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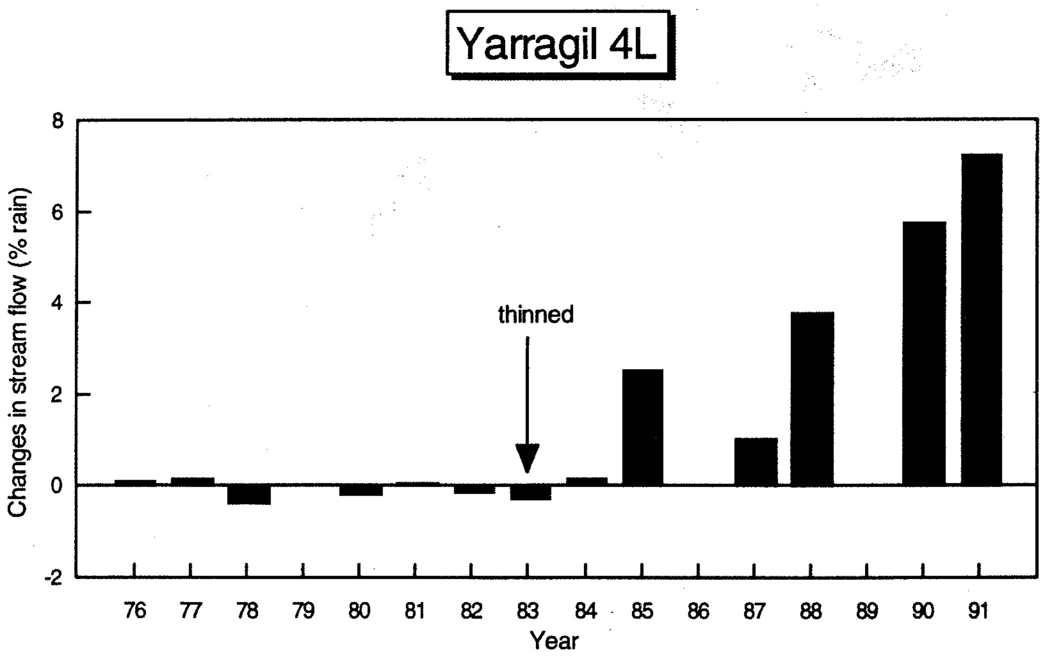
EFFECTS OF FOREST THINNING ON STREAMFLOW AND SALINITY AT YARRAGIL CATCHMENT IN THE INTERMEDIATE RAINFALL ZONE OF WESTERN AUSTRALIA



Report No. WS140
September 1994

Water Authority
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Water Resources Directorate
Surface Water Branch

EFFECTS OF FOREST THINNING ON STREAMFLOW AND SALINITY AT YARRAGIL CATCHMENT IN THE INTERMEDIATE RAINFALL ZONE OF WESTERN AUSTRALIA

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SUMMARY

The jarrah forest of south-western Australia produces low water yields (average water yield is 7% of annual rainfall). Thinning as a forest management technique has the potential to increase streamflow, which can be harnessed for water supply, and increase wood production. Catchments in the High Rainfall Zone (>1100 mmyr^{-1}) are essentially free of salinity risk while catchments in the Intermediate Rainfall Zone (IRZ) are at risk of salinization. This report describes the impact on stream salinity and stream yield of thinning a small (1.26 km^2) jarrah forest catchment located in the IRZ.

In 1976, a number of small experimental catchments were established in the Yarragil catchment located in the south-west of Western Australia. The Yarragil catchment lies mainly in the Intermediate Rainfall Zone (900-1100 mmyr^{-1}) and partly in the High Rainfall Zone. These catchments have been monitored to assess the effects of thinning on streamflow, stream salinity, groundwater levels and groundwater salinity.

In 1983, the Yarragil 4L site was thinned such that 20% of canopy cover was retained. Yarragil 4X was selected as a control catchment. The measurements from 4L and 4X were compared to account for climatic variation in assessing the response of 4L to thinning.

Groundwater levels at 4L increased relative to 4X, in bores located at both valley and mid-slope locations. In the valley area, groundwater levels at 4L increased by 4.4 m relative to 4X. Groundwater salinity at 4L showed no apparent trend or response to thinning.

Prior to treatment, annual streamflow averaged 0.5% of annual rainfall. Stream yield at 4L increased greatly following thinning. The first increase in stream yield occurred two years after thinning. Stream yield continued to increase and in 1992 the stream yield was 10.5% of annual rainfall. Salt flow also increased as a result of thinning. However, the increases in streamflow were sufficient to dilute this additional salt load such that flow weighted annual stream salinity (salinity) was generally lower than pre-treatment levels.

Therefore, the result of thinning 4L was to greatly increase quantity (stream yield) without reducing quality (*i.e.* stream salinity not significantly increased). The maximum daily stream salinity remained within the limits of potability. Thinning did not compromise either the value of the catchment as a water resource or the environmental value of the stream.

The results of this study, to date, indicate that thinning catchments in the IRZ similar to Yarragil 4L can greatly increase stream yield and not significantly increase stream salinity. Such catchments would have similar groundwater hydrology to 4L, low soil salt storage and low groundwater salinity. Leaf area or stem density would need to be thinned to the same levels as 4L if a similar response was required.

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1 INTRODUCTION

Water and timber are two of the most important products of the northern jarrah forest of Western Australia (Stoneman, 1990). Thinning as a forest management technique has the potential to both increase streamflow, which can be harnessed for water supply, and increase wood production.

The jarrah forest of south-western Australia produces low water yields (average water yield is 7% of annual rainfall). The low water yields are largely attributed to the large soil water storage available for continuous use by forest vegetation. Transpiration is the major loss component in the water balance of the jarrah forest (Ruprecht and Stoneman, 1993). Hence, a reduction in forest cover which decreases interception and transpiration can significantly increase water yields and recharge to the groundwater.

The jarrah forest of south western Australia has both significant groundwater and streamflow systems (Stoneman, 1993). The interaction of these systems is important as throughflow from perched, shallow sub-surface groundwater systems significantly contributes to streamflow (Ruprecht and Schofield, 1989). Rising groundwater levels as a consequence of agricultural clearing, in areas of intermediate to low rainfall (<1100 $mmyr^{-1}$), have been shown to cause large increases in stream salinity (Schofield *et al.*, 1988). Salt stored in the soil profile may be dissolved and brought to the surface by rising groundwater levels and associated capillary action. This can result in salinization of the surface soil and increased salt input to the stream in surface runoff and saline throughflow (Steering Committee, 1989). Another mechanism responsible for secondary soil salinization is deep saline aquifers. For instance, it has been found that in the Collie River Basin that the deeper aquifer contributed 10 per cent of the water but 90 per cent of the soluble salts (Conacher, 1990).

The area served by the Metropolitan Water Supply (MWS) system includes the Perth metropolitan area as well as Mandurah and other nearby towns. The Helena Reservoir at Mundaring, which supplies the Goldfields and Agricultural Water Supply (G&AWS) is connected to the MWS system. Population growth in the Perth and Mandurah area and on the G&AWS under a 'most-likely' population and water use scenario means that an additional 100 million kilolitres (or 100 gigalitres (Gl)) will be required by 2010. This 100 Gl is equivalent to 40% of the existing supply capacity (Stokes and Stone, 1993). Stoneman and Schofield (1989) reported that the cost of producing this water by forest thinning is likely to be less than the cost of alternative water resource developments. Research into obtaining maximum yield from water supply sources while minimising financial, environmental and social costs is therefore a vital part of planning to meet the future demand for water.

A possible option in meeting the growing demand for water resources is thinning the forests of low yielding catchments to increase streamflow. The suitability of different catchment treatments is dependent on the balance between the increase of water yield achieved and other impacts such as changes in water quality and effect on the environment. This report describes the impact on streamflow and salinity resulting from the thinning of a small (1.26 km^2) jarrah forest catchment.

2 SITE DESCRIPTION AND EXPERIMENTAL METHOD

2.1 Site Description

The experimental catchments are located in the south-west of Western Australia, about 25 kilometres south east of Dwellingup (Fig. 1). These experimental catchments are sub-catchments of the Yarragil Brook catchment which is located in the Northern Jarrah Forest. The Yarragil catchment lies mainly in the Intermediate Rainfall Zone (900-1100 $mmyr^{-1}$) and partly in the High Rainfall Zone (>1100 $mmyr^{-1}$). This region has a Mediterranean type of climate with cool, wet winters and hot, dry summers. The forest is uneven aged having been logged mainly between 1920 and 1945 (Stoneman, 1993). The regrowth consists of dense stands of jarrah (*Eucalyptus marginata*).

2.1.1 Yarragil 4L Catchment

The Yarragil 4L (4L) catchment has an area of 1.26 km^2 and is located quite high in the local landscape. The 4L catchment has a gently undulating landscape with relatively subdued incision of the valley. The soils are mainly of the lateritic gravel (72%) and the lateritic duricrust types (22%) (Stoneman, 1990). This soil profile is deep, with the depth to bedrock ranging from 24 m at the ridge to 36 m in the valley (Stoneman, 1993). Long term average annual rainfall is 1120 mm (1926-79) (Hayes and Garnaut, 1981) and soil salt storage is low at 6.5 kgm^{-2} TSS (Herbert *et al.*, 1978).

2.1.2 Yarragil 4X Catchment

Yarragil 4X was used as a control catchment so that the response of 4L to the thinning could be determined. The use of a control catchment is expected to account for any changes in behaviour due to climatic variations. The 4X catchment has an area of 2.70 km^2 and has similar slopes to the 4L catchment. Soil types are more varied than 4L being composed of lateritic duricrust (20%), lateritic gravels (32%), gravelly sands(22%) and sandy valley (19%) (Stoneman, 1990). Long term average annual rainfall is 1070 mm (1926-79) (Hayes and Garnaut, 1981) and the soil salt storage of 24.5 kgm^{-2} TSS (Herbert *et al.*, 1978) is considerably greater than at 4L.

2.2 Experimental Design

The Yarragil 4L catchment was selected to be thinned. Streamflow, groundwater and rainfall were measured from 1976 at both the 4L and 4X catchments (Fig. 2). Streamflow was determined from continuous stage measurements at V-notch weirs and stream salinity from water quality samples while continuous monitoring was performed at the 4X catchment from December 1990. Groundwater levels and salinity were monitored at intervals generally less than a month in duration. The bore hole transect in each catchment consisted of three bores located at valley, mid-slope and ridge locations (Fig. 2). Rain gauges measured daily rainfall although prior to 1984 the readings were taken at weekly intervals (Fig. 2).

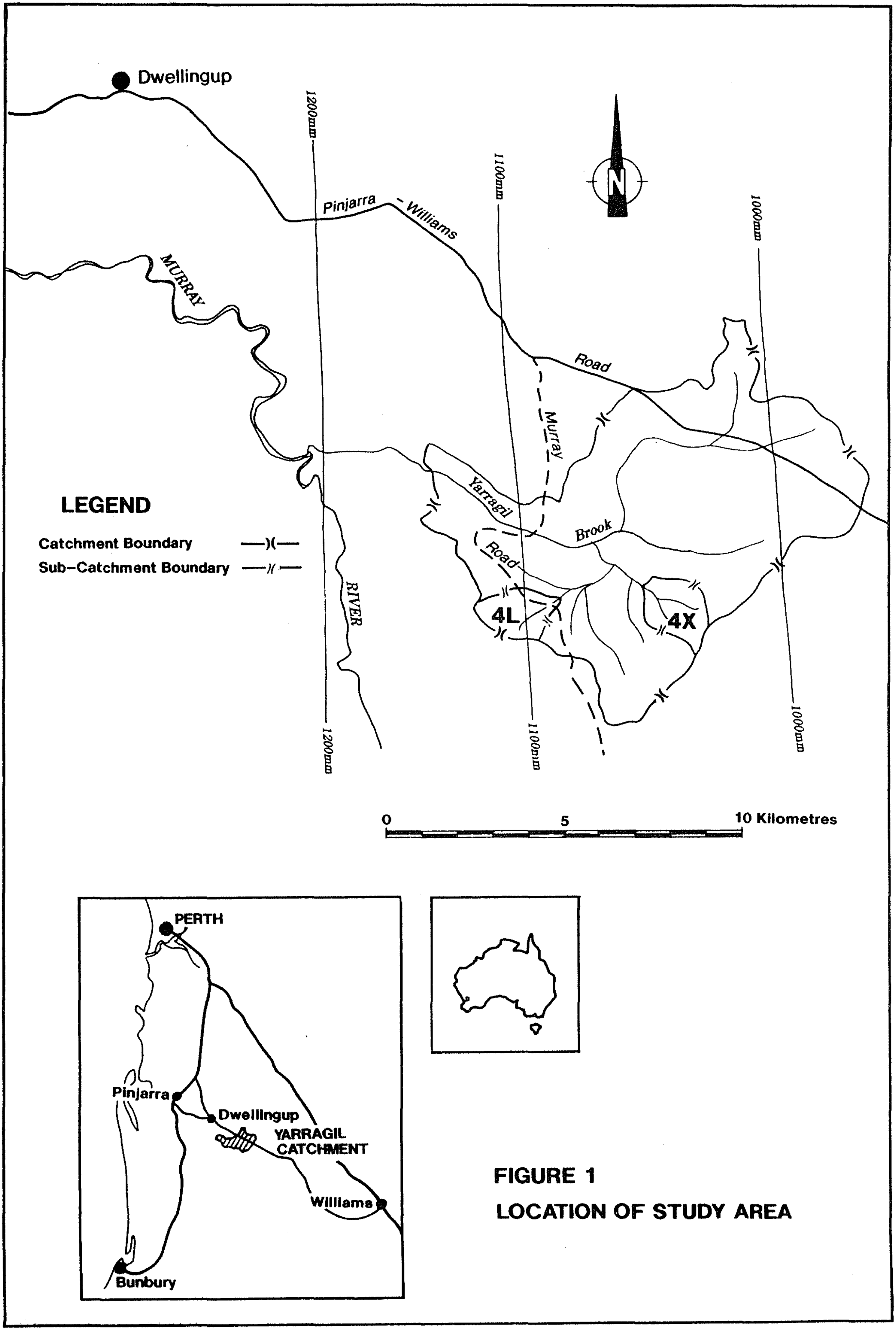

FIGURE 1
LOCATION OF STUDY AREA

2.2.1 Thinning of the 4L catchment

Logging of the catchment was undertaken between February and May 1983 such that 20 per cent of canopy cover was retained. Forest density was reduced from a basal area of 35 m^2ha^{-1} to 11 m^2ha^{-1}. Two thirds of the logging slash was burnt in the winter of 1983 with the remainder burnt in winter 1984. A fuel reduction burn in the spring of 1984 resulted in crown scorch over about 10 per cent of the catchment with virtually 100 per cent crown scorch sustained by those trees in the valley portion. Over the summer of 1984/1985, stump and ground coppice was poisoned to ensure that the thinning had a long term effect on tree density in the catchment (Stoneman, 1990).

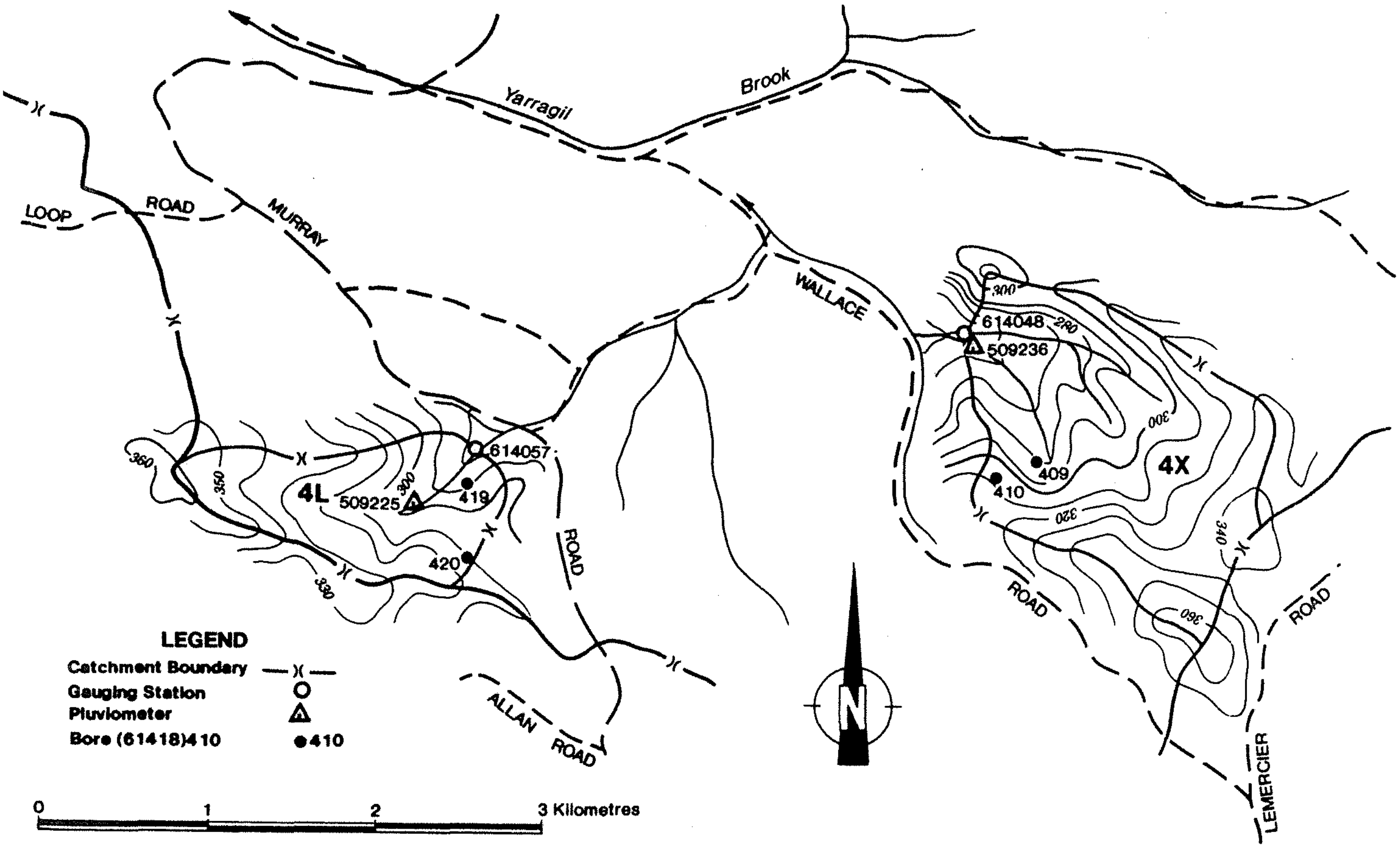

FIGURE 2 INSTRUMENT SETUP AT 4L AND 4X CATCHMENTS

3 GROUNDWATER LEVELS AND SALINITY

3.1 Groundwater Levels

The ridge bore holes at both the 4X and 4L catchments remained dry throughout the study period. Thus, only the valley and mid-slope bore holes were included in the analysis. Ritson *et al.* (1981) found the groundwater system at both sites was semi-confined.

Groundwater level was observed to be directly related to rainfall in the previous year (Fig. 3). Throughout the study period the rainfall for both the 4X and 4L catchments was typically below the long term average (Fig. 3a). On the occasions that rainfall exceeded the long term average the exceedance was relatively small (<12.7%). The groundwater levels at 4X showed a general downward trend over the study period which is probably due to the dry conditions. The 4L catchment followed a very similar trend during the pre-treatment period, reducing by more than 2 m from 1976 to 1982 (Fig. 3b).

The annual minimum groundwater level (or simply groundwater level) at 4L was compared to 4X (control). Following the thinning of 4L, groundwater levels increased relative to 4X (Fig. 3c) at both the valley and mid-slope locations. In 1992, the increase of groundwater level since 1983 at the 4L valley site was 4.4 m relative to 4X. The increase in groundwater level at 4L relative to 4X seems to have levelled out, by the end of the study period.

The actual groundwater level at 4L increased 2.3 m between 1983 and 1985 (Fig. 3b). The increasing trend in groundwater level at 4L appeared to have ceased between 1985 and 1988, but this was probably a response to the low rainfall of that period. Groundwater level at 4L started increasing again in 1988 as a result of higher rainfall in the period 1988 to 1992. By 1992, the groundwater level in the valley was at a depth of 1.45 m.

3.2 Groundwater Salinity

Herbert *et al.* (1978) reported soil salt storage calculated from soil cores taken from each bore. At 4L, the valley salt storage was 4.1 kgm^{-2} TSS and the mid-slope had 8.9 kgm^{-2} TSS. The 4X catchment contained considerably more salt with salt storage of 10.1 and 38.9 kgm^{-2} TSS at the valley and mid-slope bore holes, respectively.

Groundwater salinity at 4L had a maximum value of 354 mgL^{-1} TSS (Appendix A) which reflects the low salt storage. By comparison, the maximum groundwater salinity of 1426 mgL^{-1} TSS (Appendix A) at 4X reflects the higher salt storage. There was no apparent trend in the groundwater salinity at 4L nor was there any discernible response to thinning and the subsequent changes in groundwater levels.

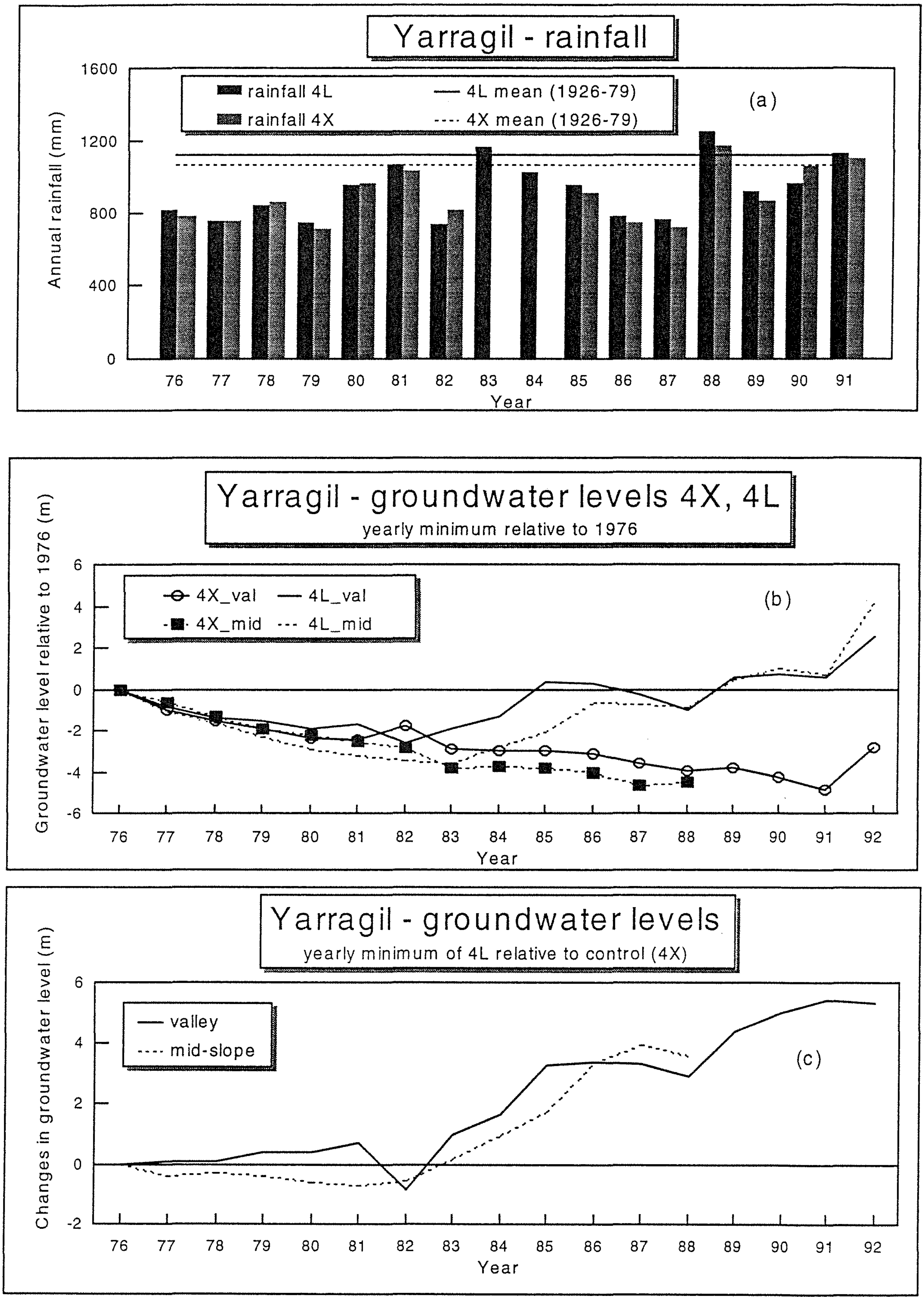

Figure 3 Response of groundwater level

4 STREAMFLOW AND SALINITY

4.1 Streamflow

4.1.1 Seasonal variations

Streamflow at Yarragil 4X generally commences in June and ends by December. By comparison, the streamflow from Yarragil 4L catchment was shorter in duration, beginning later and ending earlier (Fig. 4a). The volumes and peak flows of 4L were also less than 4X during the pre-treatment period. In response to the thinning, streamflow commenced earlier in the year. Streamflow peaked earlier and higher than at the control catchment (4X) and flow duration also increased (Fig. 4b, c). This change was obvious 5 years after the thinning (Fig. 4b) and continued to exist to the end of the study period (Fig. 4c). Prior to thinning, there was very little baseflow evident in the stream hydrograph. However, by 1993 there was obvious baseflow particularly in the later parts of the flow season.

4.1.2 Annual streamflow yield

The Yarragil 4L and 4X catchments receive similar rainfall being located within 5 kilometres of each other. Prior to treatment the average annual streamflow from 4L was much less than from 4X (Table 1). The average annual streamflow at 4X was 11.9 mm which was nearly three times the 4L streamflow of 4.5 mm. Within two years of the thinning of 4L, the streamflow exceeded that of the control catchment and continued to increase in the extent of the exceedance (Table 1).

A regression equation between annual streamflow and annual rainfall for Yarragil 4L was developed based on the pre-treatment period (1976-82). Figure 5 illustrates that, subsequent to thinning, significantly greater streamflow was yielded for a given amount of rainfall. The deviation from the pre-treatment relationship increased with time and by the end of the study period had neither begun to decline nor level out. High rainfall years accentuated this deviation by producing even greater streamflow for a given amount of rainfall.

4.1.3 Effects of thinning on streamflow

A regression equation between streamflow at 4L and 4X was developed based on the pre-treatment period (Fig. 6). This pre-treatment relationship was then used to predict streamflow at 4L as if it had not been thinned. The difference between this prediction and the actual streamflow measured at 4L was considered to be the change in streamflow attributable to thinning. Figure 6 illustrates the stable relationship between streamflow at the two catchments prior to thinning and the considerable changes in annual streamflow at 4L a few years after thinning.

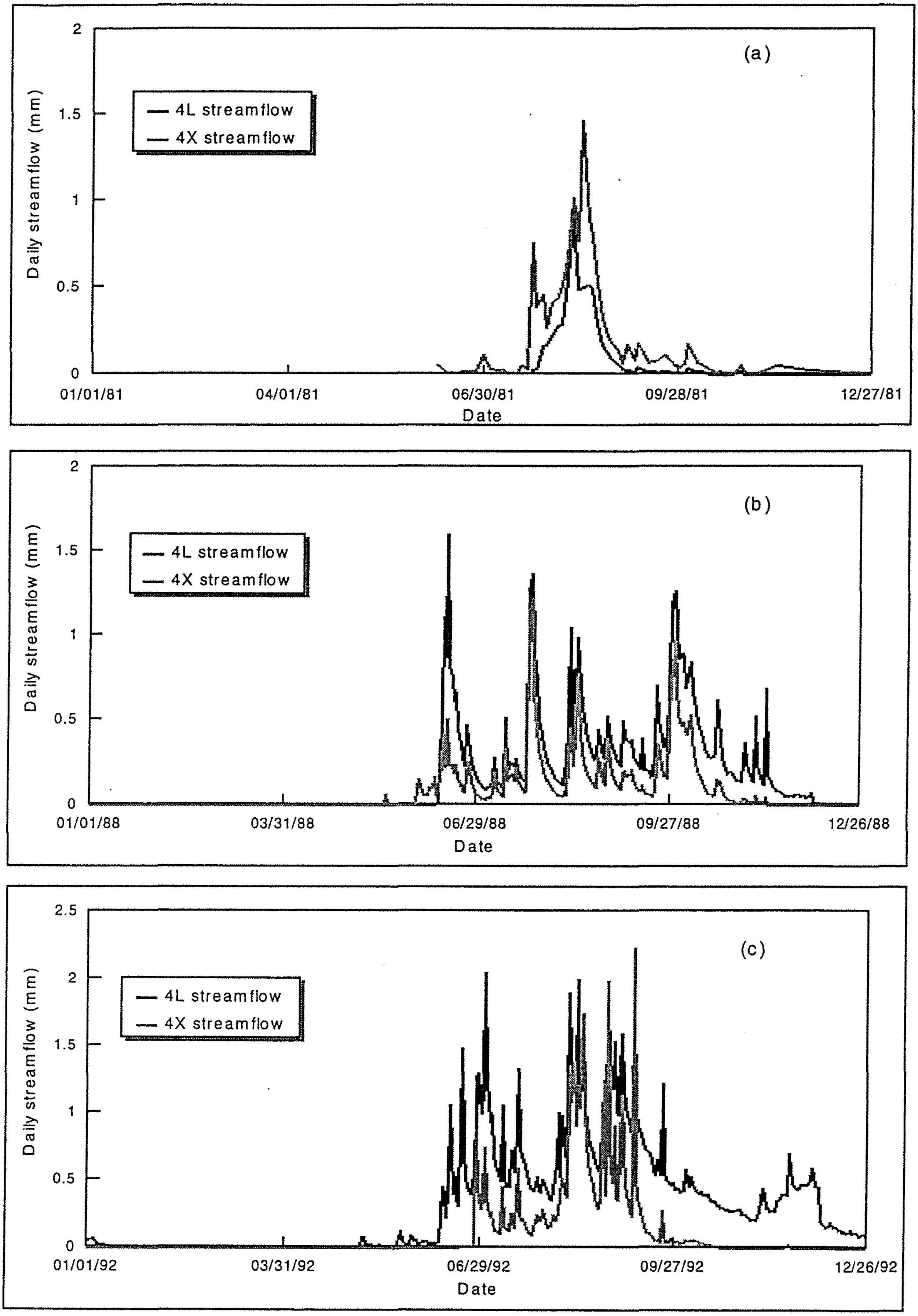

Figure 4 Streamflow hydrographs for treated and control catchment

Year	Yarragil 4L				Yarragil 4X			
	Rainfall mm	Streamflow mm	Streamflow %rain	Salinity mg/L TSS	Rainfall mm	Streamflow mm	Streamflow %rain	Salinity mg/L TSS
1976	826.0	1.3	0.2	220	790.3	3.2	0.4	622
1977	768.0	4.1	0.5	185	767.2	9.7	1.3	444
1978	858.0	3.2	0.4	147	872.6	15.6	1.8	358
1979	758.0	-	-	-	721.4	6.1	0.8	582
1980	964.0	0.8	0.1	158	970.7	9.9	1.0	396
1981	1079.0	17.3	1.6	111	1046.3	31.7	3.0	195
1982	748.4	0.1	0.0	169	823.5	7.3	0.9	389
Mean (76-82)	857.3	4.5	0.5	165	855.9	11.9	1.3	427
1983	1173.7	20.0	1.7	76	-	44.3	-	148
1984	1033.3	5.7	0.6	96	-	11.6	-	291
1985	962.5	31.2	3.2	85	921.3	16.4	1.8	215
1986	789.8	-	-	-	762.4	2.0	0.3	439
1987	777.3	7.0	0.9	173	729.7	3.3	0.5	303
1988	1261.4	63.9	5.1	120	1183.9	31.0	2.6	196
1989	933.9	-	-	-	882.2	3.2	0.4	289
1990	975.8	58.3	6.0	139	1071.6	8.6	0.8	257
1991	1139.8	91.1	8.0	148	1115.8	18.7	1.7	161
1992	1130.8	118.4	10.5	137	-	-	-	-
Mean (83-92)	1017.8	49.4	4.5	122	952.4	15.5	1.1	256

Table 1 Annual Streamflow, Rainfall and Stream Salinity at the Treated and Control Catchments

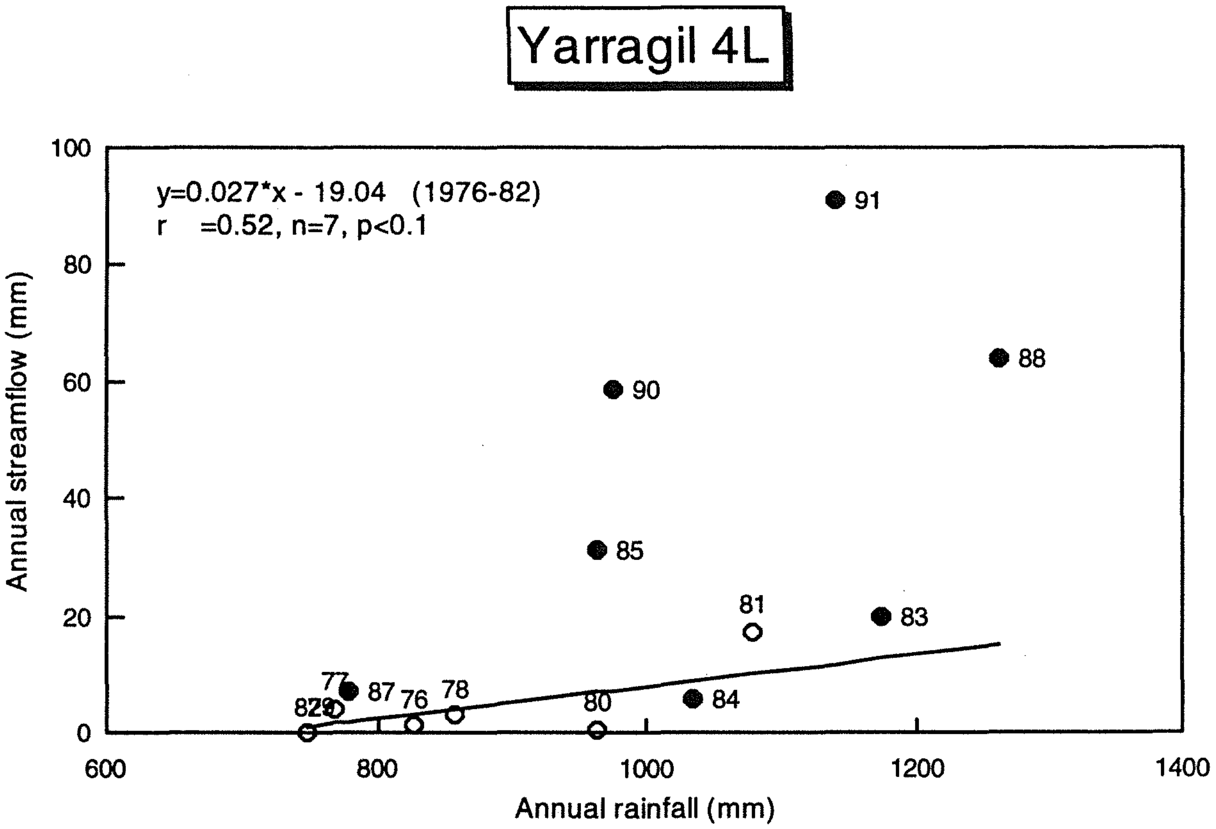
Yarragil 4L

Figure 5 Relationship between streamflow and rainfall

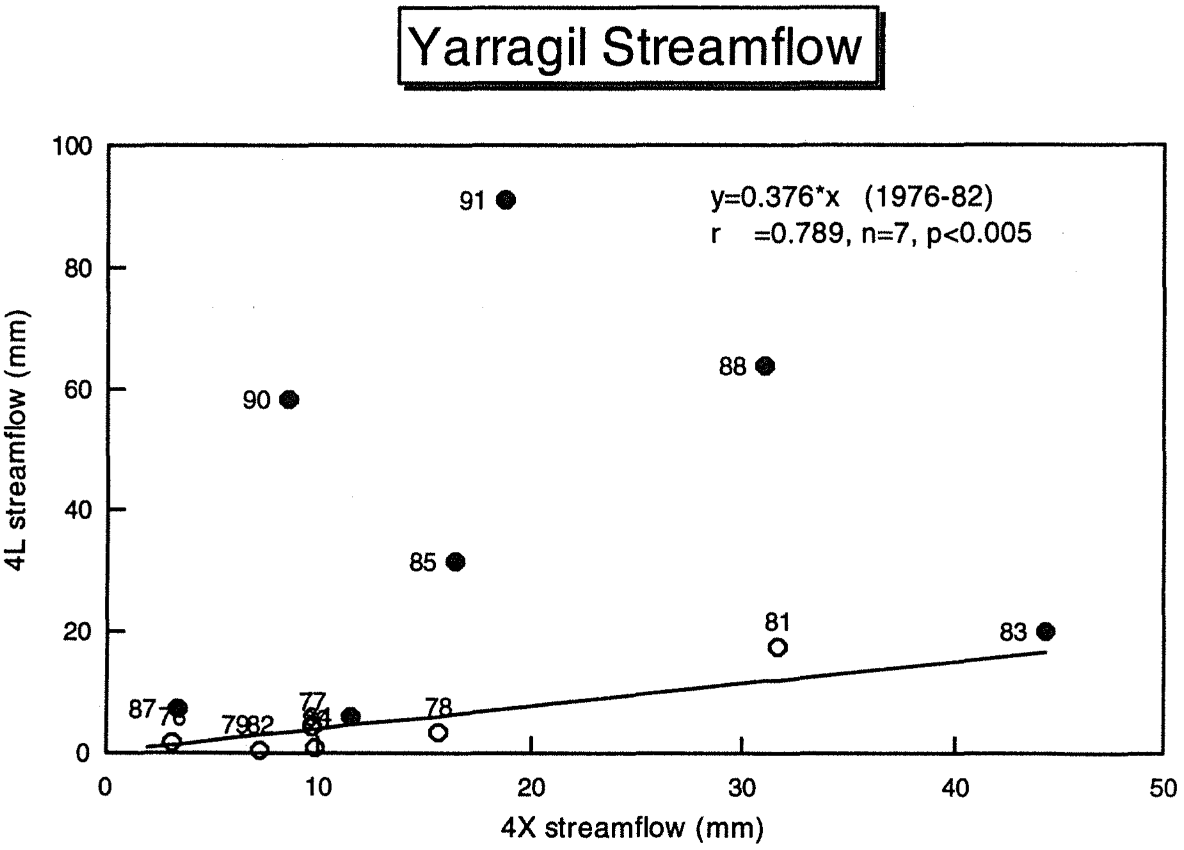
Yarragil Streamflow

Figure 6 Relationship between the streamflow of the 4L and 4X catchments

Streamflow from 4L increased from 0.5% of annual rainfall (4.5 mm) before thinning to 10.5% of annual rainfall (118.4 mm) 9 years after thinning (Table 1). The trend to 1992 was of continually increasing stream yield while the corresponding streamflow and stream yield of 4X remained similar to its 1976-82 levels. The effect of thinning on the 4L catchment has been to greatly increase streamflow and stream yield (Fig. 7).

The increase in streamflow was not evident until 1985 - two years after thinning. The change in streamflow, as a percentage of rainfall, continued to increase throughout the study period (Fig. 7). It was not obvious from the trend of increasing streamflow whether the maximum value had yet been reached. It is possible that streamflow will increase further.

4.2 Stream Salinity and Salt Load

The relationship between annual streamflow, salt load and salinity at 4L were stable during the pre-treatment period. The mean pre-treatment stream salinity at 4L was several times lower than at 4X (Table 1). Considerable changes occurred following thinning and these changes continued to develop so that the relationship had not reached a new equilibrium by the end of the study period (Fig. 8). The relationship between annual streamflow, salt load and salinity at 4X remained relatively stable throughout the study period (Appendix B). Since the control catchment showed relatively stable relationships throughout the study period, the changes observed at 4L can be attributed to the thinning treatment.

4.2.1 Effects of thinning on stream salinity

The changes in flow weighted annual stream salinity (salinity), as an effect of thinning 4L, were estimated by comparing actual salinity values with predictions of salinity as if the catchment had not been thinned. The predicted salinity was determined using a regression equation relating stream salinity to streamflow based on the pre-treatment data. Salinity predictions were then made using the predicted streamflow. The difference between the actual stream salinity and predicted values was regarded as the salinity change attributable to thinning.

The procedure for calculating stream salinity changes is illustrated in Fig. 9. This illustration uses 1985 as an example for which the actual flow was 31.2 mm and the actual salinity was 85 mgL^{-1} TSS. Using the regression equation between streamflow at 4L and 4X (Fig. 6) based on pre-treatment data, a predicted flow of 6.6 mm is obtained. This flow is an estimate as if the catchment had not been thinned. Substituting this predicted flow into the regression equation of Fig. 9 yields a predicted salinity of 142 mgL^{-1} TSS. The change in salinity attributable to thinning is then the difference between the observed and predicted salinity which has a value of -57 mgL^{-1} TSS. Thus, the 1985 change in salinity is estimated to be a decrease of 57 mgL^{-1} TSS.

Following the thinning treatment of 1983, the flow weighted annual stream salinity decreased for the first few years then tended to increase till in 1991 the salinity was again the same as if the catchment had not been thinned. The maximum decrease in stream

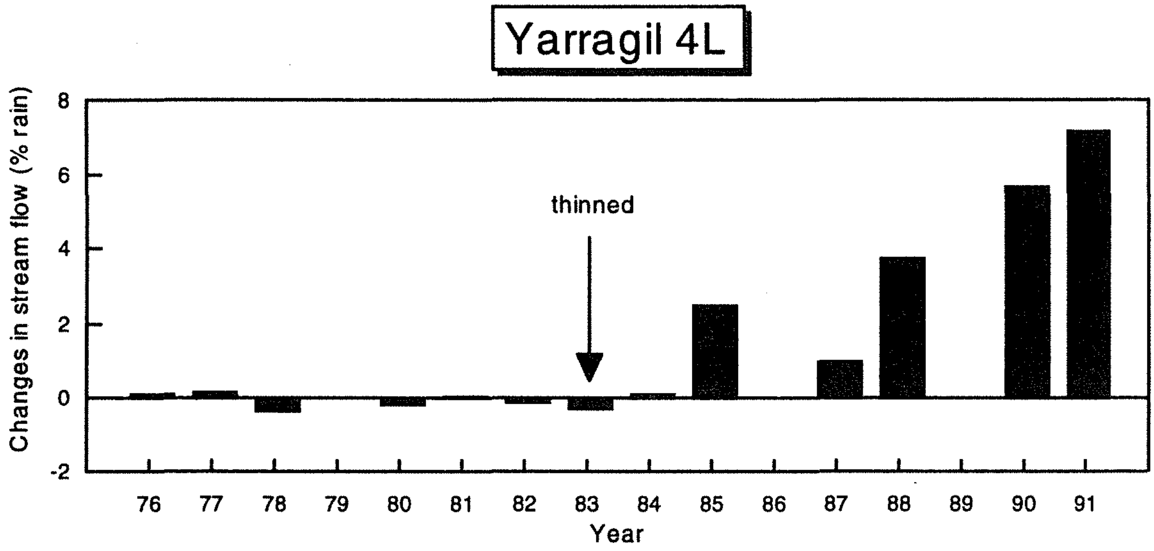

Figure 7 Changes in annual streamflow

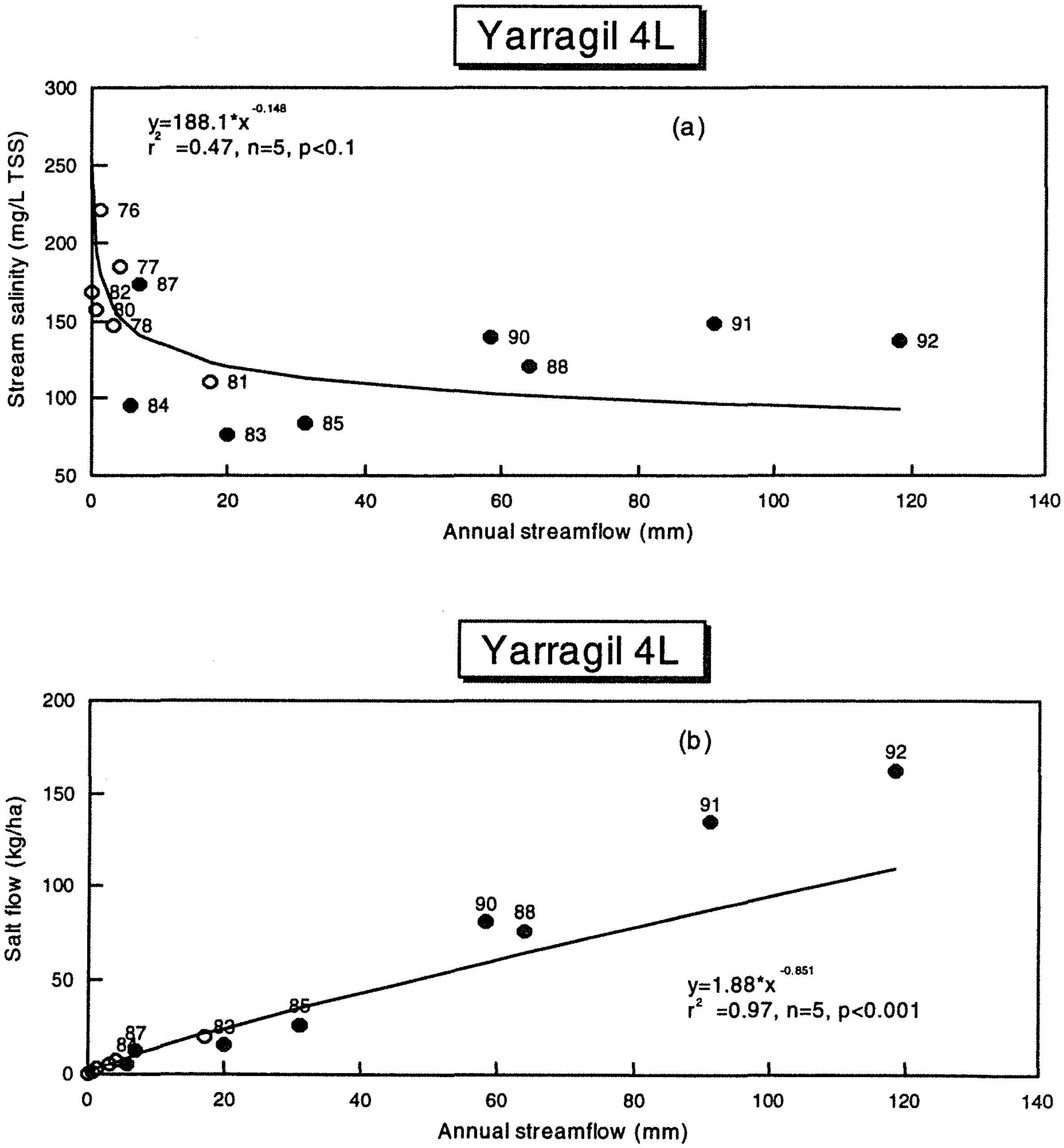

Figure 8 relationship of (a) stream salinity and (b) salt load with annual streamflow

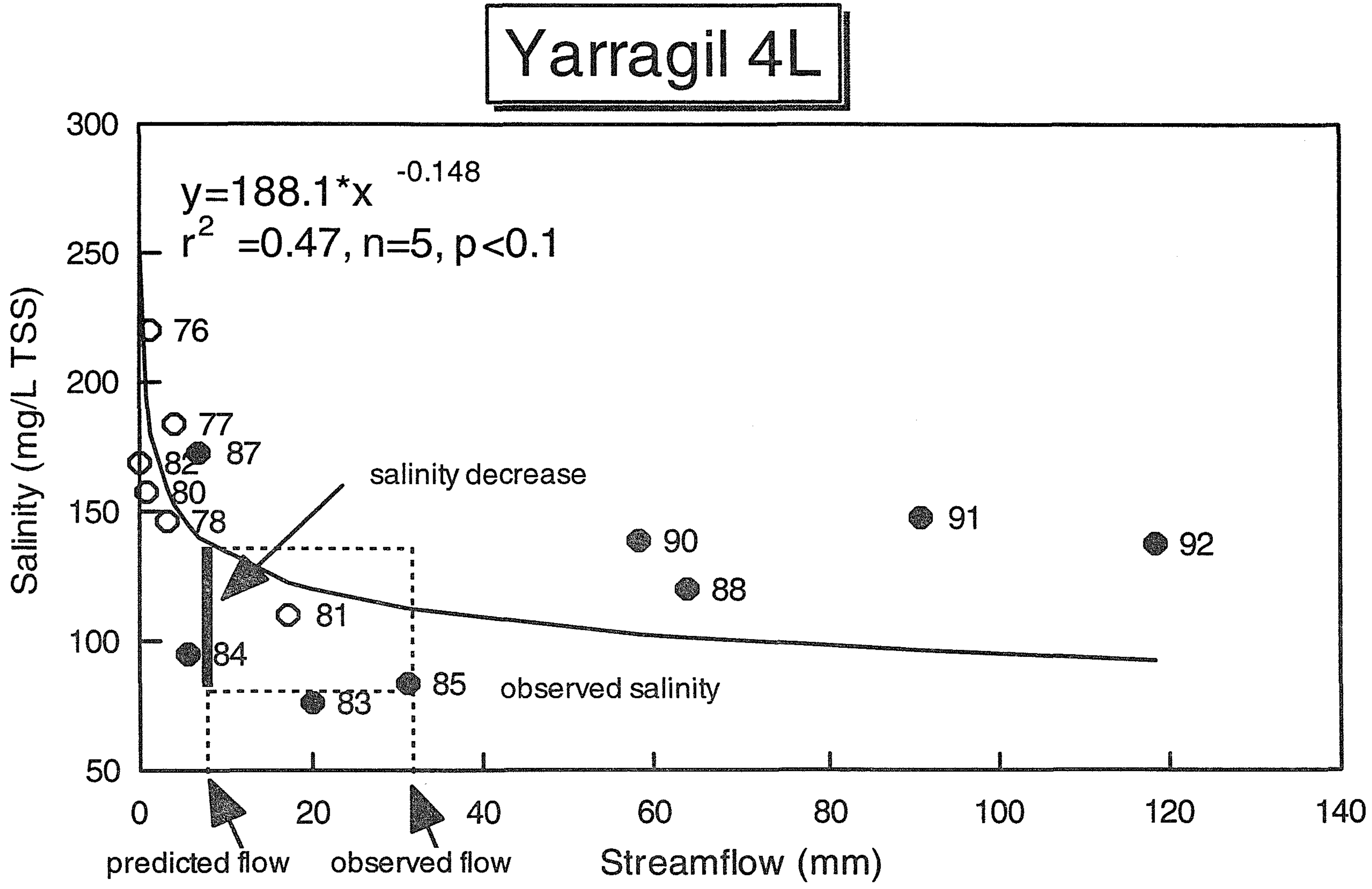

Figure 9 Calculation of stream salinity changes due to thinning

salinity was 60 mgL^{-1} TSS which occurred over 1984 and 1985 (Fig. 10a). From Table 1 it can be seen that the mean annual stream salinity has decreased since thinning. During the pre-treatment period the mean annual stream salinity was 165 mgL^{-1} TSS while following thinning the mean value was 122 mgL^{-1} TSS.

The stream salinity at 4L was determined from water quality samples. The maximum recorded salinity remained below 250 mgL^{-1} TSS throughout the study period (Appendix B). Therefore, it is expected that daily stream salinity remained below 500 mgL^{-1} TSS throughout the study period.

4.2.2 Effects on salt load

Changes in salt load due to thinning were calculated from the difference between actual and predicted salt loads. This method of calculation is the same as used to calculate the changes in stream salinity. Following thinning, actual salt load exceeded the predicted value starting in 1985. This exceedance increased for the remainder of the study period (Fig 10b). By 1991, salt flow was 135 kgha^{-1} TSS while the predicted salt flow was only 11 kgha^{-1} TSS. Therefore, salt flow had increased by 124 kgha^{-1} TSS.

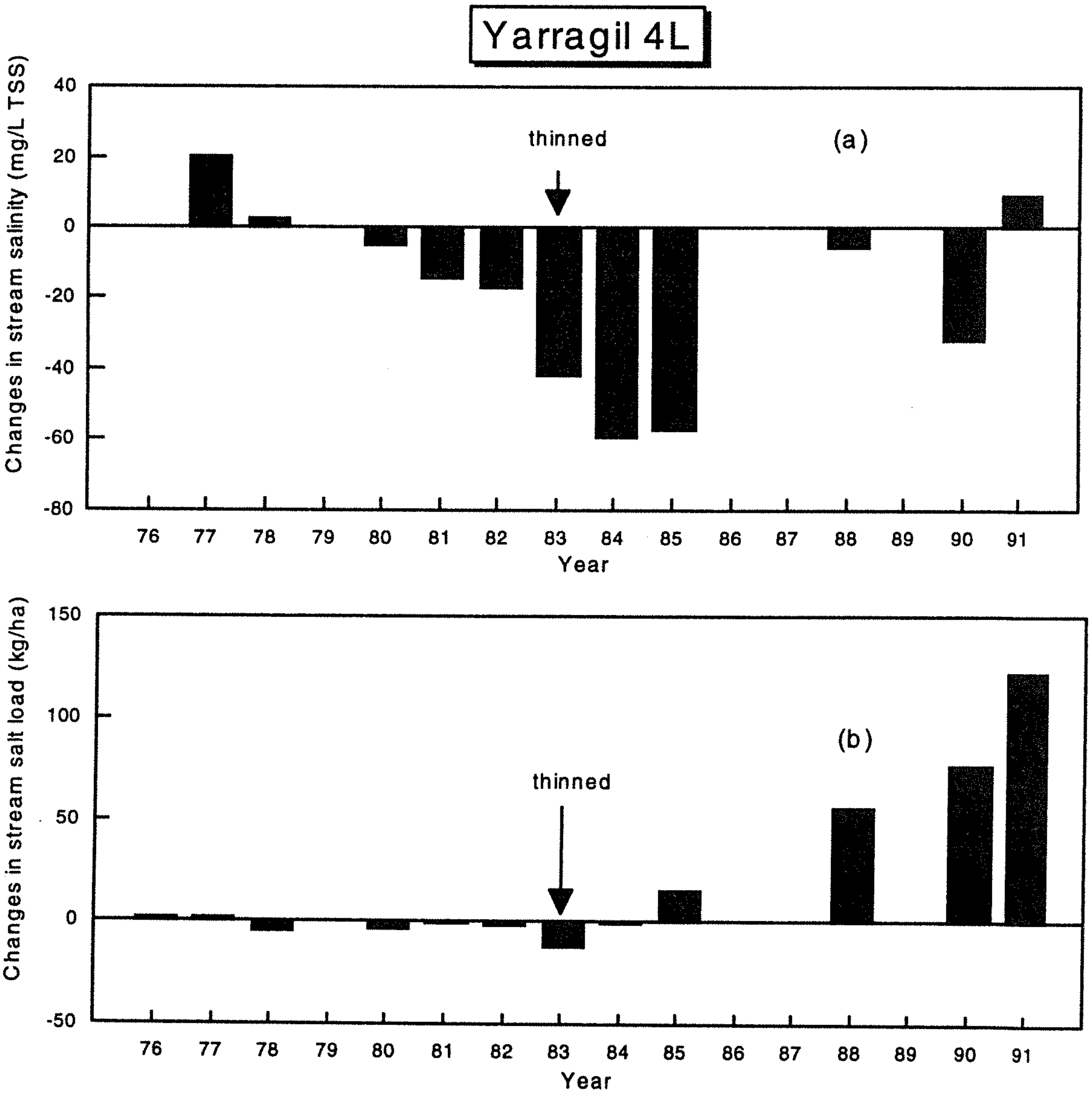

Figure 10 Changes in annual (a) stream salinity and (b) salt load

5 DISCUSSION

5.1 Annual Rainfall

Average annual rainfall during the study period was 15% lower than the long term average. If the long term average rainfall conditions had prevailed then it is likely groundwater levels, streamflow and stream salt load would have been much higher. The higher salt flow is likely to be sufficiently diluted by the increased streamflow that no increase in stream salinity would occur. This assumption is based on the observation that the stream salinity decreased following treatment until 1991, when it increased slightly.

5.2 Groundwater Level and Salinity

Groundwater salinity at Yarragil 4L remained below 360 mgL^{-1} TSS while at 4X the groundwater salinity was about 1400 mgL^{-1} TSS. The higher groundwater salinity at 4X is probably a reflection of the greater soil salt storage of 4X (24.5 kgm^{-2} TSS) compared to 4L (6.5 kgm^{-2} TSS).

Following thinning, the groundwater level at 4L increased relative to 4X but by 1992 this trend seemed to have plateaued (Fig. 3c). Comparison with the groundwater level at 4X is a method of accounting for climatic fluctuation. However, should long term average rainfall conditions prevail then the actual groundwater level at 4L may rise further. As the groundwater level is shallow, capillary action and evaporation may lead to concentration of salts near the surface. This has the potential to increase the salinity of flows in autumn and spring. This is not considered to have much potential to increase flow weighted annual stream salinity as the soil salt storage is low and the groundwater salinity of about 200 mgL^{-1} TSS is also low (Appendix A).

The trend of increasing groundwater levels can impact on soil and stream salinity as salt stored in the soil may be mobilised. In a study of soil cores from the Yarragil catchment, Herbert *et al.* (1978) noted that those soil cores with a distinct zone of salt accumulation were generally associated with an underlying groundwater table. By 1992, the water table in the Yarragil 4L mid-slope area had risen to immediately below the salt bulge. It was also observed that no increase in groundwater salinity had occurred. In this area, the zone of salt accumulation extends from 5 to 14 metres below the surface, peaking at a depth of 7 metres (Herbert *et al.*, 1978). In 1992, the groundwater level reached 15 metres below the surface which was its highest level within the study period. With further increases in groundwater level (>1m) the water table will intersect the zone of salt accumulation and possibly result in increased groundwater salinity.

Soil salt in the valley area of Yarragil 4L is less than half that of the mid-slope area (Herbert *et al.*, 1978). The soil salt profile is essentially uniform with a minor accumulation of salt at 3 metres below the surface. Groundwater levels have been above this level since 1985 with no influence on the groundwater salinity. This salt bulge has a peak salt concentration of 0.5 kgm^{-3} which is only 20% the concentration of the peak in the salt bulge in the mid-slope area. Thus, any further changes in groundwater level in the valley are not anticipated to significantly affect the groundwater salinity.

Bari and Boyd (1993) in a study of logging and regeneration in the southern forest of Western Australia found that groundwater levels rose for the first 4 to 5 years and began to fall as the vegetation grew back. This contrasts with the observations at the 4L catchment where groundwater levels rose for at least the first 9 years after clearing. The difference in groundwater response is probably accounted for by the slower regeneration of vegetation cover at Yarragil 4L compared to the southern forest catchments.

5.3 Streamflow response to thinning

The recovery of leaf area index (LAI) in jarrah stands is slow and therefore the restoration of transpiration to pre-treatment levels will also be slow. Jarrah stands thinned by two-thirds of their basal area are reported to have had a LAI 53% lower than unthinned stands 21 years after thinning (Stoneman and Schofield, 1989). The deep groundwater and large soil water storage capacity can initially absorb the reduced evapotranspiration (Stoneman, 1993). This has the effect of the streamflow peaking several years after the thinning. The streamflow response may persist for many years due to the slow recovery of transpiration following thinning. The understorey of the 4L catchment has been slow in regeneration (Stoneman pers. comm., 1994). Thus, the recovery of LAI, and hence transpiration losses at 4L, is confirmed to be slow. The response of streamflow and groundwater levels to thinning at 4L is consistent with the cited literature (Stoneman, 1993; Stoneman and Schofield, 1989). Therefore, it is expected the trend of increasing streamflow at 4L will continue for a number of years and gradually decline as the jarrah stands slowly regain their pre-treatment LAI. With the restoration of the LAI will be an associated increase in transpiration and interception losses so that the water balance and streamflow will return to the pre-treatment situation.

The stream yield at 4L first increased in 1985 and continued to increase throughout the study period. The slow initial response of streamflow to the thinning is attributed to the large soil water storage and deep groundwater typical of jarrah forests. It is possible that streamflow and stream yield had not yet reached their maximum by the end of the study period.

Streamflow response to the thinning of Yarragil 4L contrasts with the southern forest where annual streamflow was observed to increase for 4 or 5 years following logging then decline as the vegetation regenerated (Bari and Boyd, 1993). Vegetation cover of regenerating karri stands can reach pre-logging values within 5 years of logging while jarrah-marri stands exceed 70% of pre-logging values after 5 years (Stoneman *et al.*, 1988). Thus, the more rapid recovery of vegetation cover in the southern forest causes a decline in streamflow 4 or 5 years after logging whereas the slower regenerating jarrah stands of the northern forest take considerably longer to restore the pre-logging streamflow regime.

5.4 Stream Salinity and Salt Load Response to Thinning

Streams whose catchments are located in the High Rainfall Zone (>1100 $mmyr^{-1}$) are generally free of salinization risk (Steering Committee, 1989). This is based on the assumption that the high rainfall has prevented the build up of large salt concentrations in the soil and groundwater. In the Intermediate Rainfall Zone (IRZ) additional factors need to be considered in determining the salinity risk of a catchment. These are the soil and groundwater salt concentrations; the depth to groundwater and forest type.

In 1991, stream salinity was 10 mgL^{-1} TSS greater than the predicted value. Compared to 1977, where the variance from the pre-treatment relationship was 21 mgL^{-1} TSS (Fig 10a), the data for 1991 was too small an exceedance of the predicted value to constitute a statistically significant increase. Stream salinity initially declined after thinning then increased till in 1991 it was slightly larger than the predicted value. Without further years of data it is not possible to say whether the trend from 1991 would be of increasing salinity. Although the 1992 streamflow data at 4X was incomplete, an alternative prediction of 4L flow can be made from the pre-treatment relationship between 4L rainfall and streamflow. Using this method, 1992 stream salinity was 6 mgL^{-1} TSS greater than the predicted value. The 1992 estimate, while a rough guess, has not given an increase in stream salinity greater than in 1991.

The 4L catchment has been identified as having low salinity risk on account of its low soil salt storage of 6.5 kgm^{-2} TSS and groundwater salinity of 200 mgL^{-1} TSS (Ritson *et al.*, 1981). The increasing groundwater levels following thinning led to greater contribution of salts to the stream. However, this was sufficiently diluted by the increased streamflow thereby preventing any significant increase in stream salinity. Thinning did not result in undesirable salinity increases due to the low concentrations of salt present in both the soil and groundwater. Since the increase in streamflow (quantity) is accompanied by no significant increase in salt concentration, the quality of the streamflow as a source for water supply is not compromised. In similar catchments with low soil and groundwater salinity, it could be expected that thinning would likewise produce increased streamflow with little change in stream salinity. The reduction of leaf area cover or stem density in other catchments would also need to be comparable to 4L if similar response to thinning was required.

The annual maximum stream salinity determines the extreme conditions to which stream biota need to be tolerant in order to survive. In terms of water resources, fresh water is defined as having salinity less than 500 mgL^{-1} TSS (Steering Committee, 1989). The maximum daily stream salinity (Appendix B) subsequent to the thinning was both within the definition of fresh water and less than the pre-treatment maximum salinities. Therefore, it is expected that stream flora and fauna would not have been adversely affected by the salinity changes that resulted from thinning.

5.5 Implications for Management

Thinning to increase stream yield for water supply proved to be highly effective, increasing stream yield from 0.5% to 10.5% of annual rainfall 9 years after thinning. The initial increase in stream yield was delayed by 2 years after thinning. This lag time would need to be incorporated into any management strategy of stream yield for water supply.

This investigation has confirmed that the salinity consequences of thinning in this low salinity risk catchment are acceptable from the perspectives of managing the stream as a water resource and conservation of natural species. Thinning can be used to increase stream yields of a catchment and also as a forestry technique. The results of this study, to date, imply that thinning will not significantly increase stream salinity in catchments with low soil and groundwater concentrations and with groundwater hydrology that is similar to Yarragil 4L.

6 CONCLUSIONS

6.1 Groundwater Level and Salinity

(i) Following the thinning of Yarragil 4L, groundwater levels increased relative to the control (Yarragil 4X) at both the valley and mid-slope locations. The increase in groundwater level between 1983 and 1992 in the valley area was 4.41 m relative to 4X. The increase in groundwater level at 4L relative to 4X appeared to have levelled out by the end of the study period.

(ii) There was no apparent trend in the groundwater salinity at 4L nor was there any discernible response to thinning and the subsequent changes in groundwater levels.

6.2 Streamflow

(i) Annual streamflow was slow to respond to thinning - first increasing two years after thinning and from then the stream yield continued to increase throughout the study period. Streamflow in the 4L catchment increased from 0.5% of annual rainfall (4.5 mm) before thinning to 10.5% of annual rainfall (118.4 mm) 9 years after thinning. As there was no evidence of streamflow having reached a maximum value, by the end of the study period, it is possible that streamflow will increase further.

6.3 Stream Salinity and Salt Load

(i) The relationship of stream salinity and salt load with streamflow changed significantly, following thinning. These changes are continuing to develop so no new equilibrium relationship was evident by the end of the study period.

(ii) Following the thinning treatment of 1983, the flow weighted annual stream salinity decreased for the first few years then tended to increase. In 1991, salinity was the same as if the catchment had not been thinned. The stream salinity remained within the limits for drinking water potability. While salt flow increased as a consequence of thinning, the associated increases in streamflow diluted this additional salt sufficiently that flow weighted annual stream salinity did not significantly increase above pre-treatment levels. Thus, thinning enhanced the quantity (stream yield) for water resource purposes without diminishing the quality (stream salinity) of streamflow from the Yarragil 4L catchment.

(iii) The 4L catchment had not yet reached equilibrium by the end of the study period. Further changes to stream salinity are not expected to be great due to low soil salt storage and groundwater salinity. Continued collection of streamflow data will be necessary to determine the extent of these changes as the hydrologic regime of the catchment gradually returns to the pre-treatment situation.

7 RECOMMENDATIONS

This research should be continued until the stream yield returns or begins to return to pre-treatment levels. This will be of use in determining the extent and frequency of thinning required in the management of stream yield for water supply. To this end, further monitoring of streamflow and rainfall at the 4X and 4L catchments is desirable in order to determine the continuing response of the 4L catchment to its thinning. The collected data should be reviewed in eight to ten years time. This long interval, till the next review, is suggested because of the anticipated slow regeneration of the jarrah forest. Groundwater data is useful in assessing the hydrological balance in the catchments so it should still be monitored although only several measurements per year are necessary.

This study considered the effects on stream salinity of a low salinity risk catchment in the IRZ. To develop forest management and water resource management plans for the IRZ, further research is needed into effects on stream salinity of thinning catchments with greater salt concentrations in the soil and groundwater. This research would help determine the suitability of these catchments for thinning.

There are other gauged catchments within the Yarragil catchment. If these catchments are not needed for further Water Authority studies (such as the second recommendation) then the gauging stations should be closed. One possible use for these catchments may be as a control for other treated catchments in the region. The 4X catchment could serve this purpose. However, the other catchments may still be useful depending upon whether they are more suitable as control catchments than 4X.

8 ACKNOWLEDGMENTS

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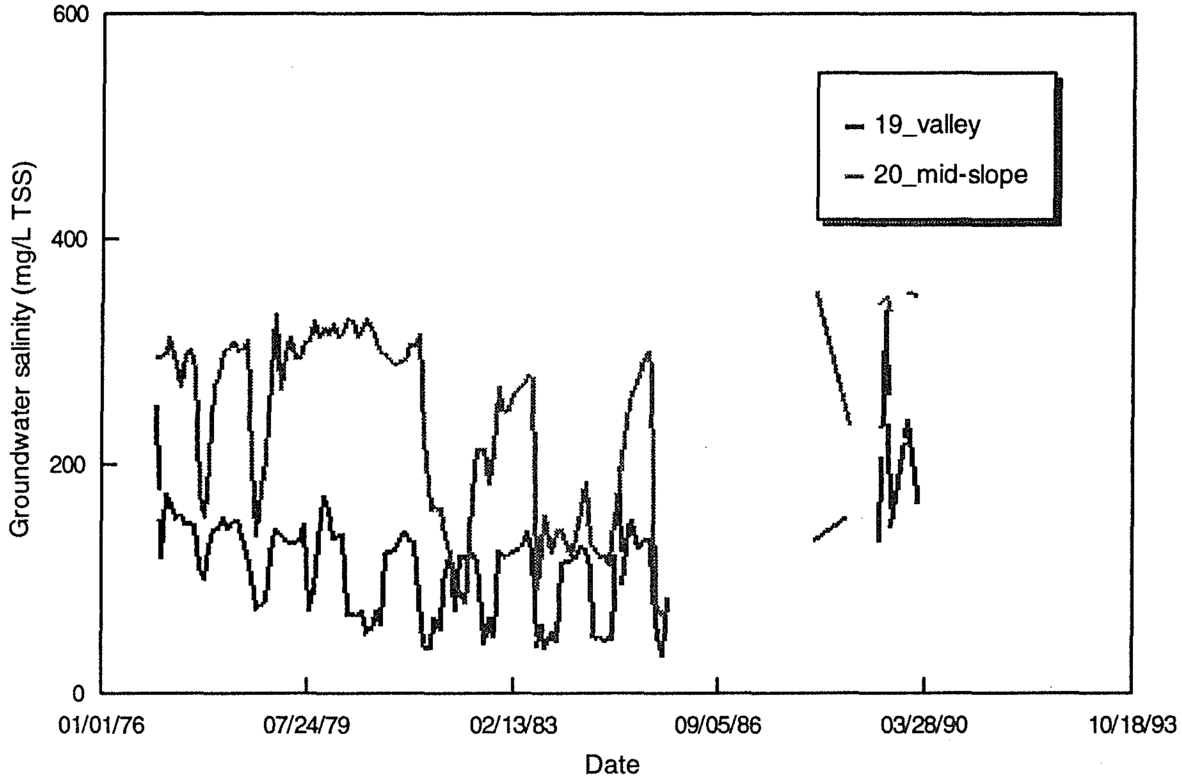
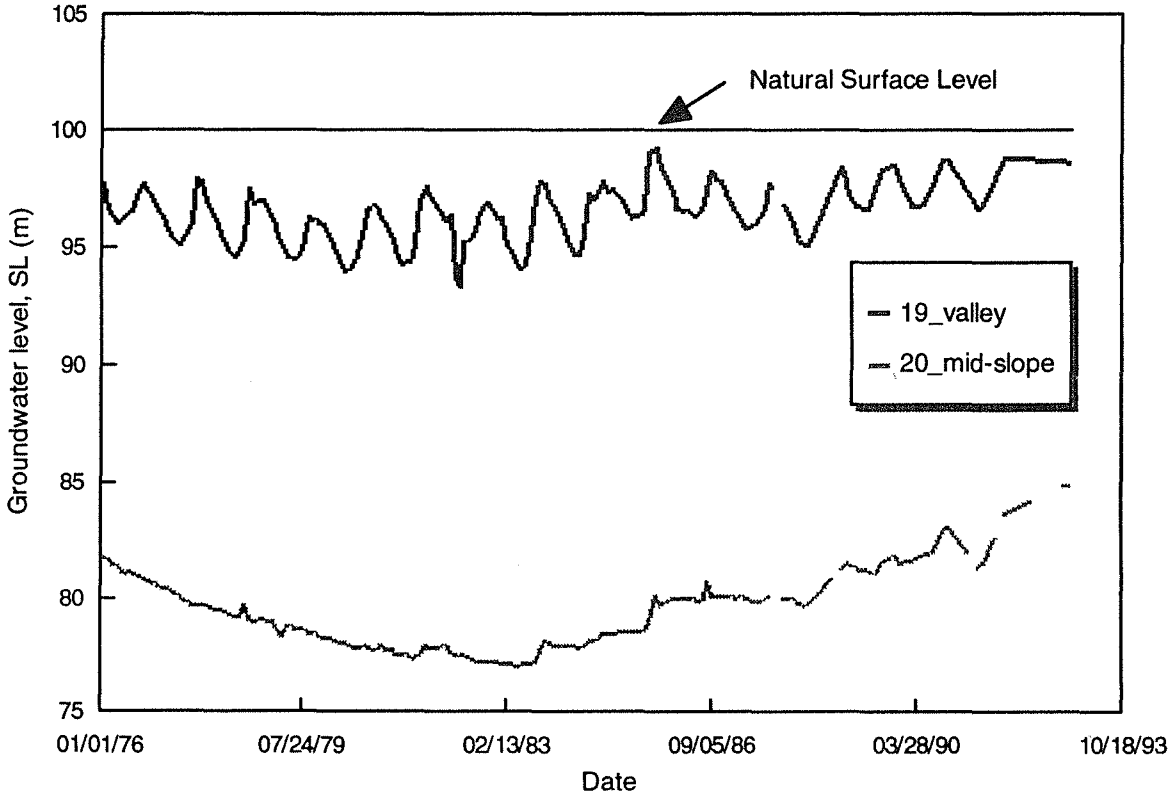
APPENDIX A

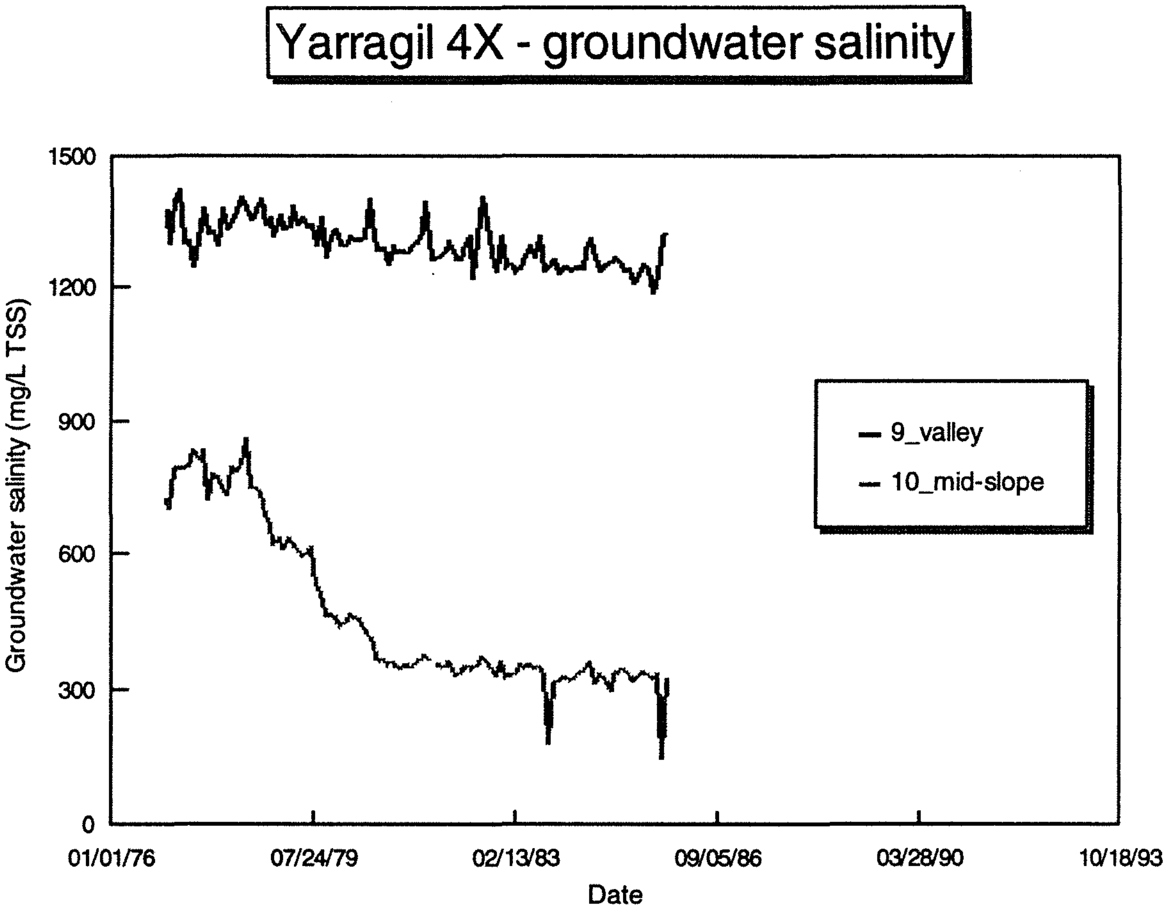
Groundwater level and salinity at 4L and 4X

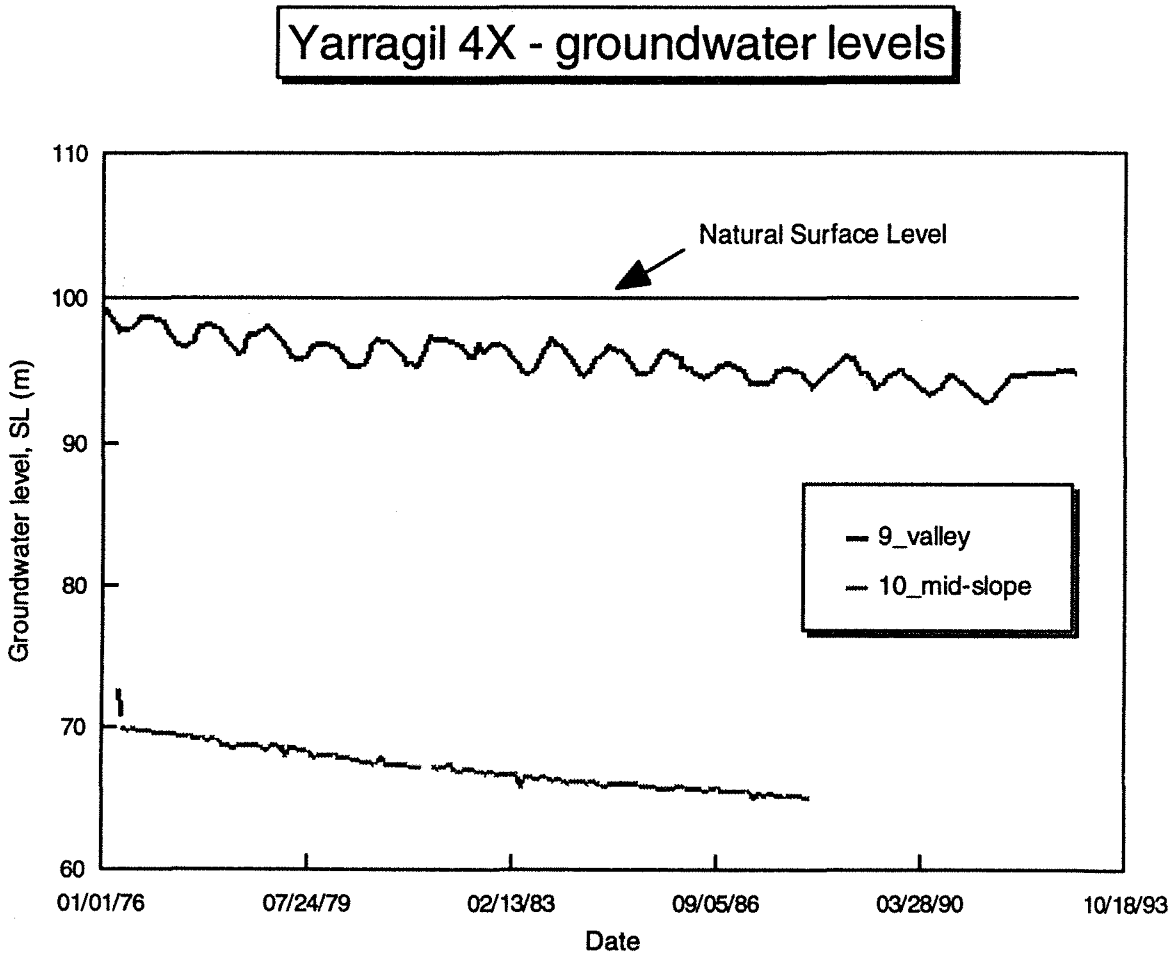
Yarragil 4L - groundwater salinity



Yarragil 4L- groundwater levels



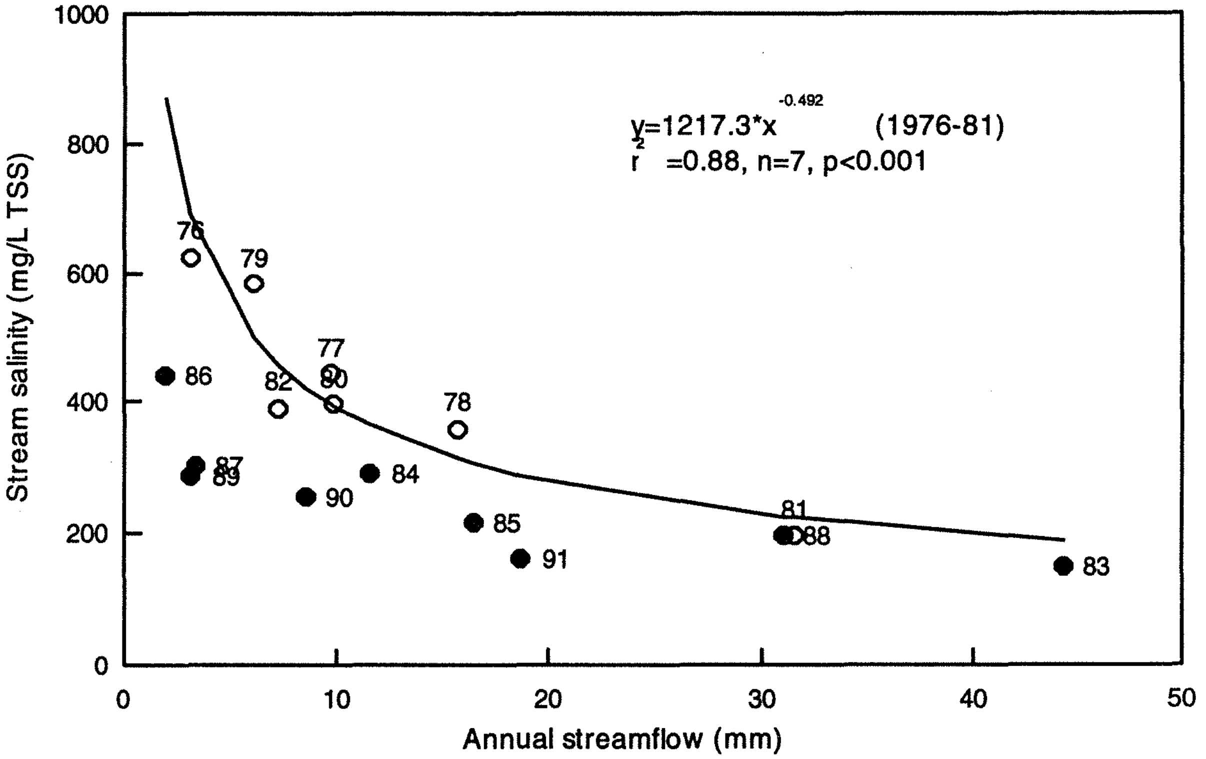

Yarragil 4X - groundwater salinity
Groundwater salinity (mg/L TSS)
1500
1200
900
600
300
0
01/01/76
07/24/79
02/13/83
09/05/86
03/28/90
10/18/93
Date
9_valley
10_mid-slope


Yarragil 4X - groundwater levels
Natural Surface Level
Groundwater level, SL (m)
110
100
90
80
70
60
01/01/76
07/24/79
02/13/83
09/05/86
03/28/90
10/18/93
Date
9_valley
10_mid-slope

APPENDIX B

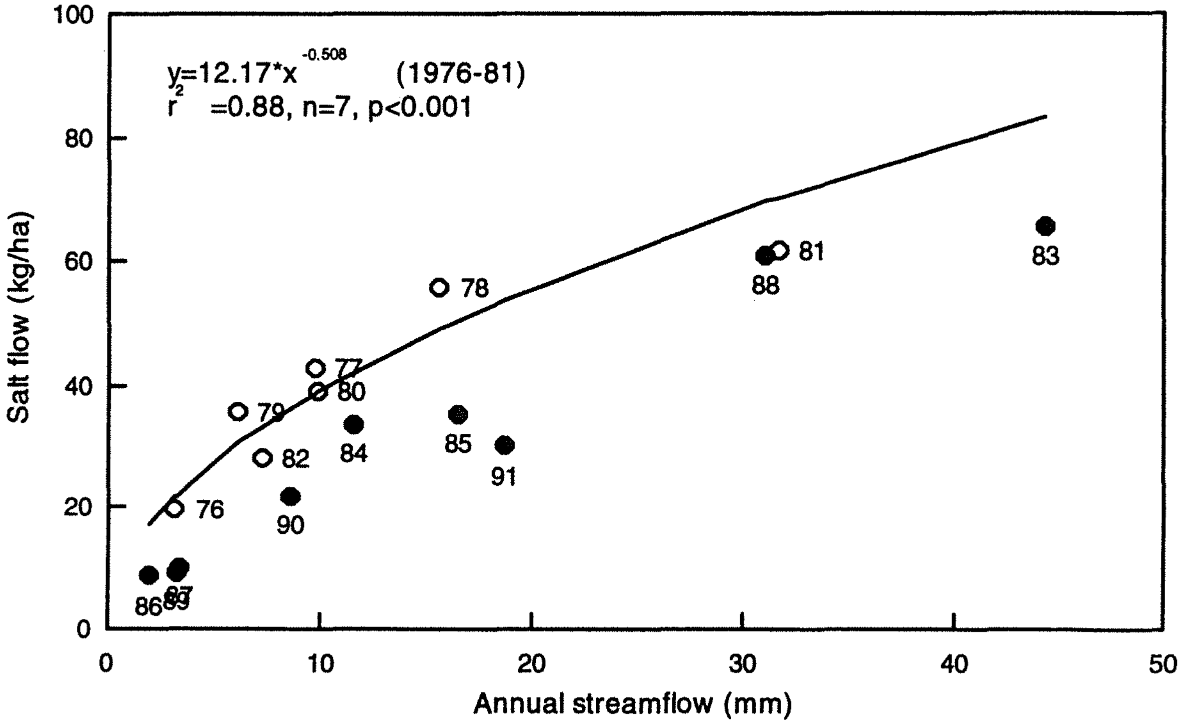
Relationships and data for stream salinity, salt load and streamflow

Yarragil 4X



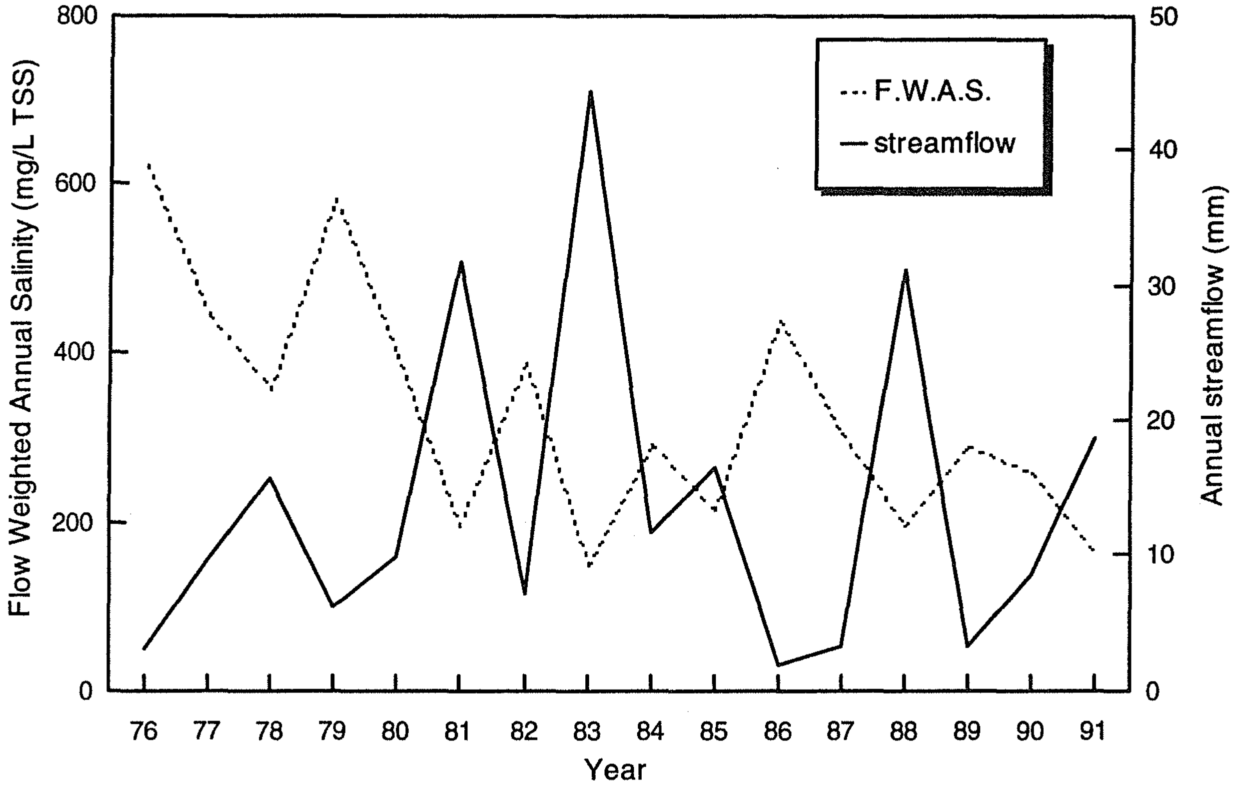
Relationship between stream salinity and streamflow

Yarragil 4X



Relationship between salt load and streamflow

Yarragil 4X



Yarragil 4L