	142.3
1986	184.6	115.9	448.4	158.6	128.1	--	--
1987	208.2	127.1	778.0	176.9	129.3	--	--
1988	126.3	84.0	216.8	107.7	103.5	93.1	100.2
1989	174.7	105.1	358.4	124.4	113.3	159.5	165.4
1990	155.1	101.3	352.0	132.3	130.4	119.8	112.4
1991	151.9	104.1	270.4	118.0	111.2	105.6	106.8
Min.	81.1	84.0	105.1	89.6	98.2	76.7	92.0
Max.	208.2	129.4	778.0	176.9	150.9	180.3	980.8
CV	0.29	0.11	0.59	0.18	0.12	0.31	0.98

Appendix C), respectively. Therefore, the estimated increase in stream salinity due to logging and subsequent regeneration was 97 mg L^{-1} TSS. The computer programme for calculating changes in streamflow and salinity is given in Appendix F.

After logging, annual stream salinity increased at all treated catchments, but in most of the years, with the exception of March Road, it remained below 200 mg L^{-1} TSS. March Road salinity peaked at 718 mg L^{-1} TSS in 1987. In all other years it was below 500 mg L^{-1} TSS (Table 6).

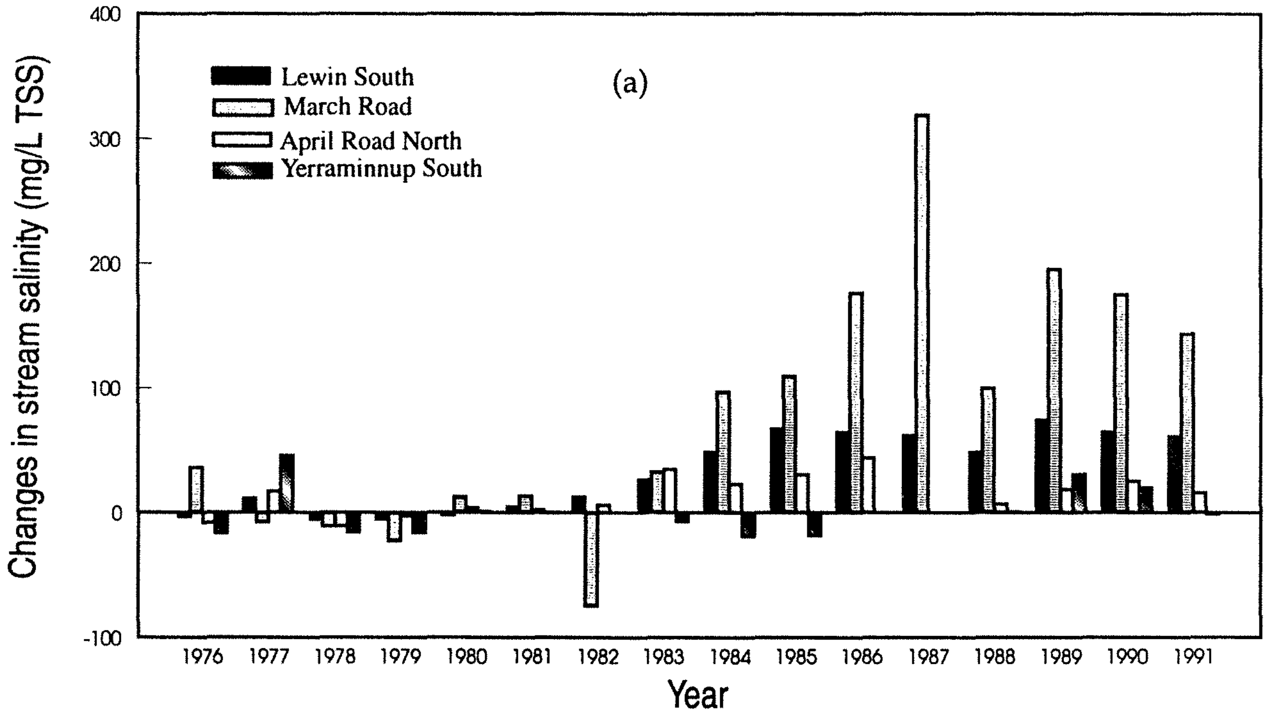
The annual stream salinity at Lewin South (HRZ) increased until 1985 and then levelled off. Except for 1987, total stream salinity remained below 200 mg L^{-1} TSS (Table 6). The daily stream salinity did not exceed 1000 mg L^{-1} TSS during low flows which occurred at the beginning and end of the wet season.

At March Road, stream salinity increased after 1982. The maximum increase due to logging (320 mg L^{-1} TSS) occurred in 1987. The annual stream salinity exceeded 500 mg L^{-1} TSS (Table 6) for the first and only time. Since then there has been a decreasing trend (Fig. 10a). During 1987, daily stream salinity at March Road exceeded 1000 mg L^{-1} TSS for 63% of the streamflow durations. Between 1982 and 1991, daily streamflow was above 1000 mg L^{-1} TSS on an average of 20% of the streamflow durations. Generally, higher stream salinity occurred during the low flows at the beginning and end of the rainy season. At April Road North, stream salinity increased until 1987 and then began to decrease. The maximum increase due to logging was 115 mg L^{-1} TSS. Annual stream salinity remained below 200 mg L^{-1} TSS. On a few occasions, daily stream salinity exceeded 1000 mg L^{-1} TSS. In 1991, the stream salinity was slightly higher than would have been expected if logging had not occurred.

There were no significant changes in stream salinity at Yerraminnup South (Fig. 10a). In fact, stream salinity declined slightly after logging, between 1983 and 1985.

6.2.2 Stream salt load

The changes in stream salt load due to logging and regeneration were calculated in a



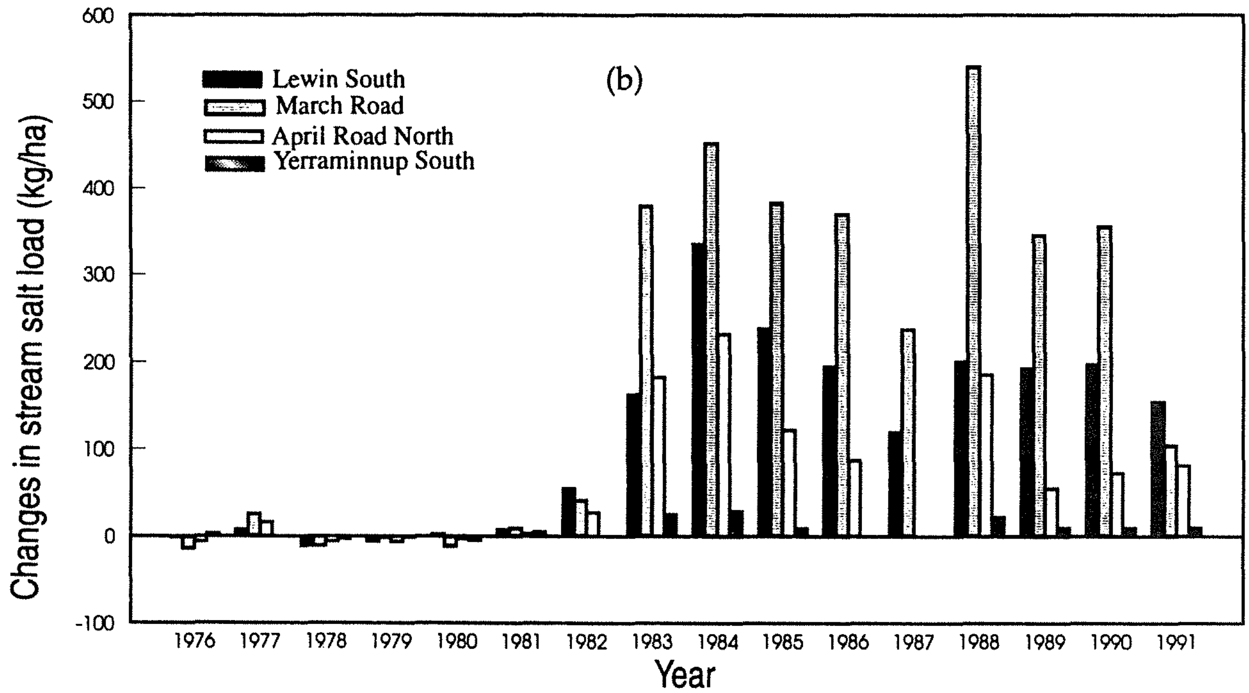


Figure 10 Changes in annual (a) stream salinity and (b) salt load

similar way to stream salinity changes. At all treated catchments, stream salt load increased following logging. The annual salt load increased at Lewin South until 1984 and then began to decline (Fig. 10b). The maximum increase was 335 kg ha^{-1} TSS in 1984. The increase in salt load at March Road was highest of four treated catchments. In 1987, March Road experienced a 540 kg ha^{-1} TSS increase in salt discharge (Fig. 10b). The increase in salt discharge from April Road North catchment was systematic until 1984 when it declined until 1988. There was an increase in salt discharge in 1988 but since then there has been a decline. In 1984, April Road North experienced the highest salt load increase of 231 kg ha^{-1} TSS. At Yerraminnup South, the increase in stream salt load was, 29 kg ha^{-1} TSS, the lowest of all treated catchments (Fig. 10b).

7 DISCUSSION

7.1 Annual Rainfall

The average annual rainfall during the study period was 6% to 12% lower than long term average (1926-76). If the long term average rainfall conditions had prevailed, it is likely the increase in streamflows, salt loads and groundwater levels which occurred after logging would have been more. But stream salinity may not have been much different because the increase in salt discharge would have been diluted by the increased streamflows. On the other hand, if the prediction of drier climate conditions for south-west of Western Australia eventuates (Pittock, 1988), then the lower rainfall would assist in lowering streamflow and groundwater levels. The lower than long term average rainfall conditions should be taken into account when interpreting results and reviewing forest management methods.

7.2 *Vegetation Regeneration*

Vegetation cover of regenerating karri stands, like those at March Road and April Road North, reaches prelogging values within five years after logging, continues to rise for another five years and remains above prelogging values (Stoneman et al., 1988). Jarrah-marri stands, like those at Lewin South and Yerraminnup South catchments, respond relatively slowly. Vegetation cover for jarrah-marri stands exceeds 70% of prelogging values within 5 years after logging, 90% within 10 years and 100% within 20-30 years (Stoneman et al., 1988). Results from all treated catchments show that vegetation cover has grown back at least at these rates or even faster (Table 3).

7.3 Groundwater Level

After logging, groundwater level rose in all four treated catchments due to the increase in groundwater recharge. But the increase in groundwater level varied from one catchment to another. The increase was dependant upon the amount of annual rainfall and of remaining vegetation cover. With less vegetation the reduction in transpiration and interception resalted in significant increases in groundwater recharge. Groundwater discharge areas increased and the depth to groundwater in the valleys decreased (Table 4). Groundwater recharge in the valleys along the stream lines, was further enhanced by increased lateral flow from upslopes. Therefore, the rise in groundwater levels in the valleys was quicker than under the upper slope areas. This was best seen at the March Road and Lewin South catchments (Fig. 3). At April Road North, groundwater level rise in the valley was slower than under the upper slope area. This response appears to be influenced by the retention of a 200 m wide stream buffer at the site. At Yerraminnup,which has a 100 m stream buffer, the response was similar in the valley and under the upper slopes (Fig. 3d). As stream buffers were retained at April Road North and Yerraminnup South, the increase that occurred in groundwater levels in the valleys can be attributed to the increase in recharge to upslope areas. If there had been no stream buffer, the increase in groundwater level in the valley areas would have been greater.

The relative increase in groundwater levels at Lewin South and April Road North (upper slope) catchments were similar. However, Lewin South is located in the High Rainfall Zone and its pan evaporation is the lowest (Table 1). If this catchment had been clear-felled, the increase in groundwater level would most likely had been the highest. March Road is located in the Intermediate Rainfall Zone. The rise in groundwater level was expected to be lower than Lewin South. But the groundwater level rise was highest at March Road because the catchment was clear-felled. The small rise in groundwater level at Yerraminnup South can be attributed to the vegetation cover left after heavy selection cutting, its location in the Low Rainfall Zone and higher pan evaporation (Table 1).

Transpiration and interception increases as vegetation grows (Borg, 1988). The subsequent decrease in groundwater recharge will result in lower groundwater levels. This appears to have happened at Lewin South and March Road catchments where the total vegetation cover is now greater than the pretreatment level. At April Road North the groundwater level beneath the slope area began to fall while the level in the valley continued to rise. However, the groundwater system of April Road North is complex, being closer to ground surface in the upslope area than in the valley (Martin, 1987). The shallow depth in the upslope areas may partially have resulted in higher evapotranspiration by young trees. Also the lesser, more constant evapotranspiration from mature trees and additional recharge from upslope may have contributed to the more gradual and delayed groundwater rise in the valley.

Early hydrologic response at similar experimental sites, which were logged in 1976-78 and in which regeneration began in 1978, show that groundwater level rose for the first 2-4 years and began to fall as the vegetation grew back (Borg, et al., 1988). Except in the valley areas of April Road North, similar trends are evident at all treated catchments.

7.4 Groundwater Salinity

The average groundwater salinity at the sites in the High and Intermediate Rainfall Zones was about 500 mg L^{-1} TSS. This was due to the presence of similar amount of salt ($\sim$12 kg ha^{-1} TSS) in the landscape (Table 4). The groundwater salinity at Yerraminnup South was very high, at about 5000 mg L^{-1} TSS (Table 4). This correlates to the high concentration of salt in the unsaturated zone which is typical of the Low Rainfall Zone.

At Lewin South, March Road and April Road North, groundwater levels rose sufficiently to dissolve salts naturally stored in the unsaturated zone of the soil column. This process led to an increase in groundwater salinity at these sites (Fig. 4). In 1985 groundwater levels began to fall at Lewin South and March Road and groundwater salinity decreased. At April Road North groundwater salinity remained stable after reaching a peak in 1985. This may be attributable to the continuous rise that has occurred in groundwater level in the valley area since logging (Fig. 3c). The groundwater salinity change at Yerraminnup South was not significant as there was very little change in groundwater level following logging.

7.5 Streamflow Response to Logging and Regeneration

The streamflow response to logging and subsequent regeneration observed in this study is consistent with the results of other studies (Malmar, 1992; Bren and Papworth, 1991; Borg, et al., 1988; Bosch and Hewlett, 1982; Hibbert, 1967). The annual streamflow of all four treated catchments increased for about 4 to 5 years and then began to decline as the vegetation grew back (Fig. 6). In 1991, streamflow at March Road was lower than pretreatment flows, while at the other three treated catchments streamflow was still higher. If the present trend continues, it is likely it will take at least another 10 years for streamflow to return to the pretreatment flows in these catchments.

The increase in streamflow since logging at March Road catchment was higher than at Lewin South although Lewin South is located in the High Rainfall Zone. This can be attributed to the retention of good quality trees at Lewin South as part of the heavy selection cutting (Table 2). The increase in streamflow at April Road South was less than at March Road. The lower increase was due to the retention of a stream buffer at April Road South as compared with March Road which had no buffer (Fig. 6). Yerraminnup South catchment with the lowest rainfall and the highest pan evaporation (Table 1), and aided by the heavy selection cutting and retention of a 100 m stream buffer produced the lowest increase in streamflow.

In Victoria it was observed that after several years of regeneration, streamflow was less than the pretreatment conditions (Kuczera, 1987; Langford, 1976). In 1991, only March Road streamflow was less than what would have been predicted if logging had not occurred (Fig. 6). Therefore results available to date are insufficient to assess whether future streamflow will be less than the pretreatment conditions. However, if a streamflow reduction does occur, trees can be thinned to reduce transpiration and interception to increase streamflow (Ruprecht et al., 1991; Shea, et al., 1975).

The changes in streamflow hydrographs following logging (Fig. 5b) were due to the lower soil water deficits at the treated catchments compared to the control catchments. This meant less rainfall was needed for streamflow to occur in treated catchments. However, by mid-winter after considerable rain had fallen, the difference in soil water deficits was less. This led to similar responses in daily streamflow (Fig. 5b). Except for peak flow, daily streamflow at treated catchments resembled that observed at control sites as the vegetation regenerated (Fig. 5c). Peak flows were higher at the treated catchments because of the increase in groundwater discharge area in the valley.

Results from experimental catchments in the south-west of Western Australia show that most of the increased streamflow after logging is generated from increased shallow subsurface runoff with relatively small amounts being contributed via surface runoff and deep groundwater flows (Williamson et al., 1987). In this study, the increase in base flow (consisting of shallow subsurface and deep groundwater flow) was more than twice the increase in surface runoff (Fig. 7). It is likely that most of the increase in base flow was from shallow subsurface flow. This result confirms previous studies undertaken in the south-west of Western Australia (Stokes and Loh, 1982; Stokes, 1985).

7.6 Effects of Logging and Regeneration on Stream salinity and Salt Load

In the south-west of Western Australia, the deep, permanent groundwater system is the greatest source of stream salt, but most of the streamflow originates from the shallow, seasonal subsurface flow (Williamson et al., 1987; Stokes, 1985; Stokes and Loh, 1982; Sharma et al., 1980). In this study, logging resulted in temporary increases in streamflows, stream salinity, salt load and groundwater levels. The way in which it affected the hydrological balance was different for each rainfall zone.

7.6.1 High Rainfall Zone

A groundwater discharge area existed at Lewin South before and after logging. This area increased after logging resulting in a slight increase in stream salinity. However, because soil salt is naturally mobile in this High Rainfall Zone and shallow subsurface flow also increased there was very little change in hydrological balance. The highest annual stream salinity observed after logging was about 200 mg L^{-1} TSS (Table 4).

7.6.2 Intermediate Rainfall Zone

The two treated catchments in the Intermediate Rainfall Zone, March Road and April

Road North responded differently to logging. A groundwater discharge area existed at March Road prior to logging. There was none at April Road North. Also stream salinity at March Road was higher than at April Road North (Table 6). After logging, the increase in stream salinity at March Road was much greater than at April Road North although the soil salt content at the two catchments were similar (Table 4). There was a more significant rise in groundwater level in the valley area at March Road. The groundwater discharge area increased resulting greater salt contribution to the stream. There was still no evidence of a groundwater discharge area at April Road North following logging. Stream salinity decreased at March Road when groundwater levels dropped in response to regeneration.

In the low rainfall year of 1987, daily stream salinity at March Road catchment exceeded 1000 mg L^{-1} TSS for 121 days (63% of the duration of streamflow). Between 1982 and 1991, daily stream salinity was above 1000 mg L^{-1} TSS on an average of 38 days per year (20% of the duration of streamflow). The high daily stream salinity was associated with the low flows which occurred at the beginning and end of the wet season. These flow events contributed relatively small amounts of salt to the stream and therefore had little effect on the flow-weighted annual stream salinity, except in 1987, when salinity was 778 mg L^{-1} TSS (Table 6). In all other years after logging, stream salinity was less than 500 mg L^{-1} TSS.

The tree buffer retained along the stream line at April Road North has lessened the increase in stream salinity. However, the groundwater system at this site has some special characteristics. Groundwater levels are closer to ground surface in the slope area than in the valley (Martin, 1987). Even though the groundwater level in the valley increased following logging it remained well below the natural surface (Table 4). The greater depth to groundwater level and the retention of a buffer were significant factors in reducing the impact on the hydrological balance. Annual stream salinity did not exceed 200 mg L^{-1} TSS.

7.6.3 Low Rainfall Zone

In the lower rainfall zone of the south-west of Western Australia, large increases in stream salinity were observed following permanent clearing of native forest for pasture development (Ruprecht and Schofield, 1989; Schofield and Ruprecht, 1989; Ruprecht and Schofield, 1991). Therefore, there was concern that logging at Yerraminnup South catchment could lead to a substantial increase in stream salinity (Steering Committee, 1987). Contrary to this expectation, the increase in stream salinity was the lowest of the four treated catchments (Fig. 10a). Logging resulted in only a slight rise in groundwater level which was not sufficient to generate groundwater contribution to streamflow (Table 4). In fact, there was a slight temporary decrease in annual stream salinity due to an increase in streamflow (Fig. 10a). The buffer retained along the stream lines and the trees left in the upslope area after heavy selection cutting have lessened the groundwater level rise. The hydrology balance has changed very little. Annual stream salinity was much the same before and after logging (Table 6). Annual stream salinity since logging has been well under 200 mg L^{-1} TSS. Similar results were also obtained at other regenerated logging sites in the low rainfall zone of Western Australia (Borg, et al., 1988). However, if groundwater was close to the surface in the LRZ, logging could result in significant increases in stream salinity.

7.7 Implications for Management

This study clearly shows logging in the southern forest of Western Australia results in only temporary increases in stream water yield and salinity. The impact of these changes do not threaten the fresh water resources in this region. However, forest management methods can be refined for the different hydrological settings to ensure the local impacts of these temporary changes are minimised.

7.7.1 High Rainfall Zone

Heavy selection cutting at Lewin South resulted in an increase in streamflow and salinity. But the annual stream salinity generally remained below 200 mg L^{-1} TSS (Table 6). Therefore, heavy selection cutting will not adversely effect stream salinity if the cleared areas were regenerated to native forest soon after logging. The impact of any temporary change will be lessened if a stream buffer is retained. This will also reduce the stream sediment concentration (Steering Committee, 1987). It may be possible to log the stream buffer after the regeneration of the upper slopes has stabilised the catchment hydrology. To protect stream banks and minimise soil disturbances, strict control measures would be essential. However, operations would have to be restricted to summer months only.

7.7.2 Intermediate Rainfall Zone

The chance of significant increases in stream salinity following logging is highest in the Intermediate Rainfall Zone. It is evident that clear-felling of native forest with no stream buffer causes the highest increase in stream salinity. In localised areas such as March Road (where groundwaters are shallow and soil salt concentrations are moderate), the annual stream salinity can be expected to exceed 500 mg L^{-1} TSS and the daily stream salinity 1000 mg L^{-1} TSS during low flows. In other localised areas (where depth to groundwater is high or shallow and soil solute concentrations are low) the retention of a 200 m stream buffer (100 m each side of the stream) resulted in a slight increase in salinity. Annual stream salinity at this site remained below 200 mg L^{-1} TSS even in dry years. Therefore, The risk and magnitude of salinity increases in the IRZ is highly variable and influenced by the degree of vegetation disturbances, the size of the buffer width, the depth of groundwater and soil solute concentration.

7.7.3 Low Rainfall Zone

In the Low Rainfall Zone, generally the depth to groundwater under native forest is sufficiently great enough not to mobilise the large amount of salts present in the unsaturated zone of the landscape (Table 4). Any change in the annual recharge from rainfall is sufficiently low that logging can be undertaken without a significant increase in stream salinity (Table 6). However, where groundwater is close to the surface, intensive logging may have greater impact on stream salinity. Provided adequate care is taken to select sites with deep groundwater systems (>5 m below natural surface), logging with the retention of an adequate stream buffer (say at least 100 m) should not pose a threat to water resources in this zone. However, further work is required to define the optimal buffer sizes for different upslope logging operations.

8 CONCLUSIONS

8.1 *Vegetation Regeneration*

(i) After logging, vegetation cover increased to the prelogging levels within 5 to 10 years in karri stands. Jarrah-marri stands responded relatively slowly, reaching 90% of prelogging values in 10 years.

8.2 Groundwater Level and Salinity

(i) Logging caused groundwater levels to rise for the first five (1982-87) years after treatment. Then levels began to decline as the forest regenerated. The highest increase in groundwater level was in the Intermediate and High Rainfall Zones. Relative to the control, the largest rise was at March Road (4.5 m) and the lowest was at Yerraminnup South (1 m). In 1991, groundwater levels relative to the control catchments were 0.5 m to 3 m higher.

(ii) In the Intermediate and High Rainfall Zones, the average groundwater salinity increased following logging but then declined as the vegetation grew. Groundwater salinity remained stable in the Low Rainfall Zone catchment of Yerraminnup South.

8.3 Streamflow and Stream Salinity

(i) Annual streamflow at the treated catchments increased systematically for the first 3 to 4 years and then began to decline. The maximum increase was 15% of annual rainfall at March Road and the lowest was 5% of rainfall at Yerraminnup South.

(ii) The increase in base flow was about twice the increase observed in the surface runoff.

(iii) Logging has led to temporary increases in stream salinity. At Lewin South and April Road North, stream salinity increased by less than 100 mg L^{-1} TSS, and in most years the total stream salinity remained below 200 mg L^{-1} TSS. The highest stream salinity increase occurred at March Road, located in the Intermediate Rainfall Zone. Daily stream salinity, in excess of 1000 mg L^{-1} TSS, was observed at low flows. The annual stream salinity exceeded 500 mg L^{-1} TSS in the low rainfall year of 1987. Clear-felling of the native forest and not having a stream buffer is seen as the reason for such an increase in salinity. The least change in stream salinity was at Yerraminnup South, although it is located in the Low Rainfall Zone. The small change can be attributed to low groundwater response and no interaction between the surface and groundwater systems. The lower rainfall and groundwater recharge, the retention of some trees over the catchment during heavy selection cutting and the retention of a 50 m tree buffer on each side along the stream line all contributed to the small increase in stream salinity.

(iv) Forest management methods used in these experiments, with the exception of clear-felling without stream buffer, will not effect the fresh water resources in the south-west of Western Australia. However, forest management methods can be refined to minimise the impact of temporary changes on the different hydrological settings within the southern forest.

9 RECOMMENDATIONS

- The current level of monitoring should be continued at catchments located in the Intermediate Rainfall Zone. In the High and Low Rainfall Zones, streamflow and stream salinity monitoring could be minimised. However, the frequency of groundwater monitoring may be reduced and only annual minimum and maximum may be recorded. The collected data should be reviewed in approximately five years time.

- To protect water quality and quantity, forest management methods should be regularly reviewed as our knowledge and understanding of hydrological processes improve.

- Further research should be undertaken to establish the minimum stream buffer widths required for different hydrological settings that exist in the southern forest.

10 ACKNOWLEDGMENTS

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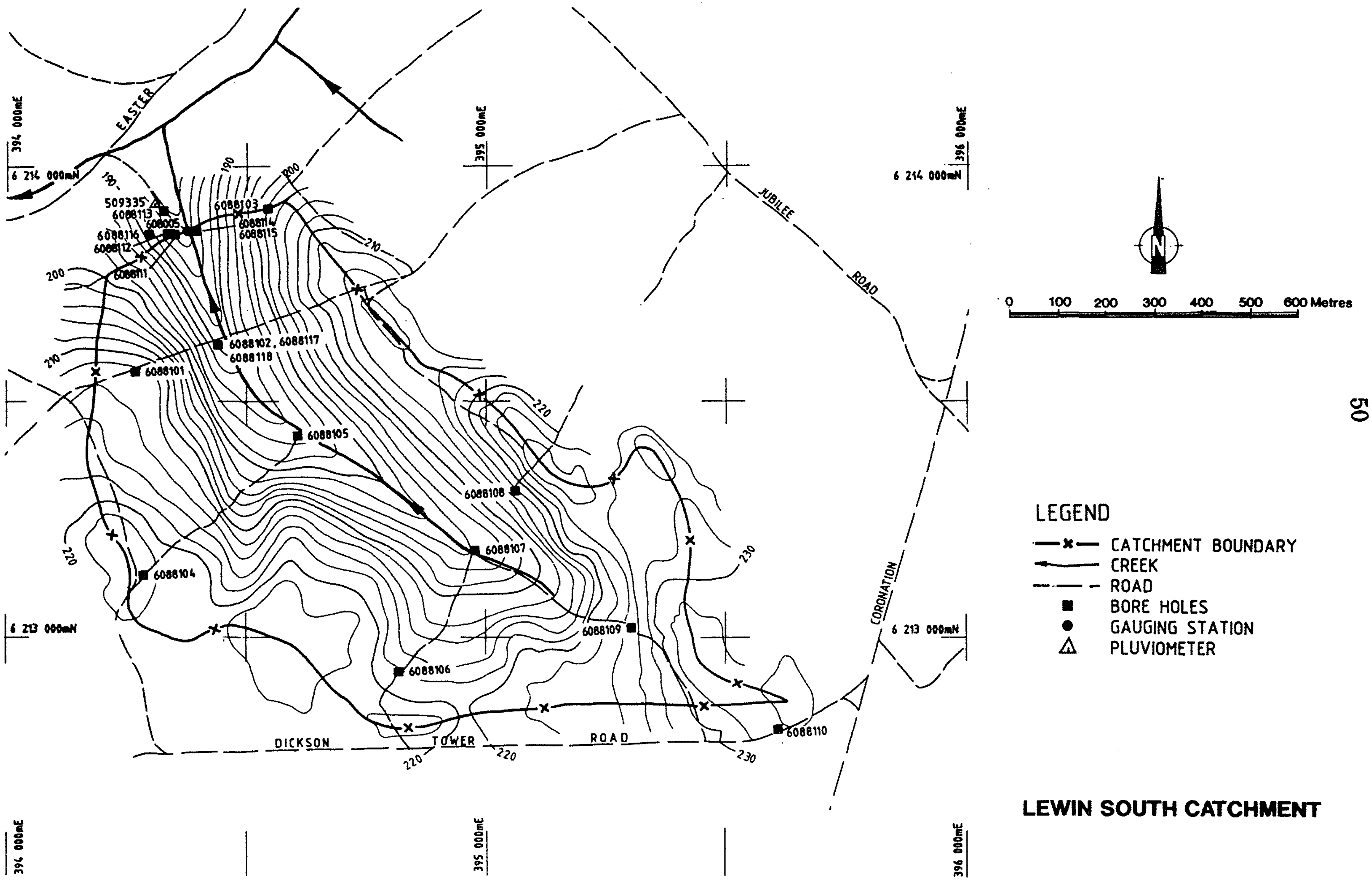
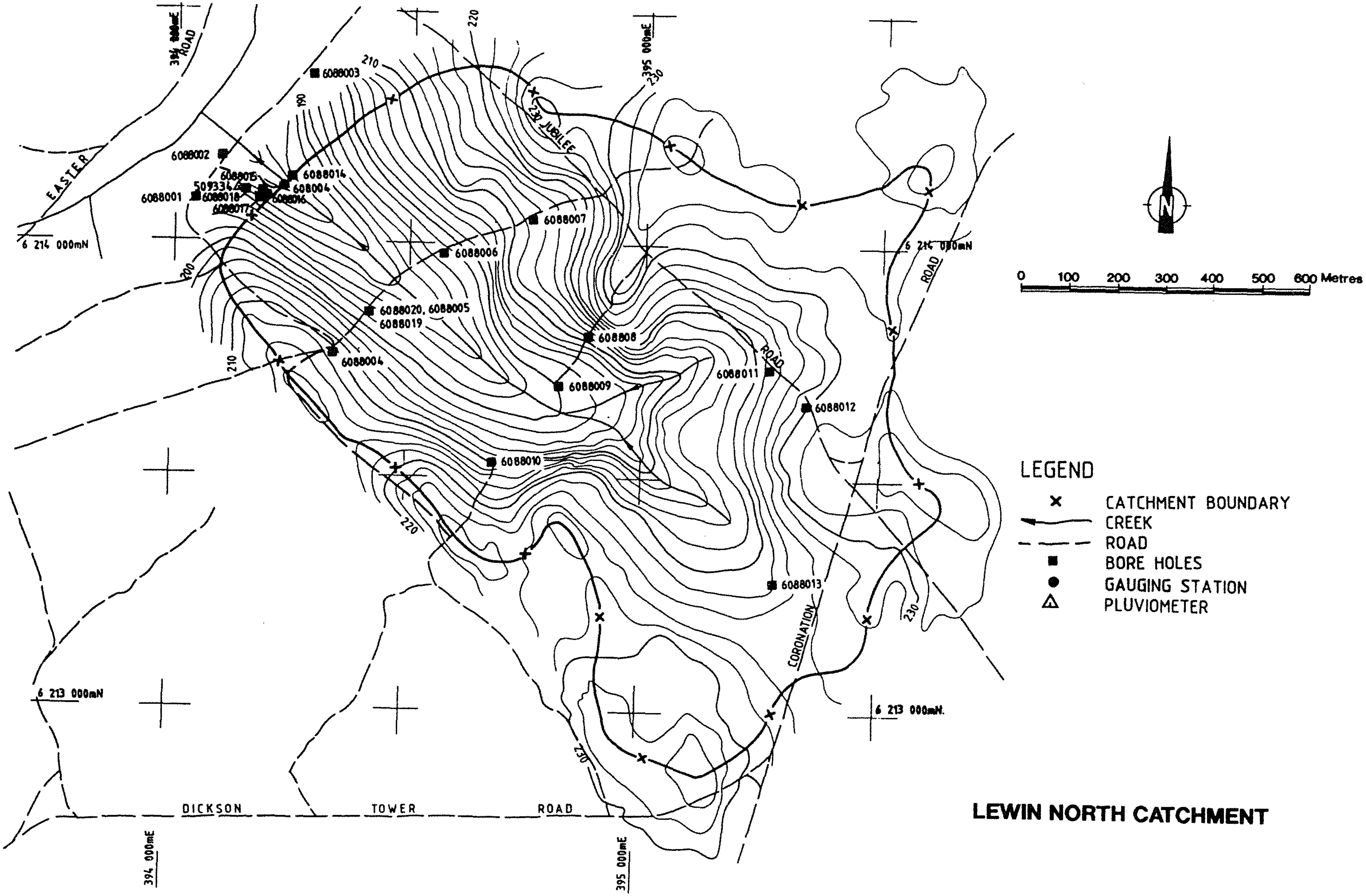
APPENDIX A

Topography and hydrometric network of experimental catchments



LEWIN SOUTH CATCHMENT



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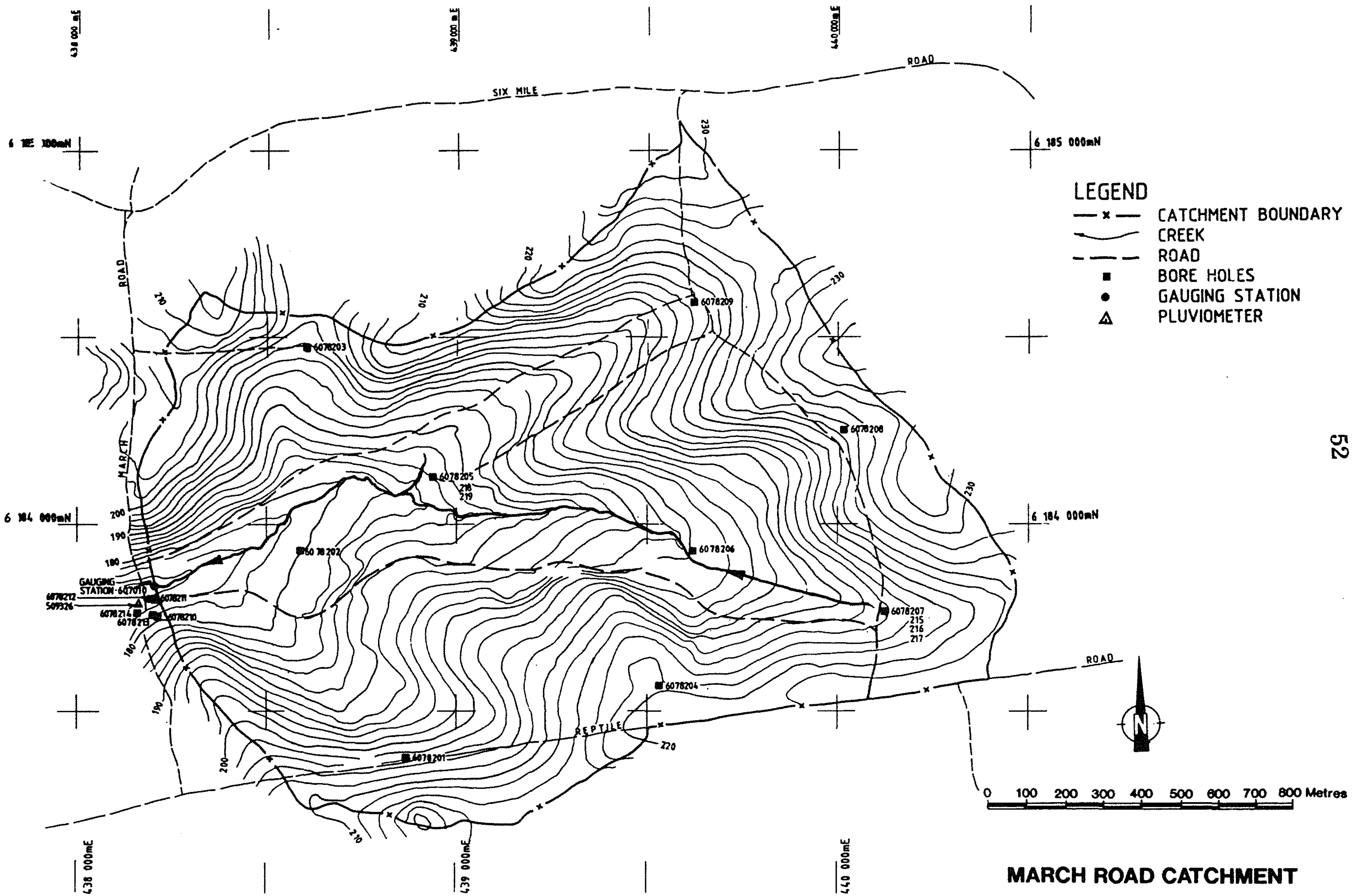
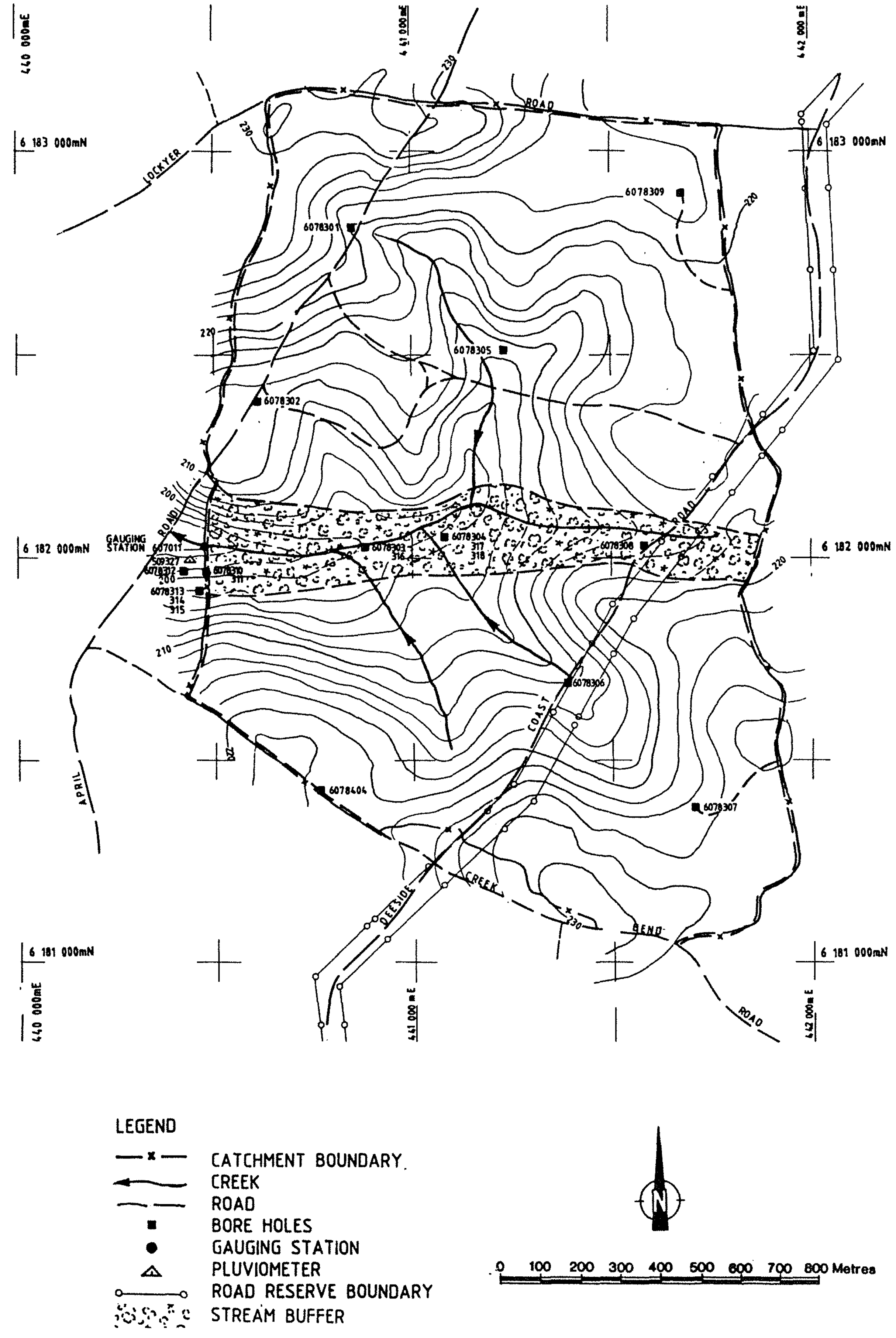
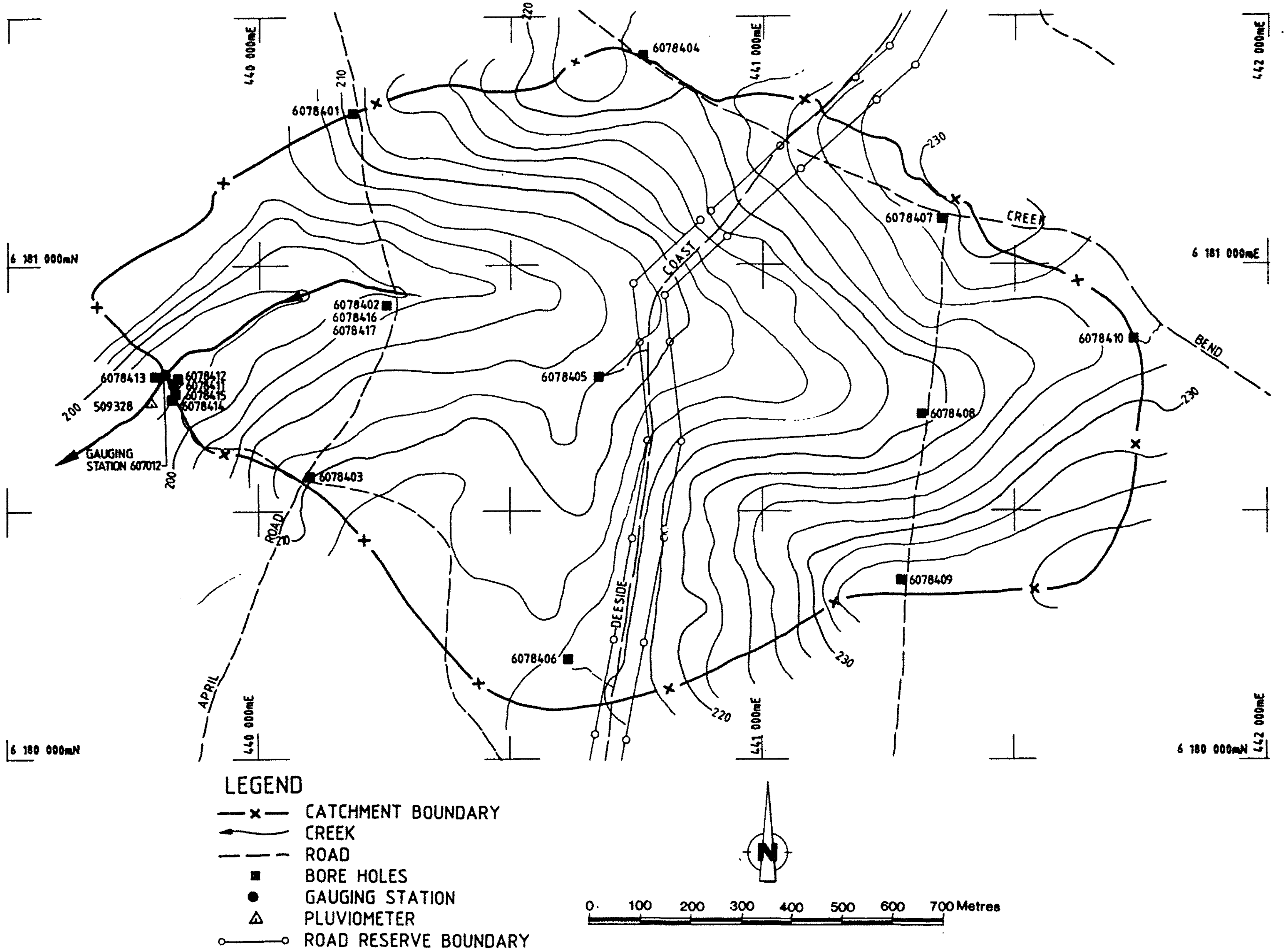

LEGEND
CATCHMENT BOUNDARY
CREEK
ROAD
BORE HOLES
GAUGING STATION
PLUVIOMETER
SIX MILE
ROAD
MARCH
ROAD
REPTILE
ROAD
438 000mE
439 000mE
440 000mE
6 185 000mN
6 184 000mN
6078201
6078202
6078203
6078204
6078205
6078206
6078207
6078208
6078209
6078210
6078211
6078212
6078213
6078214
509326
GAUGING STATION 607010
0 100 200 300 400 500 600 700 800 Metres
N
MARCH ROAD CATCHMENT



APRIL ROAD NORTH CATCHMENT



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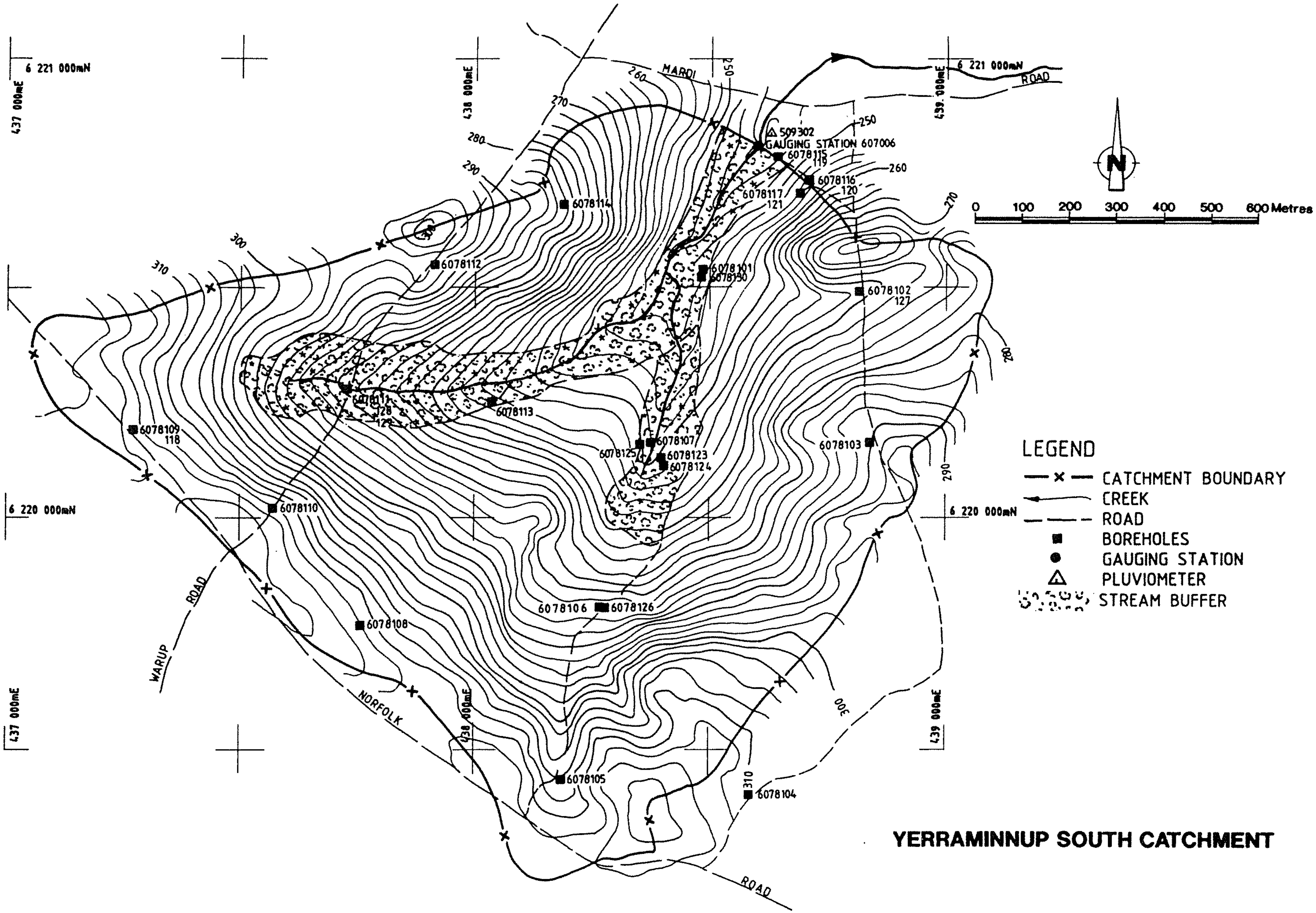
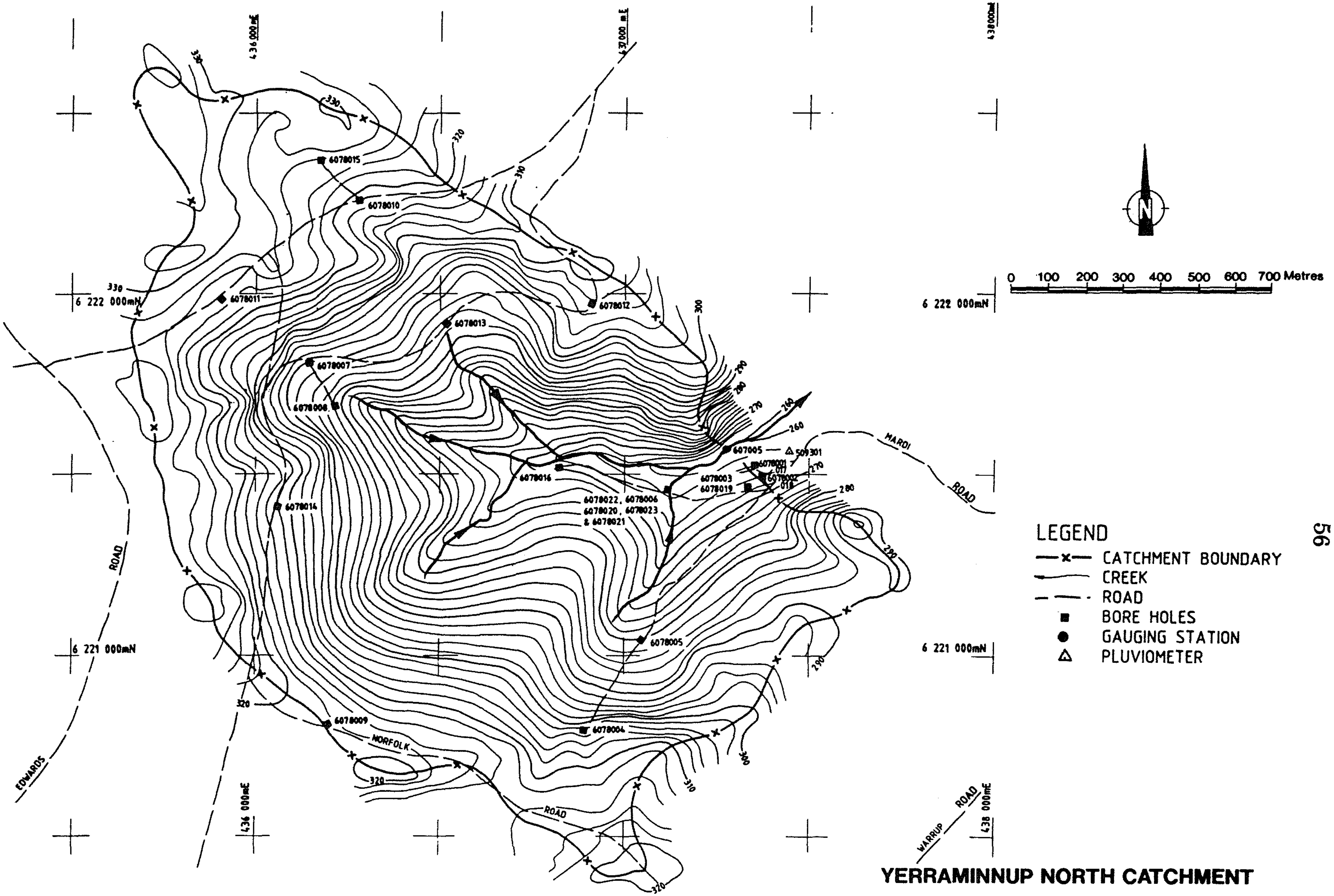


YERRAMINNUP SOUTH CATCHMENT



YERRAMINNUP NORTH CATCHMENT

APPENDIX B

Average groundwater salinity (mg L^{-1} TSS) of observation bores

LEWIN SOUTH

	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
G60818101	1125.4	917.1	515.0	3385.0	3385.3	3385.3	2069.0	1495.0	2222.8	2556.4	2523.5	1343.1	2061.8	1572.0	976.0	970.0
G60818102	191.5	163.5	161.2	167.2	159.7	165.1	168.9	164.5	171.2	165.4	164.5	173.5	170.7	158.6	140.0	141.0
G60818104	87.2	112.0	83.3	42.9	59.5	94.5	89.3	74.0	86.7	73.2	82.5	58.9	69.3	50.6	188.0	80.0
G60818105	447.3	403.5	398.2	400.4	402.3	399.5	394.2	388.3	375.0	370.3	361.9	356.4	356.8	348.1	349.3	371.0
G60818106	594.2	368.3	436.9	454.6	445.2	349.5	540.0	622.6	774.3	917.3	919.6	881.5	643.3	614.0	714.5	530.0
G60818107	166.0	172.0	164.4	159.2	163.1	166.5	166.9	167.5	165.4	168.4	164.6	169.5	171.5	172.1	176.6	179.0
G60818108	351.7	299.6	274.5	274.7	271.2	294.0	838.5	2691.8	2649.6	2758.0	901.1	307.8	389.4	359.1	356.6	587.0

LEWIN NORTH

	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
G60818001	792.0	761.8	732.2	560.2	349.0	737.4	645.3	460.8	529.6	554.5	639.5	311.7	498.0	404.3	612.0
G60818002	409.2	255.6	240.3	232.2	205.5	323.0	348.8	231.8	281.4	285.8	337.4	191.7	218.8	226.6	232.0
G60818005	825.9	388.5	476.9	251.4	319.3	880.2	274.8	254.2	276.9	243.5	238.5	170.7	263.7	198.1	451.0
G60818006	257.8	221.1	216.4	164.2	211.5	287.7	203.8	186.9	242.4	231.8	206.8	158.5	201.5	155.3	167.0
G60818007	143.1	124.9	141.8	156.9	214.5	334.8	348.6	221.2	299.1	342.7	254.4	193.8	112.6	115.2	220.0
G60818008	237.5	211.4	261.6	178.4	314.5	350.2	401.4	384.1	431.4	411.6	481.5	237.0	357.0	198.4	711.0
G60818009	336.6	331.6	333.2	333.6	331.5	327.8	332.1	332.2	325.7	332.7	322.2	323.2	334.1	336.8	340.0
G60818010	164.7	122.2	104.2	94.8	134.0	161.6	232.1	91.9	87.8	98.0	112.7	82.4	107.3	65.8	54.0
G60818011	269.5	261.5	265.9	268.0	266.0	262.0	262.5	258.7	262.6	253.9	254.5	259.7	257.7	259.8	244.0
G60818013	556.0	453.8	416.5	640.8	634.0	448.6	482.6	399.8	443.2	421.0	413.9	363.0	427.6	442.1	426.0

MARCH ROAD

	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
G60718201	311.7	297.6	246.9	186.4	242.0	291.7	308.3	314.9	1084.8	1992.5	1899.1	762.6	938.2	124.7	627.0	627.0
G60718202	488.4	465.8	438.1	453.9	464.2	468.5	472.8	534.3	490.5	457.7	464.1	464.4	488.8	458.6	450.9	457.0
G60718205	1097.7	851.6	664.6	926.1	801.8	582.3	759.5	763.4	653.8	890.8	875.8	1076.8	685.2	952.1	838.2	872.0
G60718206	848.6	410.7	238.0	476.4	773.3	508.5	549.1	706.2	942.5	646.3	625.2	638.5	710.4	659.7	686.4	602.0
G60718207	243.9	169.2	99.6	98.1	99.0	109.0	104.0	158.8	123.1	129.1	116.5	126.1	97.9	105.7	94.2	112.0

APRIL ROAD NORTH

	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
G60718301	252.4	266.3	277.6	275.9	283.5	291.8	293.7	275.7	259.7	254.8	251.3	271.5	282.0	277.7	266.0	267.0
G60718302	710.6	246.4	97.2	89.8	70.7	92.0	85.1	114.8	126.2	199.6	359.9	422.0	458.6	469.3	443.4	468.0
G60718303	607.2	319.0	214.6	269.9	237.6	276.3	287.2	321.8	323.5	548.8	583.8	781.3	827.3	1022.3	956.7	864.0
G60718304	621.6	549.1	293.1	471.2	322.3	320.7	568.4	493.4	416.4	767.0	917.2	1098.9	883.3	1159.7	845.6	1486.0
G60718305	1758.9	1630.1	1339.8	1689.9	1709.8	1061.0	1656.6	1119.8	1190.2	1693.1	1678.8	1679.5	1609.3	1629.3	1438.6	1663.0
G60718306	926.6	647.4	179.5	414.1	275.4	410.0	332.1	427.8	604.8	920.4	943.6	838.4	759.2	903.8	912.6	985.0
G60718307	374.7	285.4	269.9	282.0	278.1	236.0	274.3	226.7	155.8	177.5	213.9	225.0	110.8	143.7	150.0	138.0
G60718308	517.9	261.7	219.6	359.9	290.8	347.5	346.0	318.2	324.1	343.8	344.5	351.5	318.5	337.3	329.5	335.0
G60718309	1331.6	1096.8	776.3	993.4	1075.7	1074.0	1269.6	1246.3	1458.7	1580.9	1792.1	1660.4	1072.9	1391.8	1281.2	1332.0
G60718404	351.5	129.4	118.9	122.6	106.2	148.5	134.7	129.9	121.1	116.1	124.4	116.2	108.1	128.2	113.4	155.0

APRIL ROAD SOUTH

	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
G60718402	942.9	942.9	1186.2	1282.8	1265.0	1724.4	1715.2	1723.2	1823.4	1874.4	1889.9	2374.6	2002.5	1906.2	1793.0
G60718403	1123.0	589.0	892.8	598.4	542.0	872.6	713.1	501.7	715.9	988.6	1060.6	385.7	524.7	414.2	647.0
60718405	739.8	729.8	775.2	803.8	782.0	808.5	791.3	784.4	792.1	791.3	785.8	798.3	800.7	772.6	793.0
G60718406	282.4	290.6	369.2	258.9	350.0	1020.8	1009.5	757.0	1743.0	2125.0	119.8	129.1	278.5	221.6	479.0
G60718407	1462.9	146.9	237.5	376.2	351.0	462.6	1081.3	510.4	1006.5	1496.1	1174.3	240.5	496.8	382.3	690.0
G60718408	883.5	842.4	957.1	1079.2	924.5	815.0	874.7	1036.9	839.8	918.1	889.2	988.3	908.9	970.3	726.0
G60718410	131.9	99.5	98.7	97.2	110.0	116.5	107.0	105.1	111.3	105.0	102.1	102.1	112.3	109.7	136.0

YERRAMINNUP SOUTH

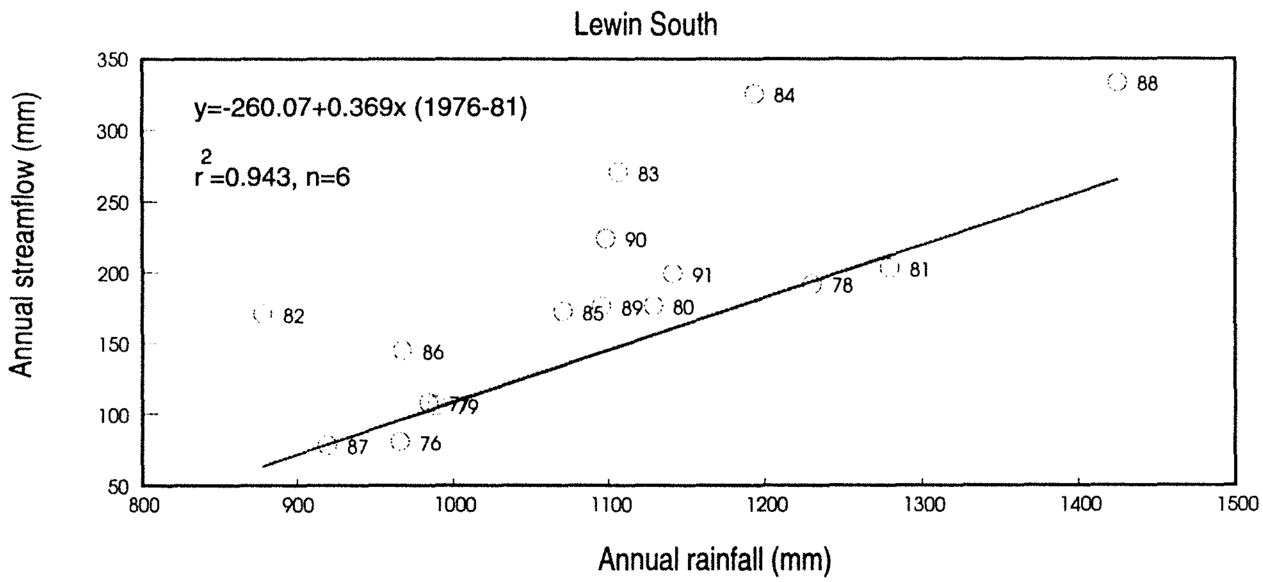
	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
G60718101	4517.3	7082.0	6552.1	6221.4	6121.1	1082.7	5382.7	4936.9	3581.8	5197.3	5747.8	6504.0	4328.0	6251.3	4393.9	7354.0
G60718115	8595.2	4071.6	701.3	831.4	626.4	216.3	162.7	610.9	996.5	118.2	593.2	1827.1	998.3	184.8	216.2	156.0
G60718116	4506.1	5056.3	4866.2	5046.4	4999.9	4942.8	5070.8	4664.1	4916.1	5031.8	4909.6	4792.5	5000.9	5350.5	4960.2	5081.0
G60718117	2174.0	2859.6	2787.8	2337.8	2343.9	2438.8	2514.0	2528.8	2551.6	2603.6	2464.2	2383.5	2495.9	2795.7	2417.5	2725.0
G60718119	6261.3	8040.7	8145.2	8270.2	8412.5	8546.5	7658.6	7690.4	7326.5	6571.5	7611.2	7561.6	7020.6	7458.7	6956.5	7650.0
G60718120	3857.2	5385.8	5386.3	6458.3	6620.1	6720.5	6677.3	6776.3	6796.4	6652.6	6930.4	7386.8	7846.8	8290.1	9049.3	6823.0
G60718121	3740.5	5283.0	5719.8	5955.6	6092.1	6374.0	6487.1	6579.7	6612.2	6162.4	6326.2	5954.9	6173.1	6121.5	5882.1	5355.0

YERRAMINNUP NORTH

	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
G60718001	5701.6	6024.0	1532.6	5046.9	4406.8	3479.3	5018.9	2949.4	3776.8	6233.2	6548.9	6340.2	2490.0	4109.5	1872.1	4102.0
G60718002	928.6	531.5	227.3	217.4	173.6	163.8	231.4	205.6	169.1	222.1	324.6	540.4	342.8	239.4	216.5	155.0
G60718003	351.6	368.6	717.8	289.8	218.5	172.8	340.5	286.3	284.3	307.7	171.8	258.9	268.8	299.5	349.6	212.0
G60718005	4536.1	4925.5	2405.1	4253.2	3846.2	4428.5	5276.7	3190.1	2040.1	2575.8	4762.4	5135.2	1265.6	2038.0	1505.0	4125.0
G60718006	1816.4	721.6	601.6	480.0	245.5	462.3	573.2	470.9	397.1	431.3	384.4	894.5	337.7	348.0	241.5	165.0
G60718007	2865.3	3078.4	773.0	2176.6	1645.3	1429.0	2591.6	1839.2	2172.7	2508.9	2702.3	2689.2	1980.8	2663.8	2150.7	2765.0
G60718008	1639.1	2345.2	1022.8	1789.8	1179.1	1201.5	2257.1	963.4	610.5	997.9	2326.9	1727.8	480.8	252.8	168.5	324.0
G60818009	323.8	336.6	331.6	333.2	333.6	331.5	327.8	332.1	332.2	325.7	332.7	322.2	323.2	334.1	336.8	334.5
G60718010	660.4	383.7	144.1	162.7	134.8	135.0	114.3	113.2	111.9	131.5	106.9	111.9	107.6	107.7	120.6	161.0
G60718013	324.0	1053.2	335.6	190.1	181.1	142.0	152.7	131.6	113.2	122.0	121.6	133.0	108.9	91.0	105.4	101.0
G60718017	1964.1	5970.4	5587.8	5851.0	6055.1	5703.8	6097.0	6128.3	6244.1	6235.1	6146.6	5692.2	5029.3	5078.9	5312.2	6673.0
G60718018	619.9	903.9	651.3	1226.2	1604.4	1522.3	3350.6	4278.3	3623.7	4827.7	5947.1	5041.8	2713.3	3483.6	2726.4	7142.0

APPENDIX C

Relationships between streamflow, rainfall, stream salinity and salt load


Lewin South
y=-260.07+0.369x (1976-81)
r^2=0.943, n=6
Annual streamflow (mm)
Annual rainfall (mm)
84
88
83
90
91
81
78
82
85
89
80
86
77
79
87
76
350
300
250
200
150
100
50
800
900
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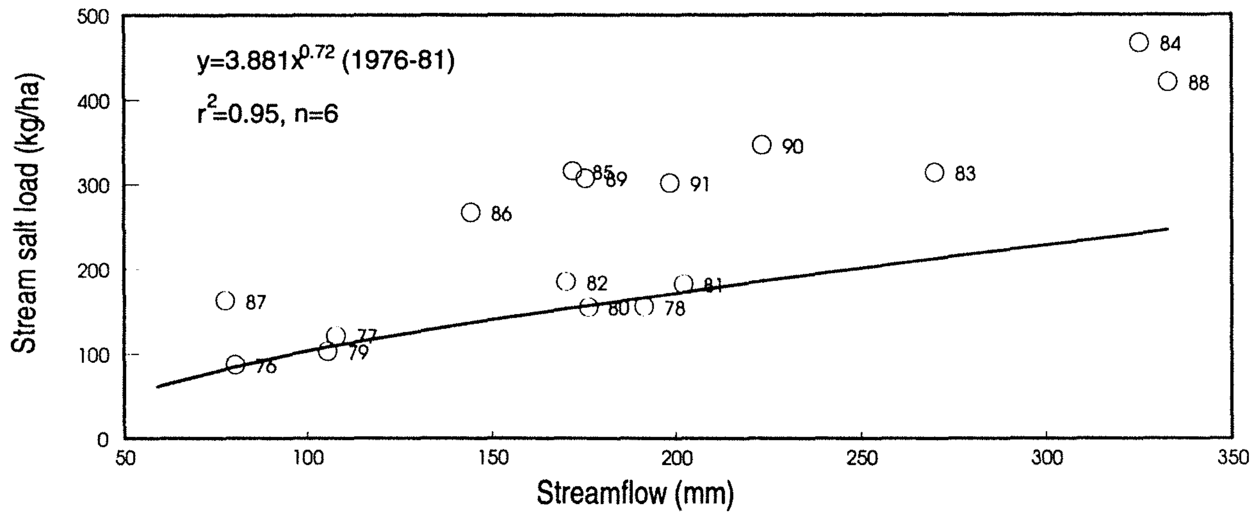
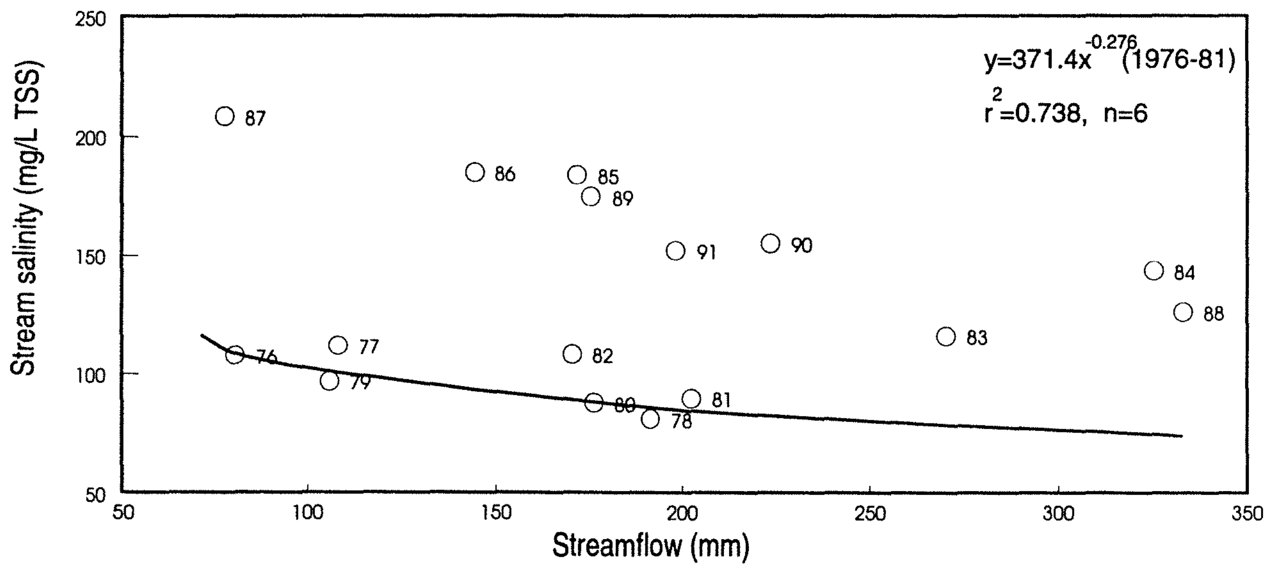
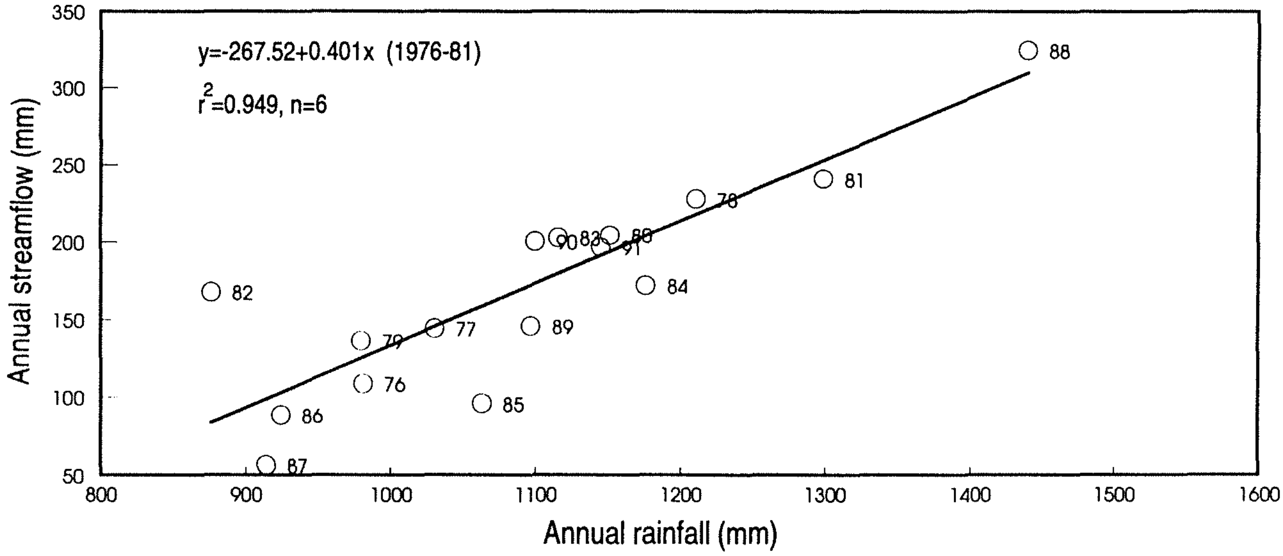
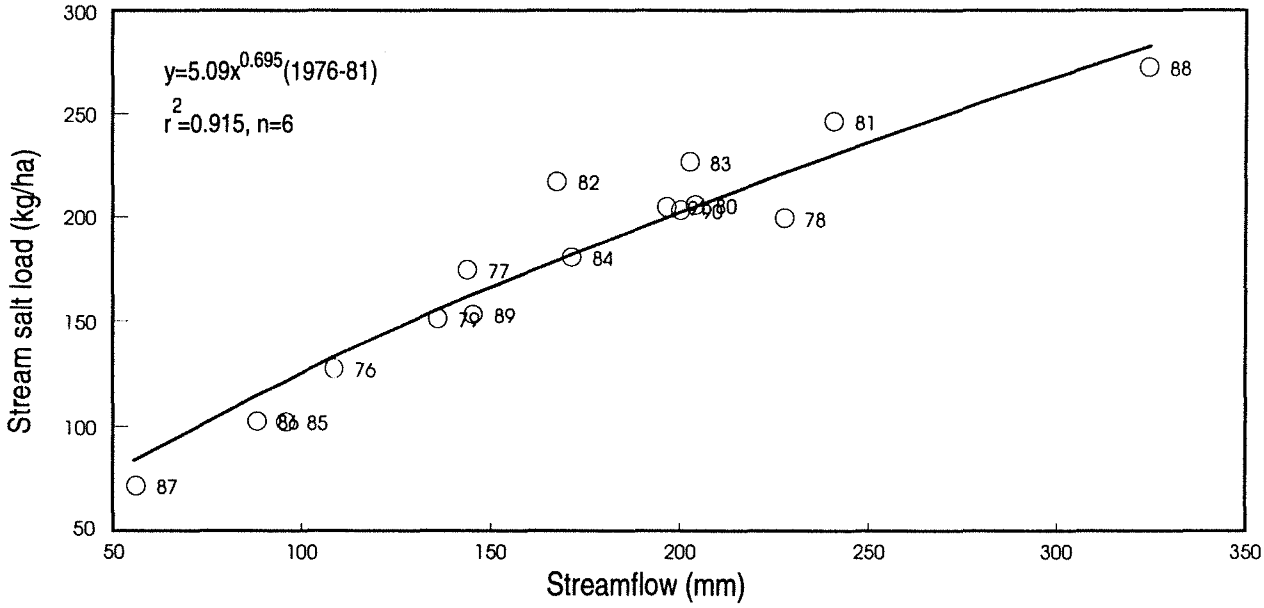
1100
1200
1300
1400
1500

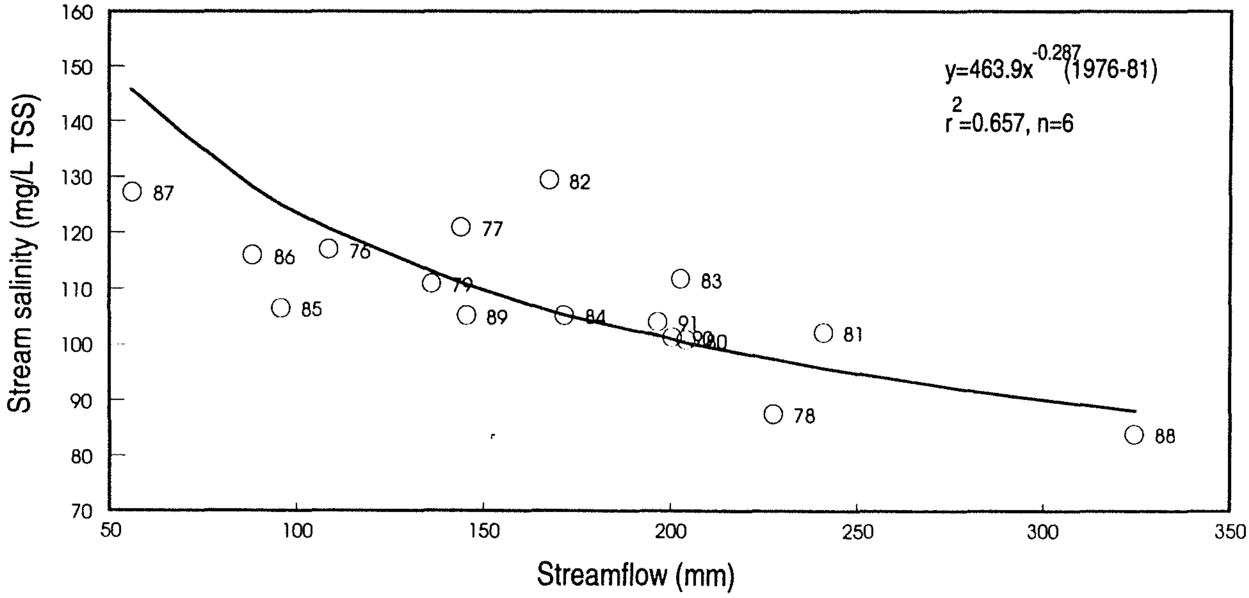

y=3.881x^0.72 (1976-81)
r^2=0.95, n=6
Stream salt load (kg/ha)
Streamflow (mm)
84
88
90
85
89
91
83
86
82
81
87
80
78
77
76
79
500
400
300
200
100
0
50
100
150
200
250
300
350


y=371.4x^-0.276 (1976-81)
r^2=0.738, n=6
Stream salinity (mg/L TSS)
Streamflow (mm)
87
86
85
89
91
90
84
88
83
76
77
82
79
80
81
78
250
200
150
100
50
50
100
150
200
250
300
350

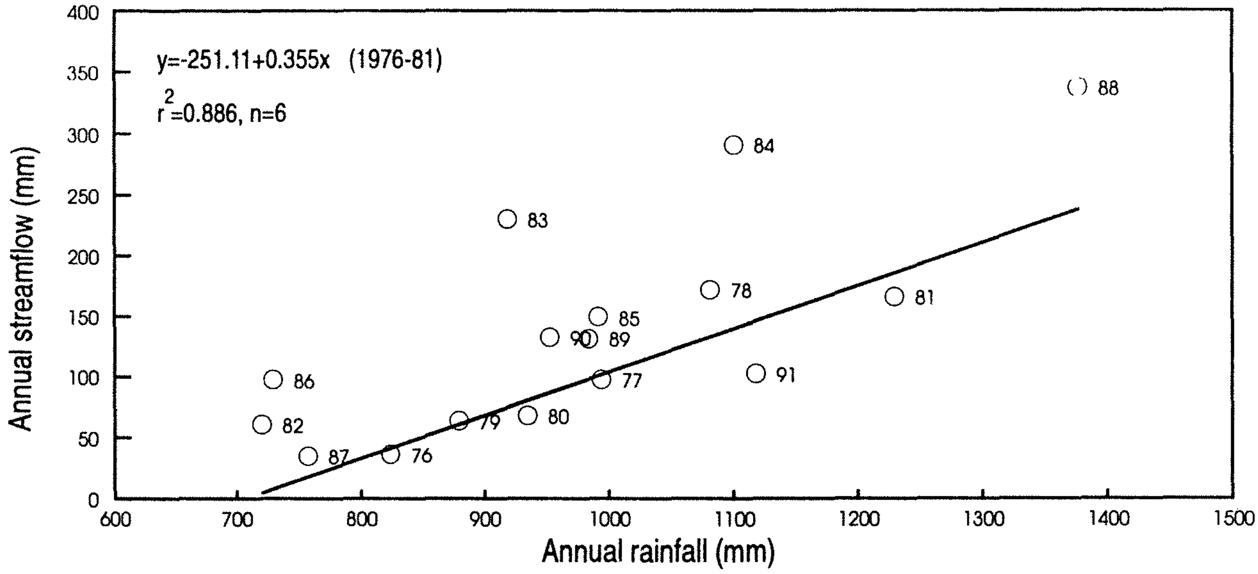
Lewin North

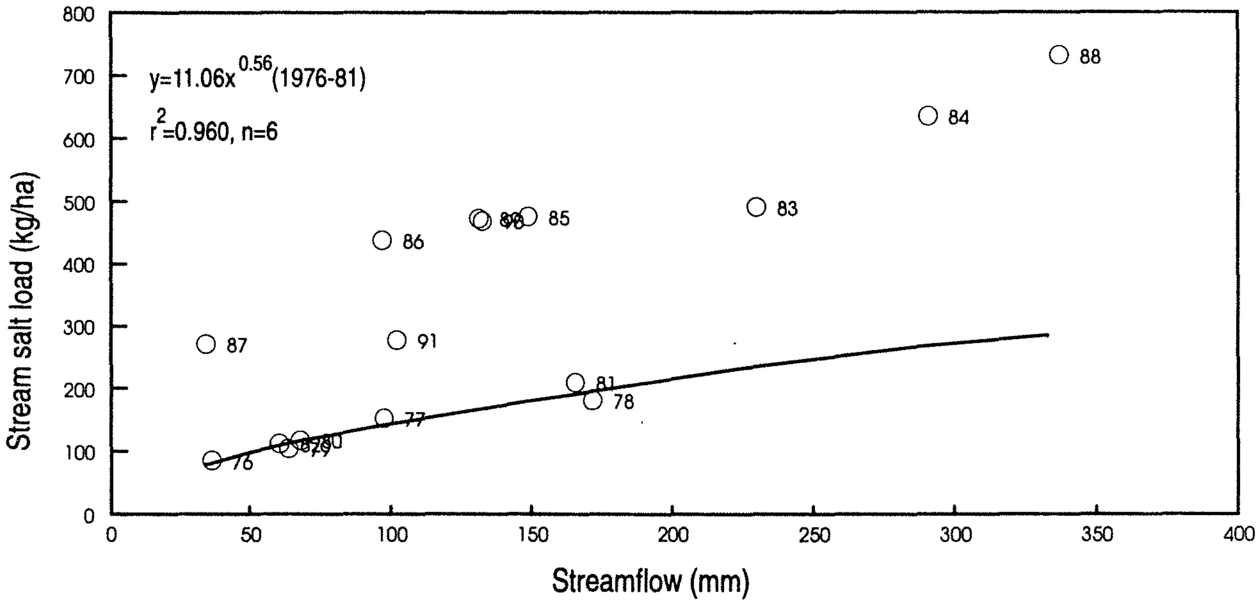

y=-267.52+0.401x (1976-81)
r2=0.949, n=6
Annual streamflow (mm)
Annual rainfall (mm)

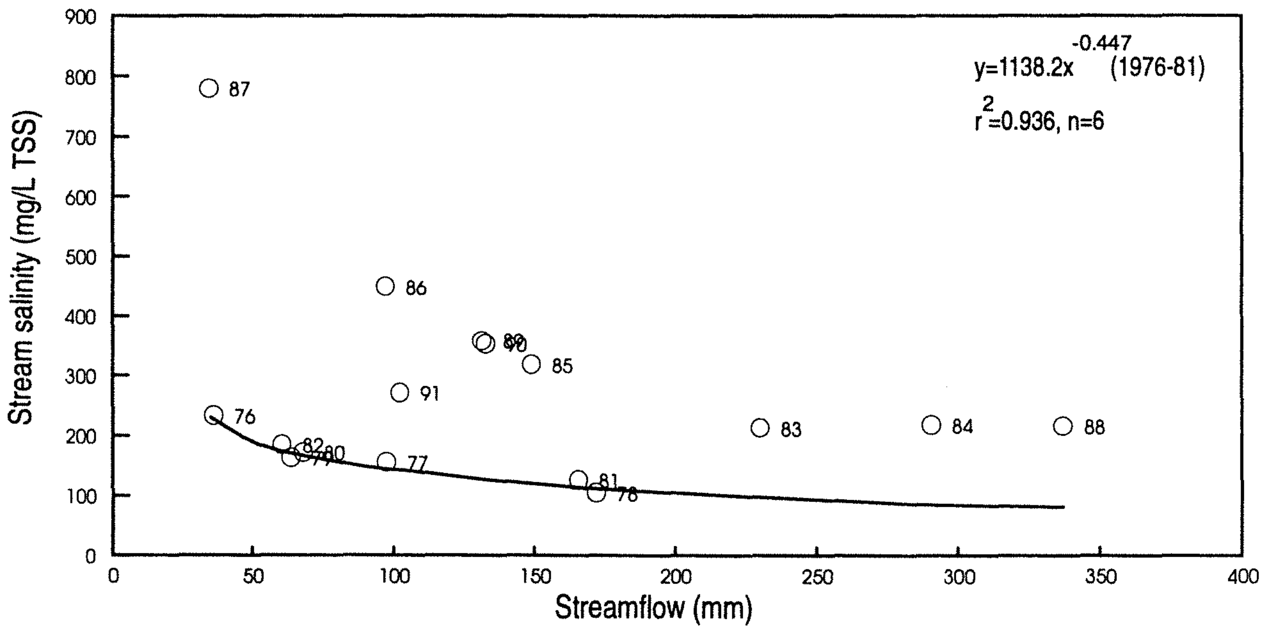

y=5.09x0.695(1976-81)
r2=0.915, n=6
Stream salt load (kg/ha)
Streamflow (mm)


y=463.9x-0.287(1976-81)
r2=0.657, n=6
Stream salinity (mg/L TSS)
Streamflow (mm)

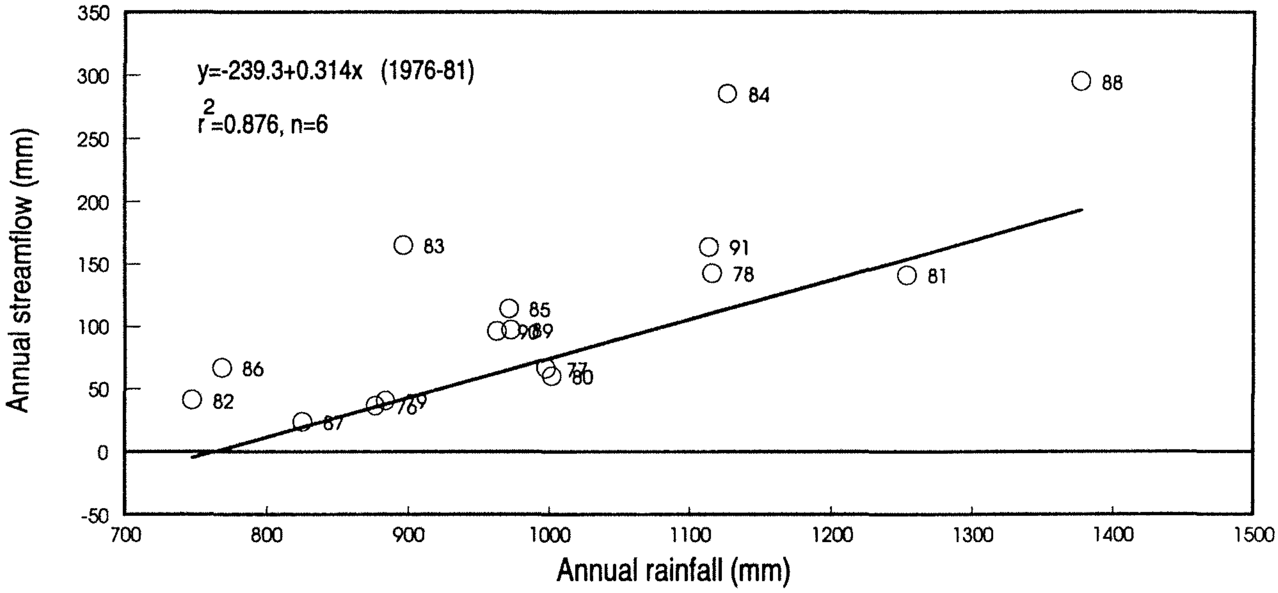
March Road

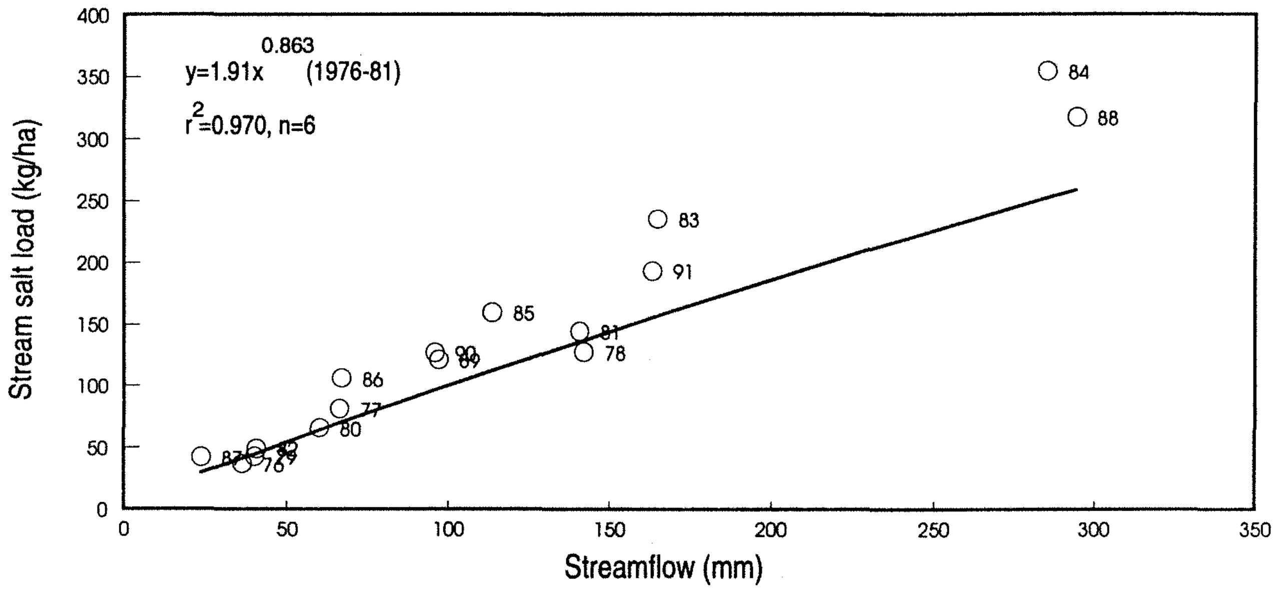

y=-251.11+0.355x (1976-81)
r2=0.886, n=6
Annual streamflow (mm)
Annual rainfall (mm)
0
50
100
150
200
250
300
350
400
600
700
800
900
1000
1100
1200
1300
1400
1500
88
84
83
78
81
85
90
89
86
77
91
82
79
80
87
76

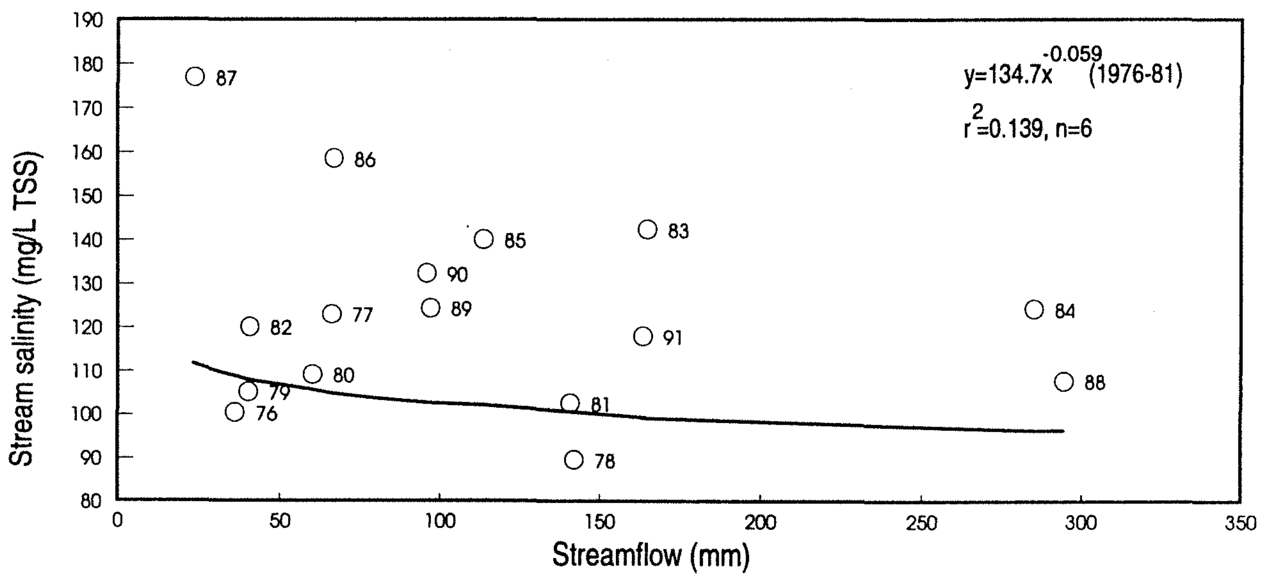

y=11.06x0.56(1976-81)
r2=0.960, n=6
Stream salt load (kg/ha)
Streamflow (mm)
0
100
200
300
400
500
600
700
800
50
150
250
350
88
84
83
85
86
87
91
81
78
77
76
79

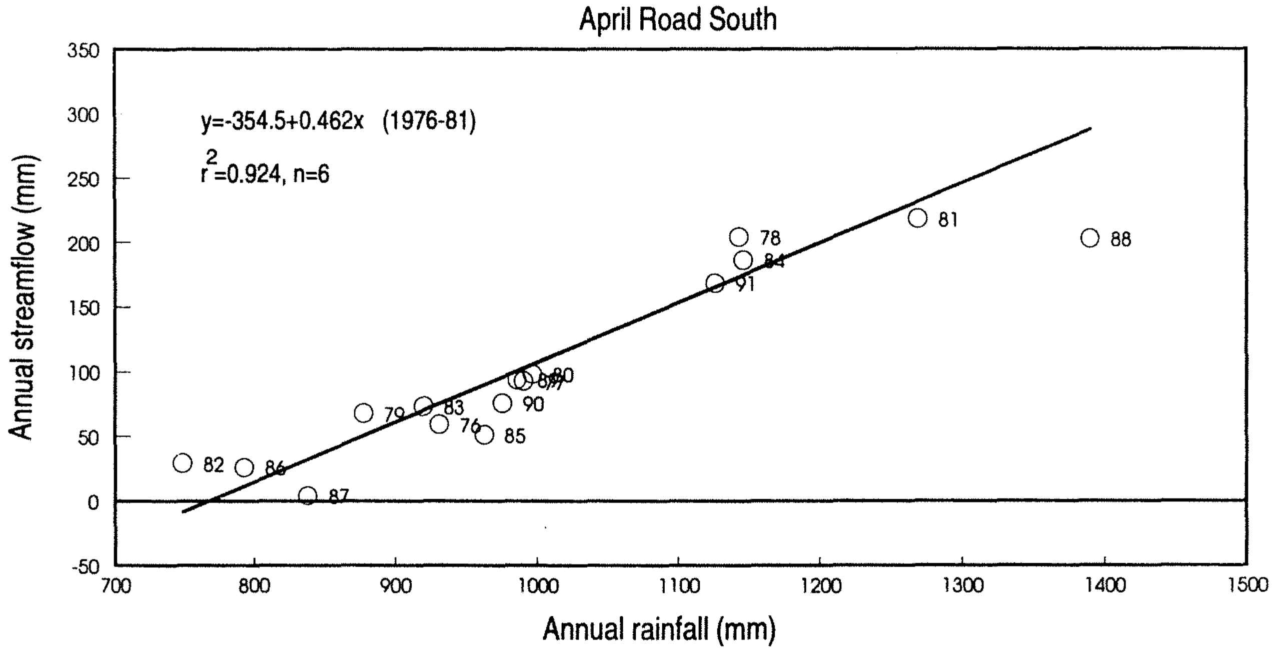

y=1138.2x-0.447 (1976-81)
r2=0.936, n=6
Stream salinity (mg/L TSS)
Streamflow (mm)
0
100
200
300
400
500
600
700
800
900
50
150
250
350
87
86
85
91
76
83
84
88
82
80
77
81
78

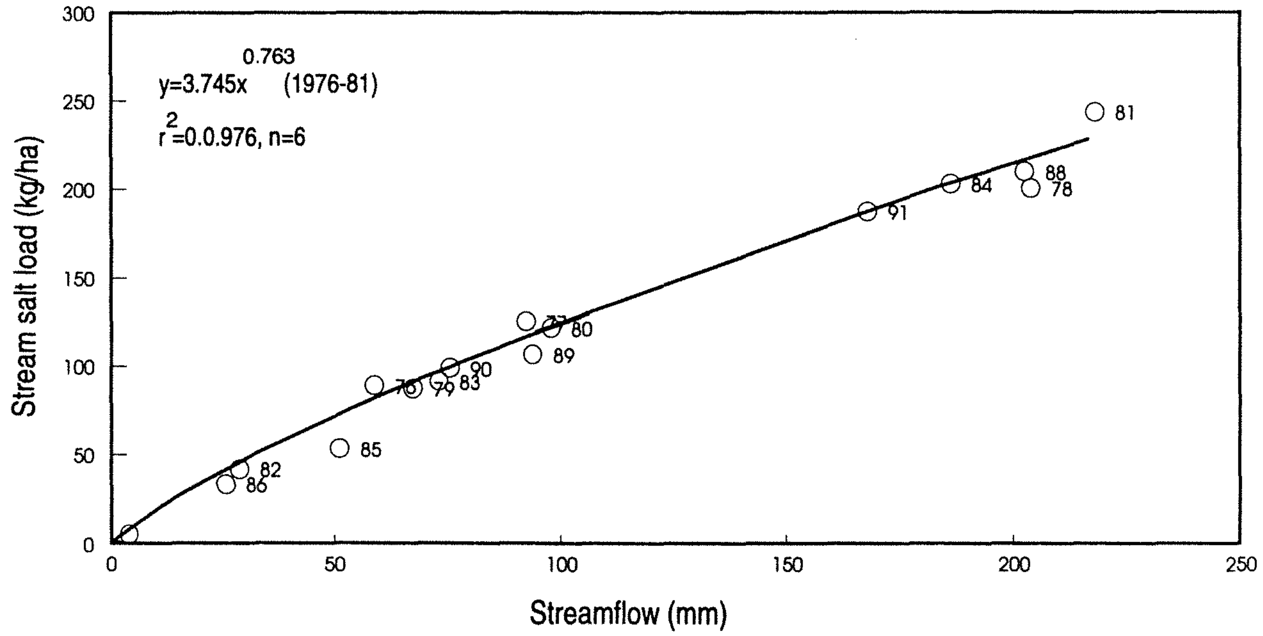
April Road North

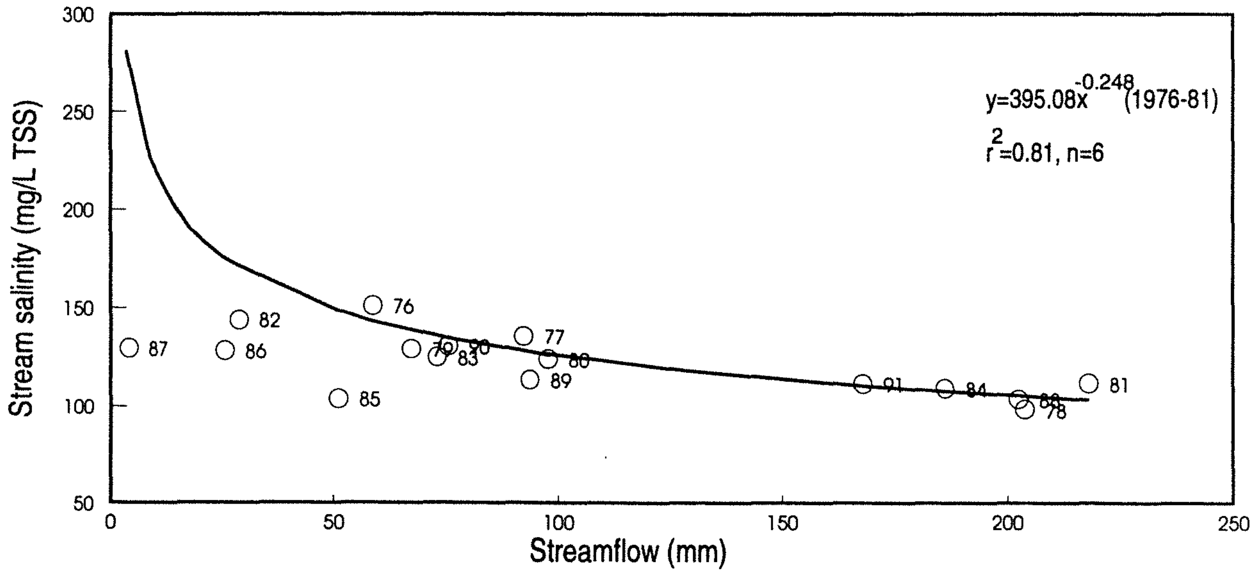




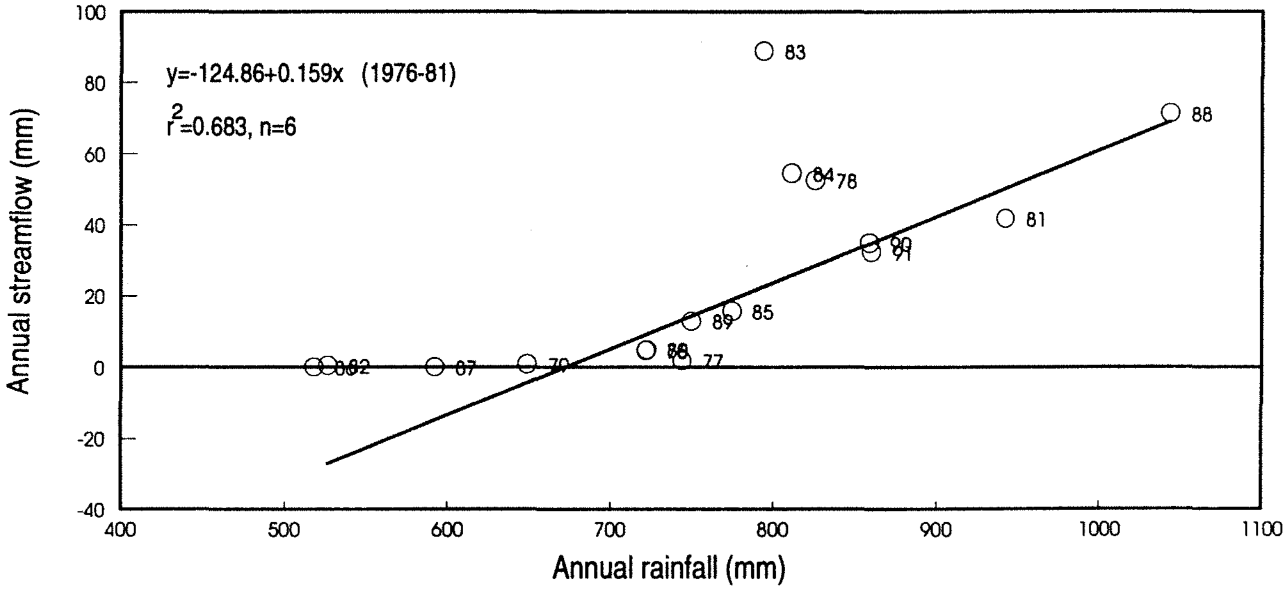


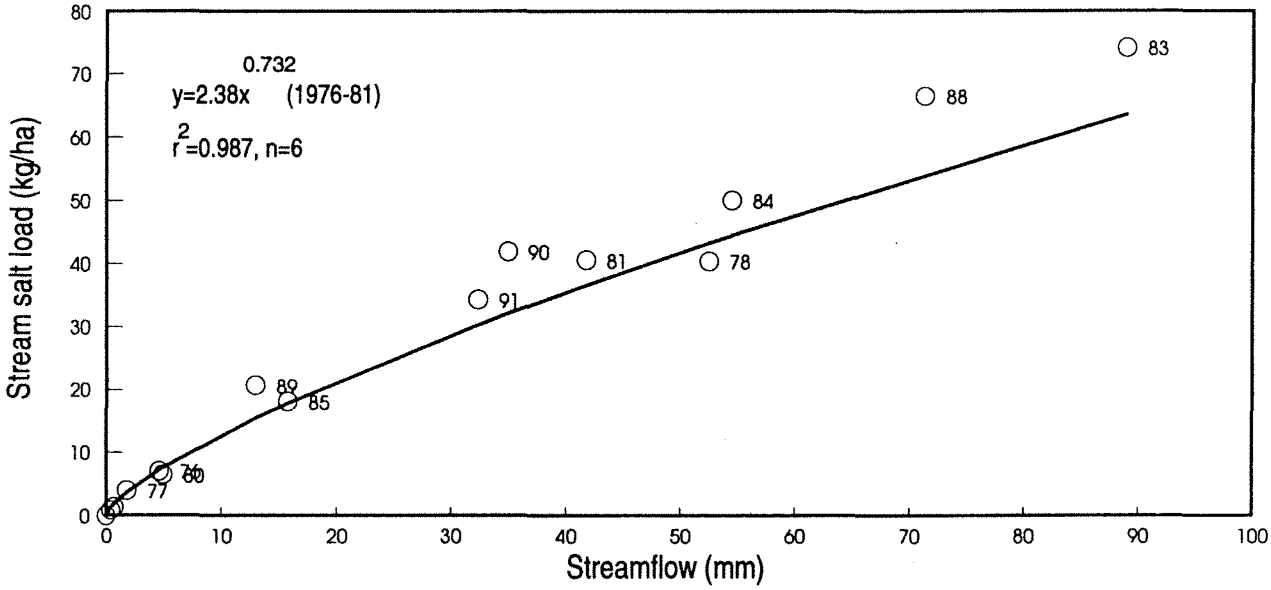

April Road South
y=-354.5+0.462x (1976-81)
r2=0.924, n=6
Annual streamflow (mm)
Annual rainfall (mm)

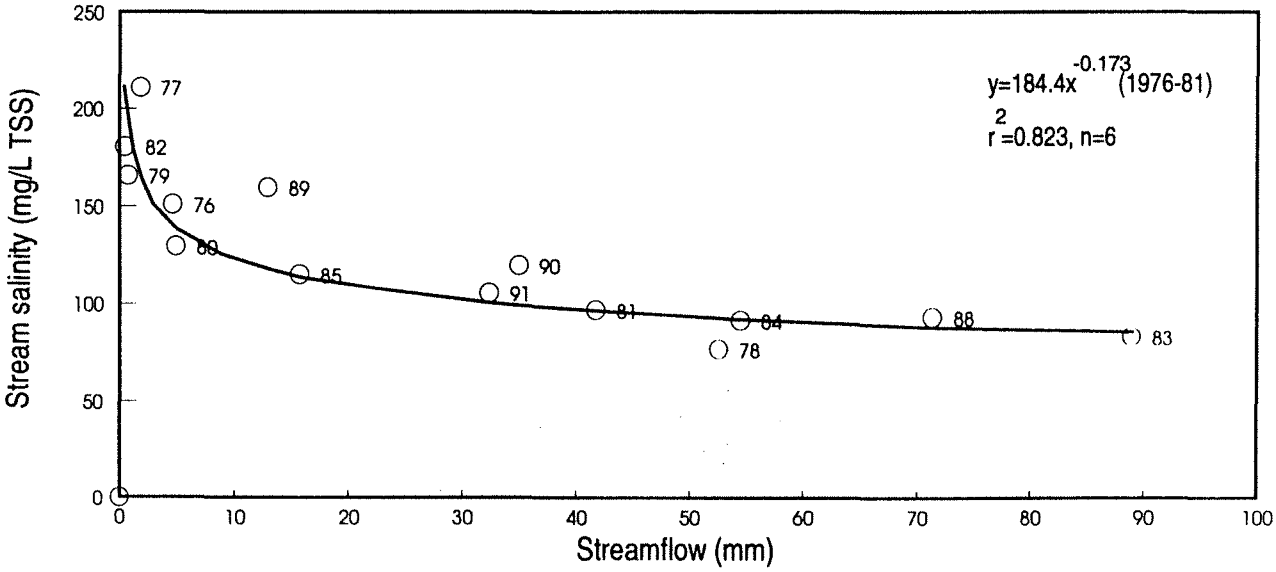

y=3.745x 0.763 (1976-81)
r2=0.0.976, n=6
Stream salt load (kg/ha)
Streamflow (mm)


y=395.08x-0.248 (1976-81)
r2=0.81, n=6
Stream salinity (mg/L TSS)
Streamflow (mm)

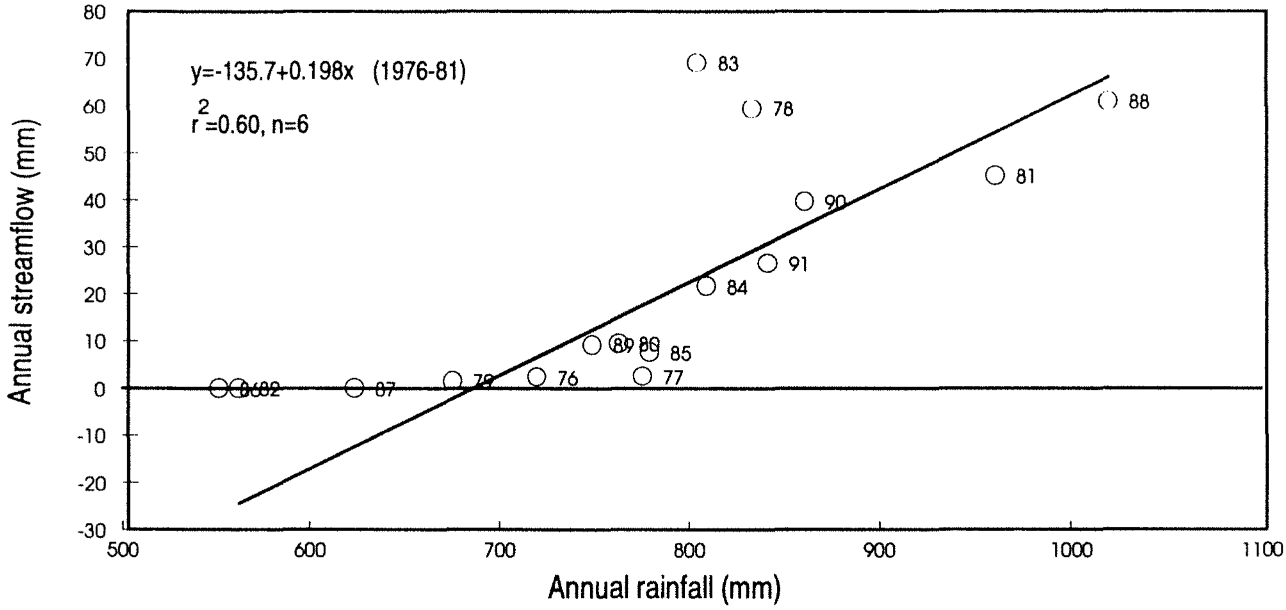
Yerraminnup South

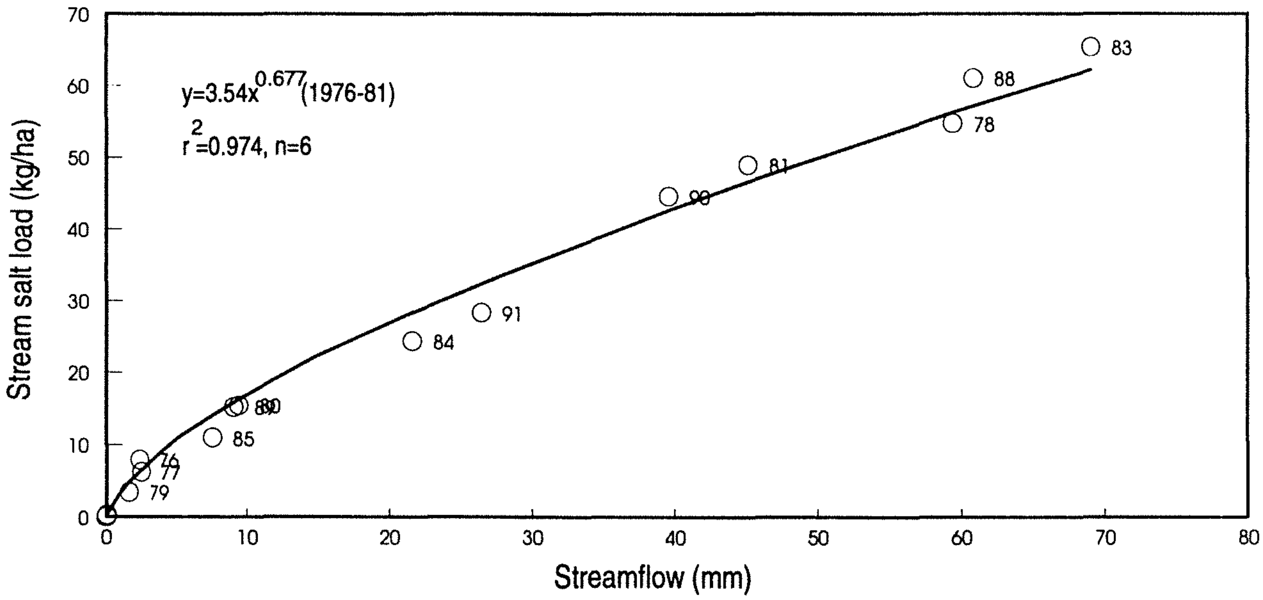


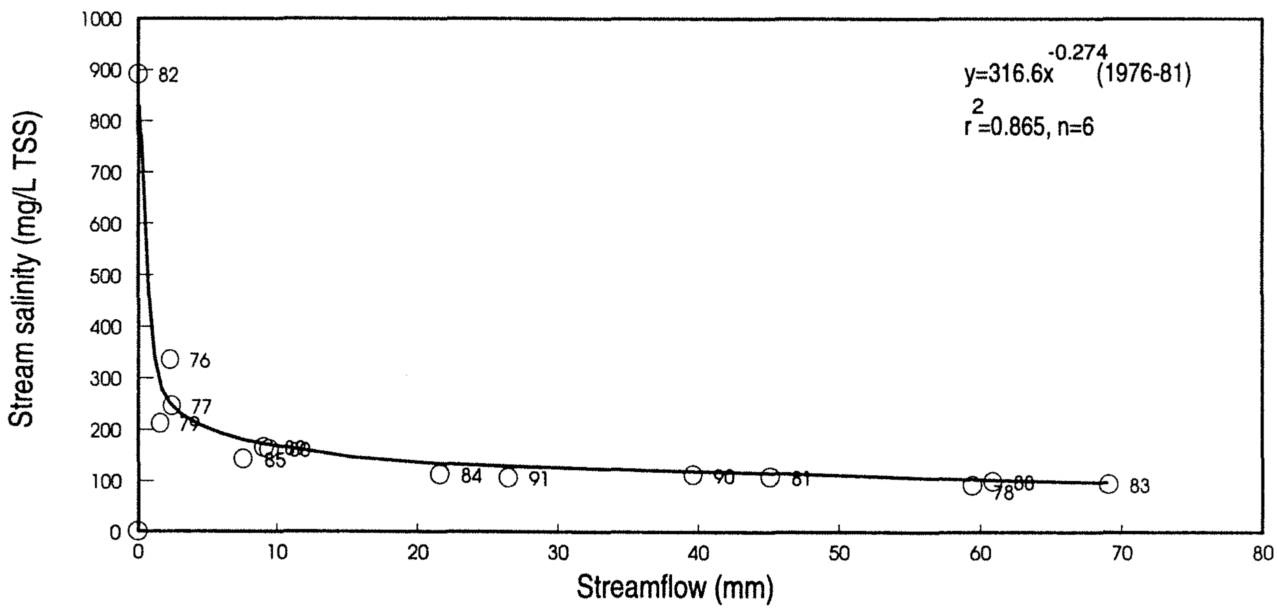




Yerraminnup North

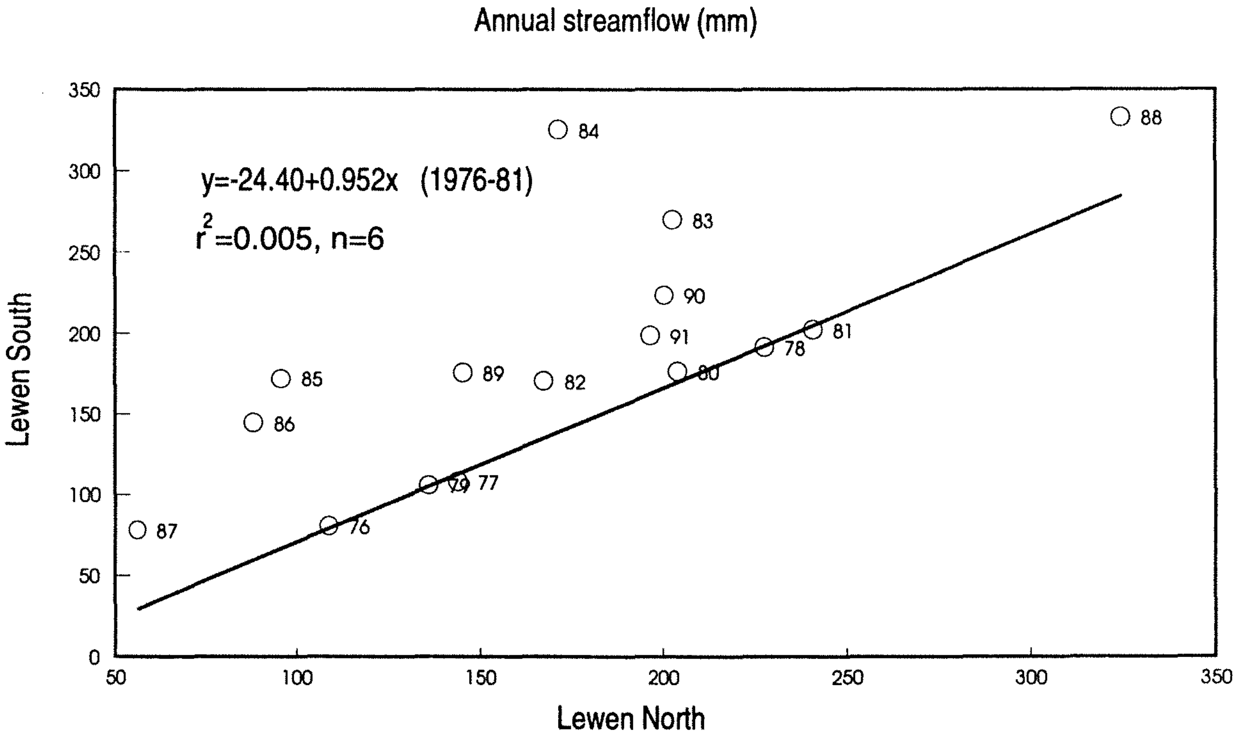




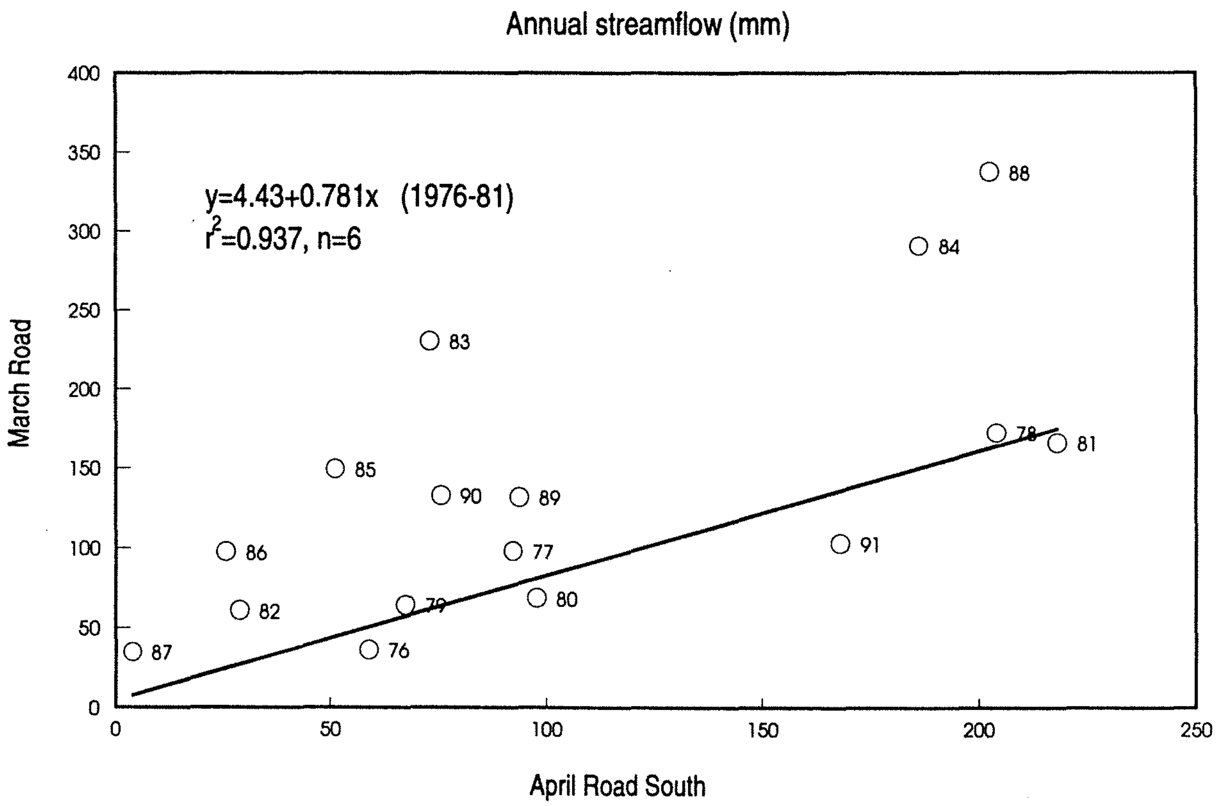


APPENDIX D

Relationships between streamflows of treated and control catchments

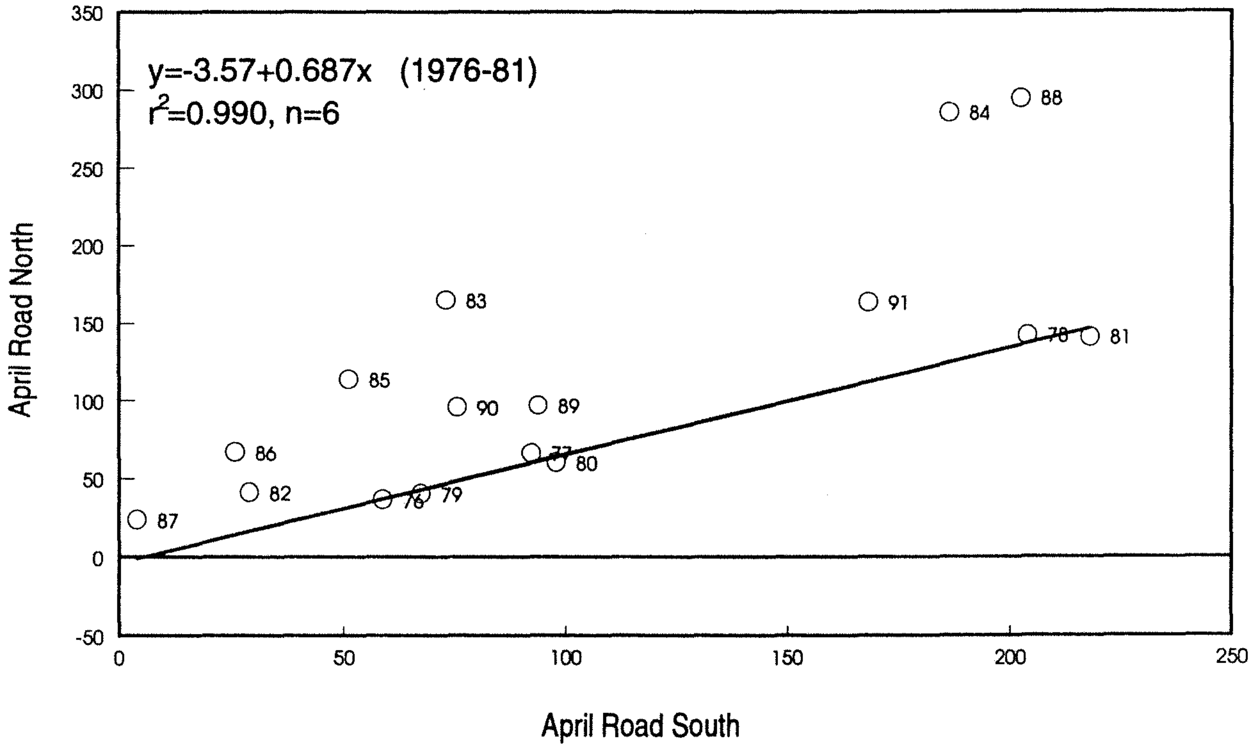


Annual streamflow (mm)
y=-24.40+0.952x (1976-81)
r2=0.005, n=6
Lewen South
Lewen North
0
50
100
150
200
250
300
350
84
88
83
90
91
81
78
80
85
89
82
86
79
77
87
76

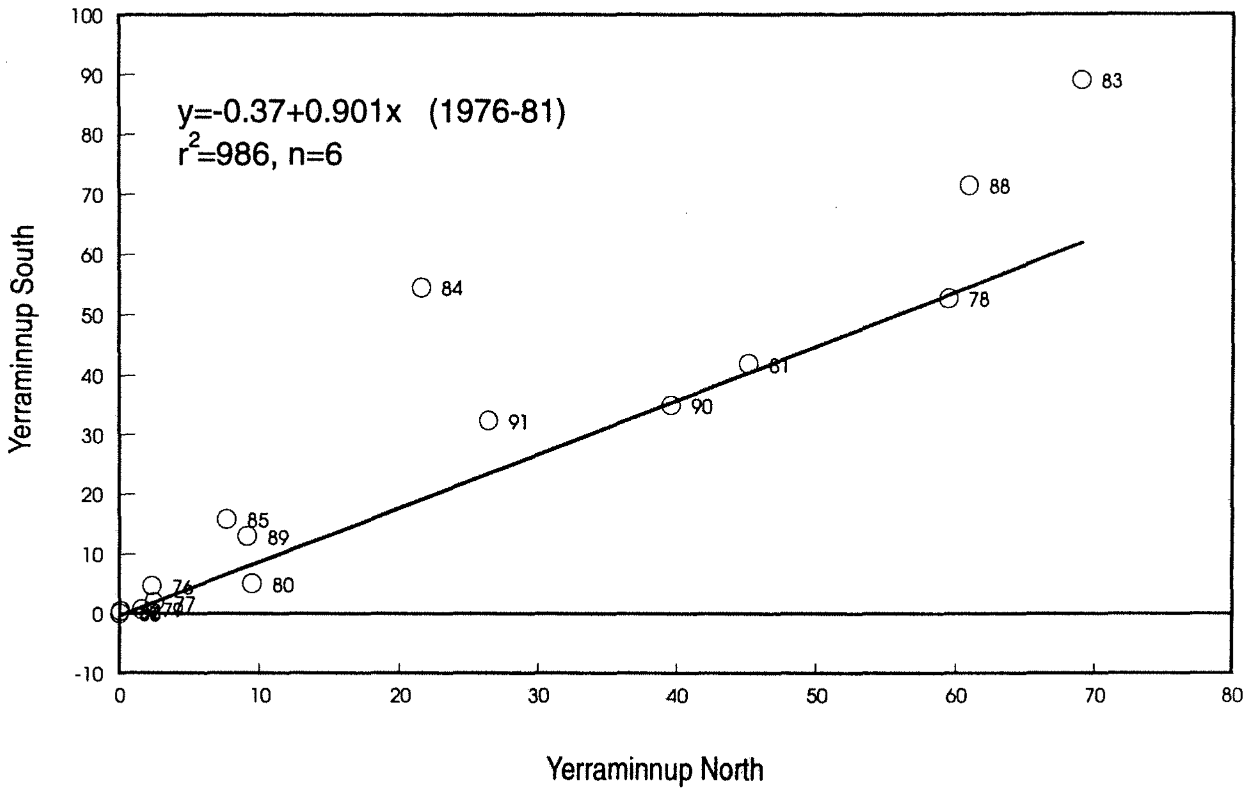


Annual streamflow (mm)
y=4.43+0.781x (1976-81)
r2=0.937, n=6
March Road
April Road South
0
50
100
150
200
250
300
350
400
88
84
83
78
81
85
90
89
86
77
91
82
79
80
87
76

Annual streamflow (mm)

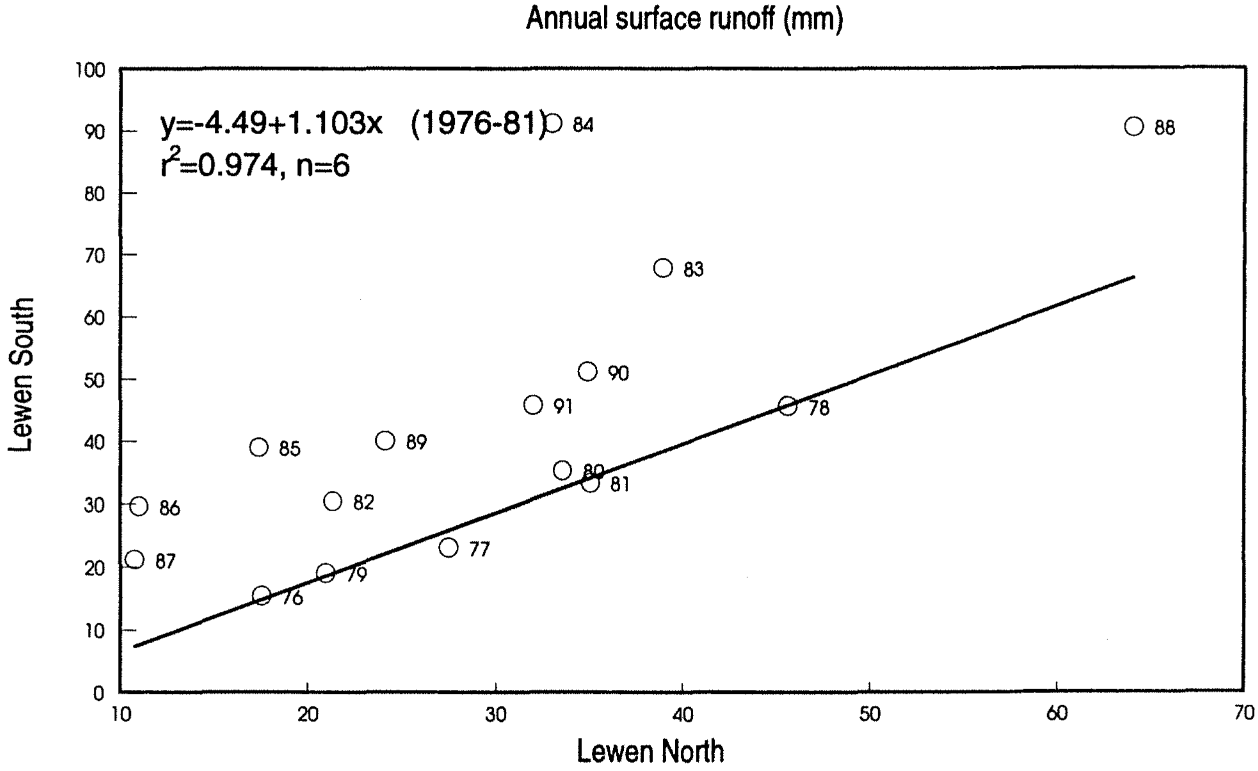


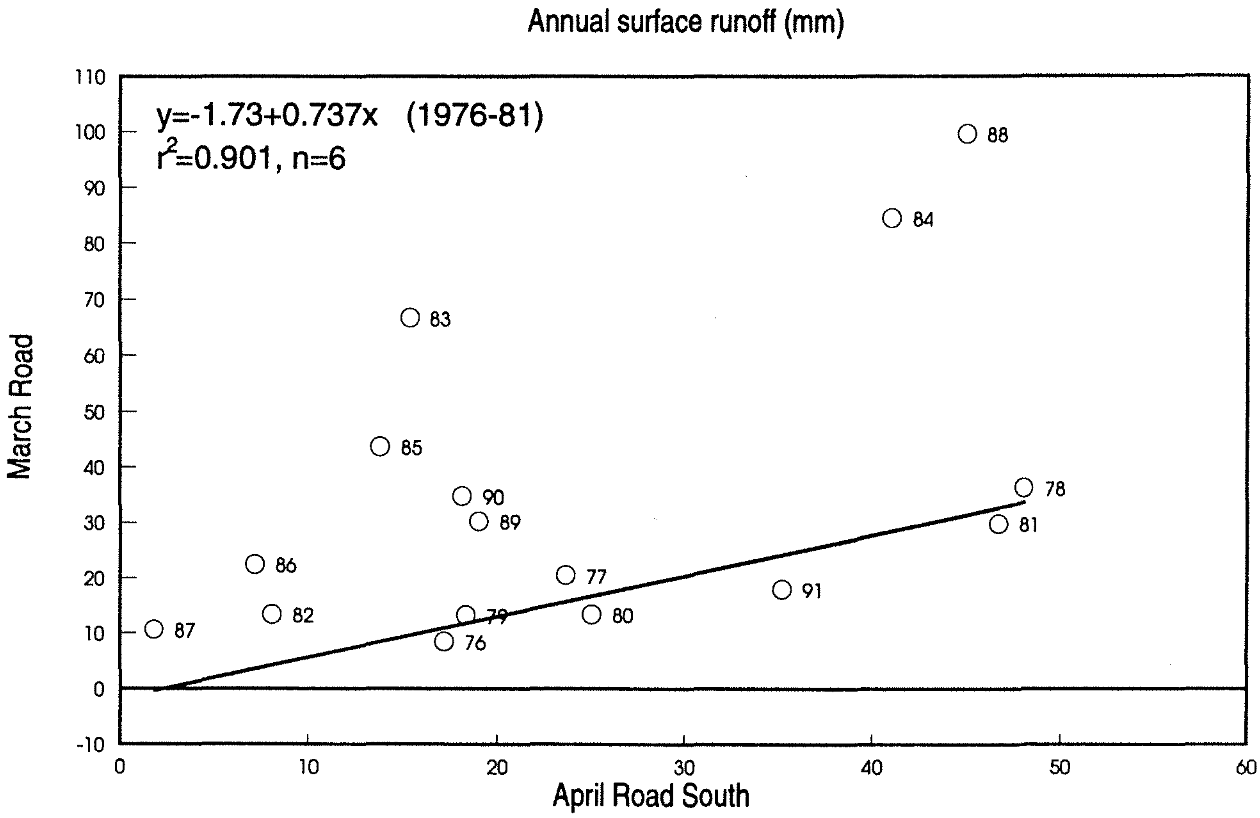
Annual streamflow (mm)



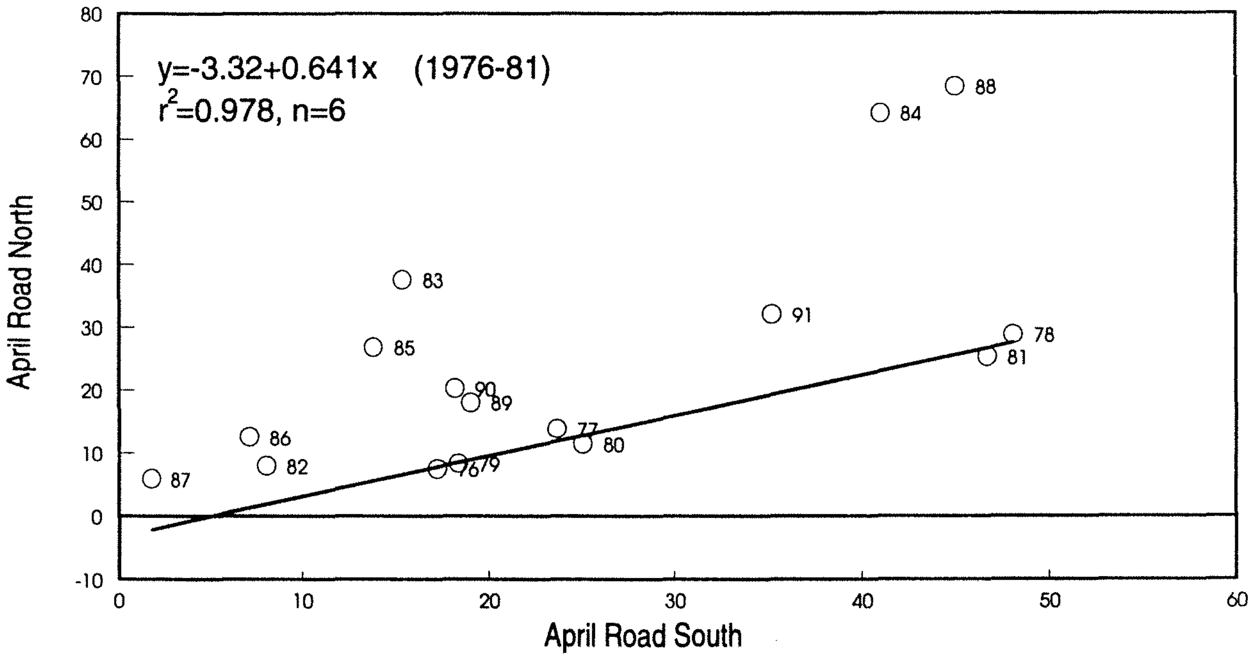
APPENDIX E

Relationships for surface runoff and base flow components between treated and control catchments

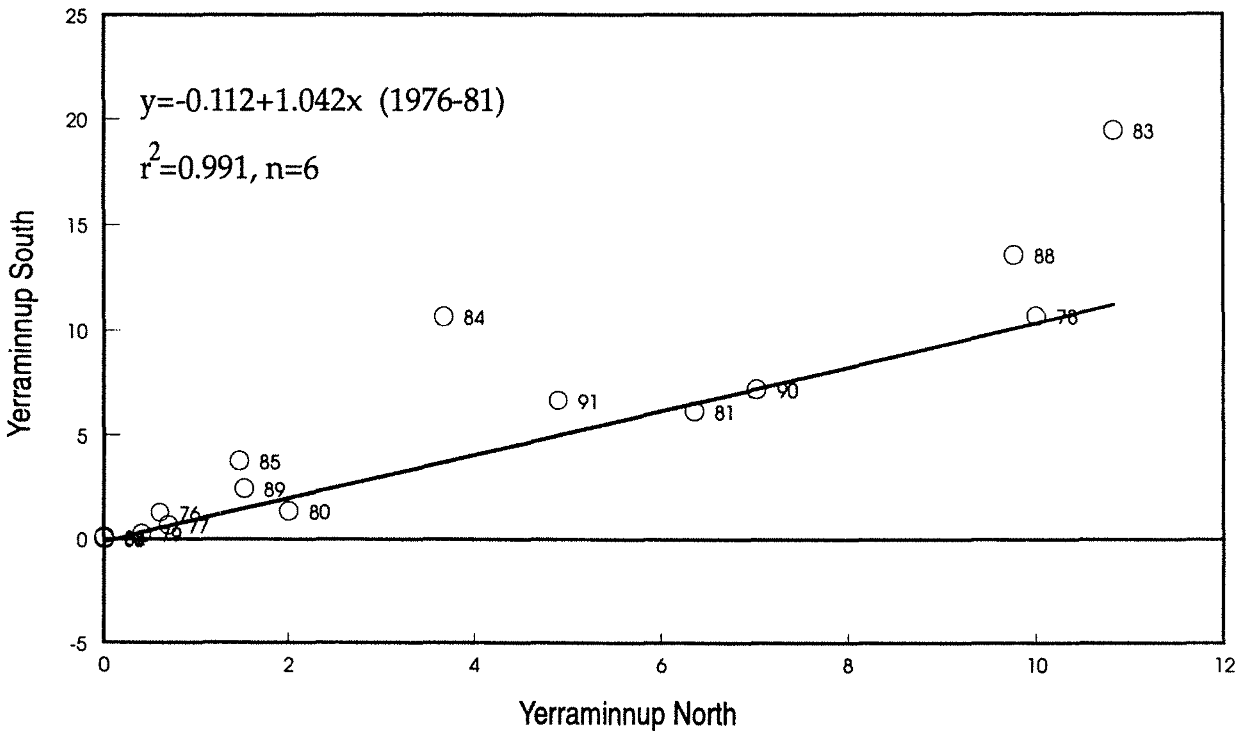

Annual surface runoff (mm)
y=-4.49+1.103x (1976-81)
r2=0.974, n=6
Lewen South
Lewen North
84
88
83
90
91
78
85
89
80
81
86
82
77
87
79
76
0
10
20
30
40
50
60
70
80
90
100


Annual surface runoff (mm)
y=-1.73+0.737x (1976-81)
r2=0.901, n=6
March Road
April Road South
88
84
83
85
90
89
78
81
86
77
91
87
82
79
80
76
-10
0
10
20
30
40
50
60
70
80
90
100
110

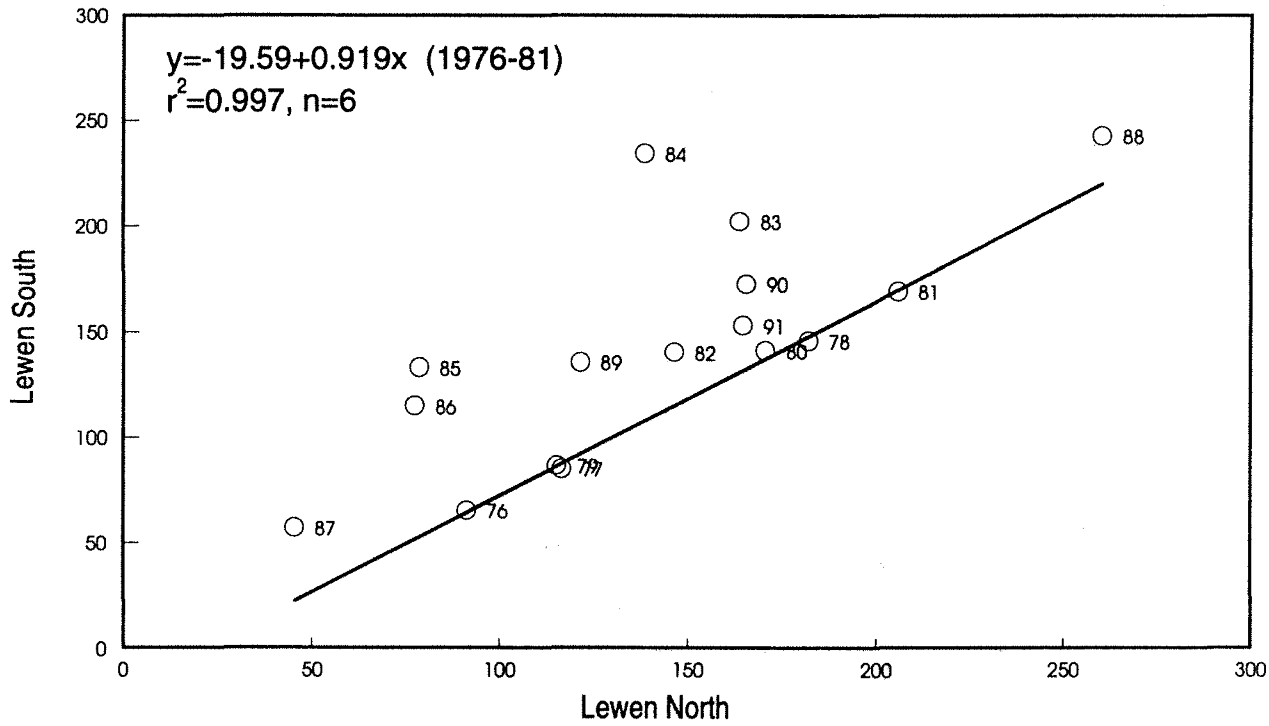
Annual surface runoff (mm)



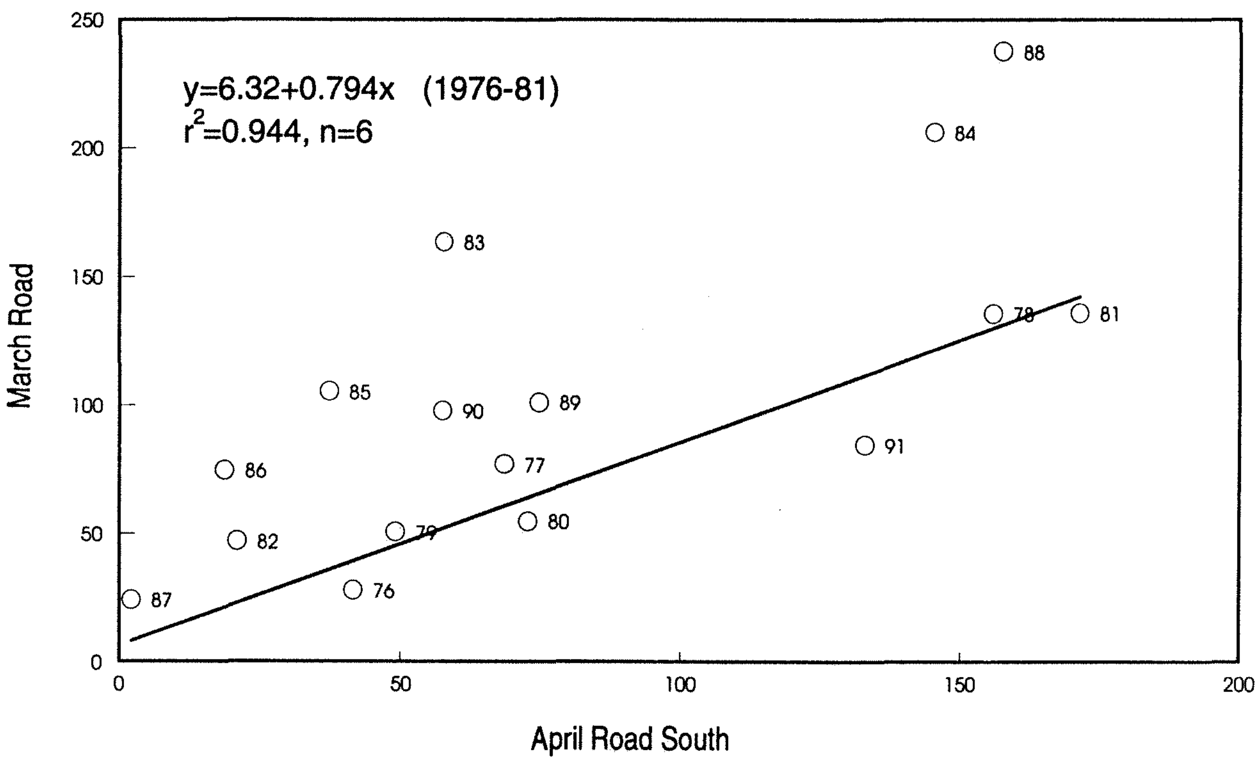
Annual surface runoff (mm)

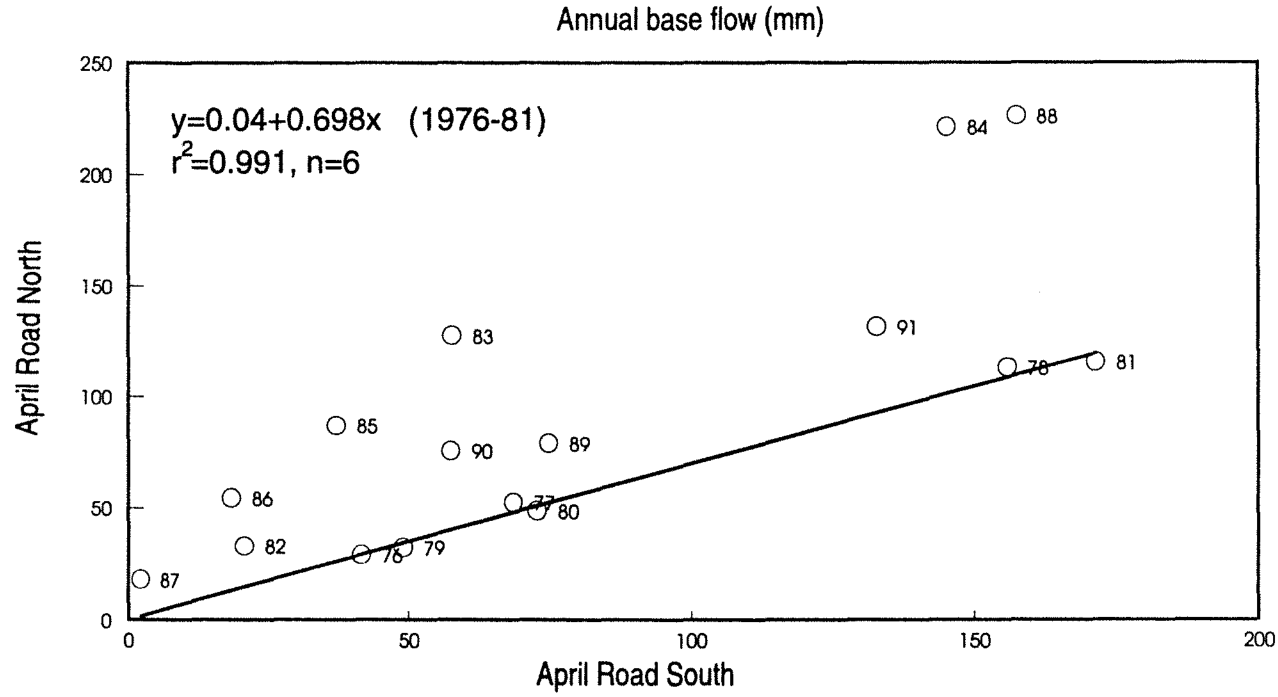


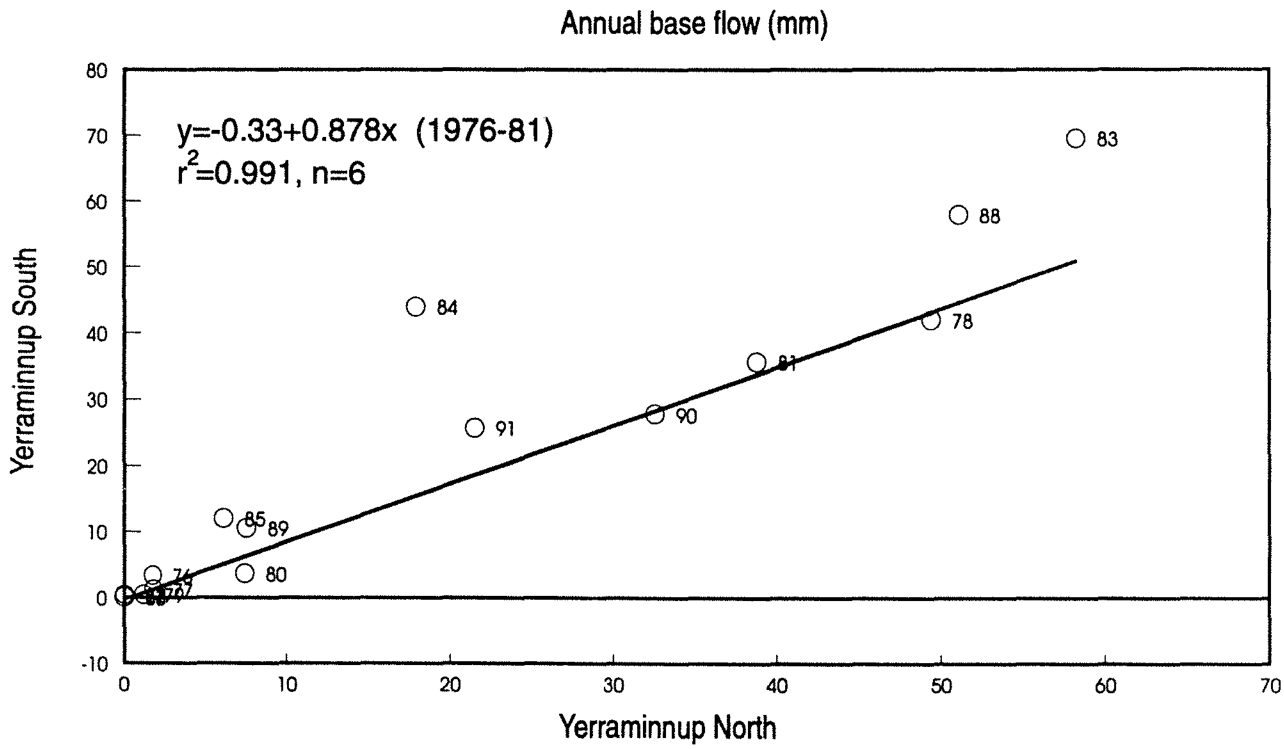
Annual base flow (mm)



Annual base flow (mm)




Annual base flow (mm)
y=0.04+0.698x (1976-81)
r^2=0.991, n=6
April Road North
April Road South
84
88
83
91
78
81
85
90
89
86
77
80
82
76
79
87
0
50
100
150
200
250


Annual base flow (mm)
y=-0.33+0.878x (1976-81)
r^2=0.991, n=6
Yerraminnup South
Yerraminnup North
83
88
84
78
81
91
90
85
89
80
0
10
20
30
40
50
60
70
80
-10

APPENDIX F

The computer programme

```
C     THIS PROGRAM IS WRITTEN TO DETERMINE STREAM SALINITY,
C     STREAM SALT LOAD AND STREAM FLOW COMPONENTS
C      water year
      DIMENSION FLOWMR(20,15),
     + FLOWMB(20,15), FLOWMT(20,15), SALTMT(20,15),
     + RANM(20,15),
     + RANM1(15), RAIN(9000), TSST(9000), SALTT(9000),FLOWT(9000),
     + FLOWB(9000), FLOWR(9000),IMNTH(9000),
     + IYEAR(9000),
     + FLOWDB(9000),
     + IDAY(9000) ,sflowmt(20),sflowmr(20),flowpk(20),
     + sflowmb(20),ssaltmt(20),tssct(20),
     + iyer(20),sranmt(20)
      data a/0.65/
      CHARACTER*80 DUMMY
      CHARACTER*60 FILNAM1
      CHARACTER*60 FILNAM2
 110  CONTINUE
      WRITE(*,210)
 210  FORMAT(1X,'**********************************************',/,
     +       1X,'WHAT IS THE NAME OF THE FLOW   INTPUT FILE  ',/,
     +       1X,'-------------------------------------------',/)
      READ(*,*,ERR=110) FILNAM1
      OPEN(UNIT=11,FILE=FILNAM1, STATUS='OLD')
 510  CONTINUE
      WRITE(*,610)
 610  FORMAT(1X,'**********************************************',/,
     +       1X,'WHAT IS THE CATCHMENT AREA (HA)              ',/,
     +       1X,'-------------------------------------------',/)
      READ(*,*,ERR=510) area
      area=area/100
 310  CONTINUE
      WRITE(*,410)
 410  FORMAT(1X,'**********************************************',/,
     +       1X,'WHAT IS THE NAME OF THE OUTTPUT FILE  ',/,
     +       1X,'-------------------------------------------',/)
      READ(*,*,ERR=310) FILNAM2
      OPEN(UNIT=21,FILE=FILNAM2, STATUS='NEW')
C
C
      READ(11,31) DUMMY
      READ(11,31) DUMMY
      READ(11,31) DUMMY
      READ(11,31) DUMMY
      READ(11,31) DUMMY
      READ(11,31) DUMMY
      READ(11,31) DUMMY
 31   FORMAT(A80)
```

```
C
      KK=0
      READ(11,41) IDAY(1), IMNTH(1), IYEAR(1), SALTT(1),
     + FLOWT(1), TSST(1), RAIND
      DO 10 J=2,500000
      READ(11,41,END=99) IDAY(J),IMNTH(J), IYEAR(J), SALTT(J),
     + FLOWT(J),
     + TSST(J), RAIND
41    FORMAT(16X,i2,1X,I2,1X,I4,9X,F10.4,12X,F10.4,10X,F12.4,
     + 4X,F8.1,
     + 4X,F8.1)
      KK= KK+1
      RAIN(J) = RAIND
10    CONTINUE
99    CONTINUE
C
C     SEPERATION OF BASE FLOW AND DIRECT RUNOFF
C
      N=0
      DO 60 J=2, kk
      IF(FLOWT(J).EQ.0.0) GO TO 70
      FLOWR(J)=A*FLOWR(J-1)+0.5*(1.0+A)*(FLOWT(J)-FLOWT(J-1))
      IF(FLOWR(J).LT.0.009) FLOWR(J)=0.0
      FLOWB(J)=FLOWT(J)-FLOWR(J)
C
111   FORMAT(3I5,12F10.2)
      GO TO 60
 70   CONTINUE
      FLOWR(J)=0.0
      FLOWB(J)=FLOWT(J)
60     CONTINUE
C
C
C     get monthly values
C     NK=0
      kky=1
c     iyear1=iyear(1)
      dumypk=flowt(1)
      DO 100 I=2, KK
      IDIFY = IYEAR(I)-IYEAR(I-1)
      IDIFF = IMNTH(I) - IMNTH(I-1)
        IF(FLOWT(I).NE.0.0) NK=NK+1
         if(flowt(i).gt.dumypk) dumypk=flowt(i)
C       SUM UP MONTHLY VALUES
C
       IF(IDIFF.EQ.0) THEN
       SUMSALTD=SUMSALTD+SALTT(I)
       SUMFLOWD=SUMFLOWD+FLOWT(I)
```

```
      SUMFLWDb= SUMFLWDb+ FLOWb(I)
      SUMFLWDR= SUMFLWDR+ FLOWR(I)
      SUMRAIND=SUMRAIND+RAIN(I)
      else
c      if(imnth1.le.3) imnt1=imnth1+12
       imnt1=imnth1
c     WRITE(21,71) Ky, imnt1
      SALTMT(kky,IMNT1)=SUMSALTD
      FLOWMT(kky,IMNT1)=SUMFLOWD
      FLOWMR(kky,IMNT1) = SUMFLWDR
      FLOWMb(kky,IMNT1) = SUMFLWDb
      RANM(kky,IMNT1) =SUMRAIND
61     FORMAT(10X,2I10, 10F10.4//)
      SUMSALTD=SALTT(I)
      SUMFLOWD=FLOWT(I)
      SUMFLWDR=FLOWR(I)
      SUMFLWDb=FLOWb(I)
      SUMRAIND=RAIN(I)
C       SMFLTSY=SUMFLTSS
      SUMFLTSS=FLOWT(I)*TSST(I)/1000.0
      IMNT  = IMNTH1
      IYER(kky) = IYEAR1
      IMNTH1 = IMNTH(I)
      IYEAR1 = IYEAR(I)
      ENDIF
      IF(IDIFY.EQ.0) GO TO 100
      flowpk(kky)=dumypk/area
      dumypk=0.0
      kky=kky+1
100    continue
c     ky=ky-1
C      SUM UP ALL MONTHLY VALUES
C
      do 200 ky=1, kky
c     WRITE(21,71) kKy, imnt1
      NK=0
      SFLOWMT1=0.0
      SFLOWMR1=0.0
      SFLOWMb1=0.0
      SSALTMT1=0.0
      SRANMT1 =0.0
      SUMFLTSY1=0.0
      DO 30 II=4, 12
      SFLOWMT1 = SFLOWMT1+ FLOWMT(ky,II)
      SFLOWMR1 = SFLOWMR1+ FLOWMR(ky,II)
      SFLOWMb1 = SFLOWMb1+ FLOWMb(ky,II)
      SSALTMT1 = SSALTMT1+ SALTMT(ky,II)
      SRANMT1 = SRANMT1+ RANM(ky,II)
```

```
30     CONTINUE
c
c
       DO 80 II=1, 3
       SFLOWMT1 = SFLOWMT1+ FLOWMT(ky+1,II)
       SFLOWMR1 = SFLOWMR1+ FLOWMR(ky+1,II)
       SFLOWMb1 = SFLOWMb1+ FLOWMb(ky+1,II)
       SSALTMT1 = SSALTMT1+ SALTMT(ky+1,II)
       SRANMT1 = SRANMT1+ RANM(ky+1,II)
80      CONTINUE
      SFLOWMT(ky) = SFLOWMT1
      SFLOWMT(ky) = SFLOWMT1
      SFLOWMR(ky) = SFLOWMR1
      SFLOWMb(ky) = SFLOWMb1
      SSALTMT(ky) = SSALTMT1
      SRANMT(ky) = SRANMT1
      IYEAR1=IYEAR(I)
c     ky=ky+1
c     IMNTH1=IMNTH(I)
200    CONTINUE
71     FORMAT(1X, 2I10, 12F10.2)
       do 300 i=1,kky-1
       if(sflowmt(i).ne.0.0) then
        tssct(i)=ssaltmt(i)*1000.0/sflowmt(i)
       else
        tssct(i)=0.0
       endif
       WRITE(21,71) i,IYER(i), sranmt(i), SFLOWMT(i)/area,sflowmr(i)
     +  /area, sflowmb(i)/area, ssaltmt(i)*10/area,tssct(i),flowpk(i)
       smrn=smrn+sranmt(i)
       smft=smft+sflowmt(i)/area
       smfr=smfr+sflowmr(i)/area
       smfb=smfb+sflowmb(i)/area
       smst=smst+ssaltmt(i)*10/area
300     continue
       write(21,81)
81      format(//)
       write(21,91) smrn,smft,smfr,smfb,smst
91      format(21x, 12f10.2)
c
c       call write1(iyer,flowmt,kky)
c
c       call write1(iyer,flowmr,kky)
c
c       call write1(iyer,flowmb,kky)
c
c       call write1(iyer,ranm,kky)
c
```

```
      STOP
      END
c
c     new subroutine
c
      subroutine write1(iyer,flowmr,kky)
c
      dimension iyer(20), flowmr(20,15), sum(20)
c
      write(21,121)
121    format(//)
      do 20 i=1,12
        sum1=0.0
        do 30 j=1, kky-1
        sum1=sum1+flowmr(j,i)
30     continue
      sum(i)=sum1
      sum1=0.0
20     continue
      do 10 i=1,kky-1
      write(21,111) iyer(i),( flowmr(i,j),j=1,12)
111    format(1x, i10, 12f8.2)
10     continue
      write(21,121) (sum(i),i=1,12)
131    format(11x,12f8.2)
      return
      end
```