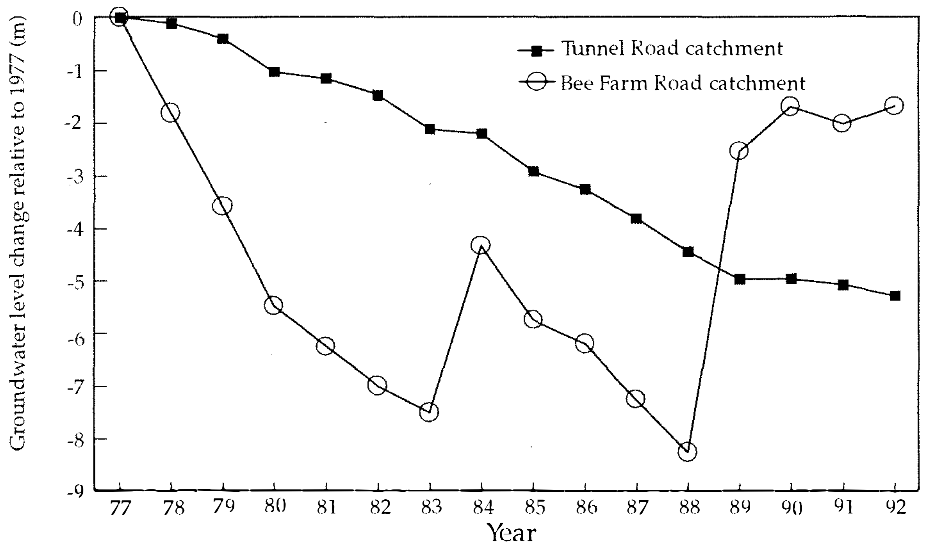
Water Authority
of Western Australia

MOUNT SADDLEBACK PAIRED CATCHMENT STUDY:

THE EFFECT OF BAUXITE MINING ON THE HYDROLOGY OF BEE FARM ROAD CATCHMENT



Report No. WS110
October 1992

Water Authority
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Surface Water Branch

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SUMMARY

A small (1.81 km^2) forested catchment at Mt Saddleback in south-west Western Australia, was partially mined and rehabilitated to study the effects of bauxite mining on the surface water and groundwater systems of a catchment within the low rainfall zone (annual rainfall < 900 mm). Approximately 10% of Bee Farm Road catchment was mined during the period 1986 to 1990. Mining primarily occurred across the lowest one third of the catchment.

Groundwater levels in the vicinity of mining rose sharply approximately 2 years after initial clearing (1986). Groundwater levels rose in the order of 8 metres to 1992, in response to mining. The variability in groundwater level behaviour lowered the confidence with which the response to mining was identified.

Water yield from the catchment was extremely low during the period of monitoring (< 1 mm) and the increase in water yield (0.06 mm) due to mining was negligible. However as a proportion, streamflow increased between 30% (for annual rainfall of 690 mm) and 90% (for annual rainfall of 900 mm) of pre-mining streamflow.

Stream salinity rose from an average 24 mg L^{-1} chloride (Cl^-) to 149 mg L^{-1} Cl^- in the first year of flow following mining (1989). Stream salinity in 1990 and 1991 averaged 72 mg L^{-1} Cl^-. This compares to an average salinity encountered between 1975 and 1977 of 475 mg L^{-1} Cl^-, when groundwater contributed to surface flow .

This experiment was conducted within an extended period of below average rainfall. The hydrological results should be considered in this context, as it is likely the same trial conducted under different antecedent conditions would have significantly different outcomes.

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1. INTRODUCTION

Bauxite mining is a major land use within the jarrah forest of the Darling Range. Mining currently occurs at four sites within the principal mineralized area, which extends south from Armadale to Harvey and east from the Darling Scarp to Boddington. Three of these mines lie in the high rainfall zone (>1100 mm annnual rainfall), the fourth within the low rainfall zone (<900 mm annual rainfall) at Mt Saddleback, south of Boddington.

In general higher concentrations of bauxite occur in the western margin of the jarrah forest. However substantial reserves exist to the east, in regions of lower rainfall. An established programme is in place to research the effects of bauxite mining on catchment hydrology and salinity in the high and intermediate rainfall zones. Mt Saddleback represents the only trial mining experiment in the low rainfall zone.

The catchments studied at Mt Saddleback, Bee Farm Road and Tunnel Road, have been monitored for various hydrological parameters since 1975. Stokes (1983) reviewed the data after 6 years of monitoring. Stokes found the groundwater flow system did not strongly reflect surface topography and estimated groundwater underflow on both catchments was between 1 and 4 times the magnitude of streamflow. Declining groundwater contribution to streamflow in this period resulted in reductions in streamflow and stream salinity.

Mining commenced on Bee Farm Road catchment during 1986. This report describes the early response of the surface water and groundwater systems to bauxite mining on part of Bee Farm Road catchment.

2. SITE DESCRIPTION

Bee Farm Road and Tunnel Road catchments are located on the eastern slopes of Mt Saddleback, 128 km south east of Perth (Fig. 1). The catchments are 1.81 km^2 and 2.07 km^2 respectively, and are within the basin of the Murray River.

The climate of the region is characterized by cool wet winters and warm to hot, dry summers. The long term average rainfall was 740 mm.

The catchments are steep, with a change in elevation exceeding 200 m from the catchment outlets to the upslope boundaries. Both have abrupt changes of slope mid-catchment, from average slopes in the upper portion of 12% (Bee Farm Road) and 23% (Tunnel Road) to average slopes in the lower half of approximately 6% and 11% respectively. Tunnel Road catchment is considerably steeper than Bee Farm Road catchment.

The steeper upslope areas have soil salt storages between 0.1 kg m^{-3} and 0.3 kg m^{-3} total soluble salts (TSS). Salt storage on the lower, flatter slopes ranged between 0.9 kg m^{-3} and 3.5 kg m^{-3} TSS. Averaged values for the catchments were between 30% and 50% of salt storage values estimated to be typical of this region (Stokes, 1983). Groundwater salinity ranged between 49 mg L^{-1} TSS (~ 14 mg L^{-1} Cl^-) and 2180 mg L^{-1} TSS (~1124 mg L^{-1} Cl^-), and averaged 566 mg L^{-1} (~255 mg L^{-1} Cl^-) across both catchments.

Vegetation is typical of the region. An open forest of jarrah (Eucalyptus marginata) and marri (E. calophylla) exists on the steeper upslope sections, whilst on the lower, flatter portions of the catchments an open woodland of wandoo (E. wandoo) is prevalent. This in part, reflects a distribution of free draining, lateritic gravels and duricrust mid to upslope and heavier clay soils on the lower flats. In the upslope areas bedrock of basic volcanic and metasedimentary rocks occurs under a deep (20 - 30 metres) weathered profile, whereas downslope bedrock comprises granite and dolerite.

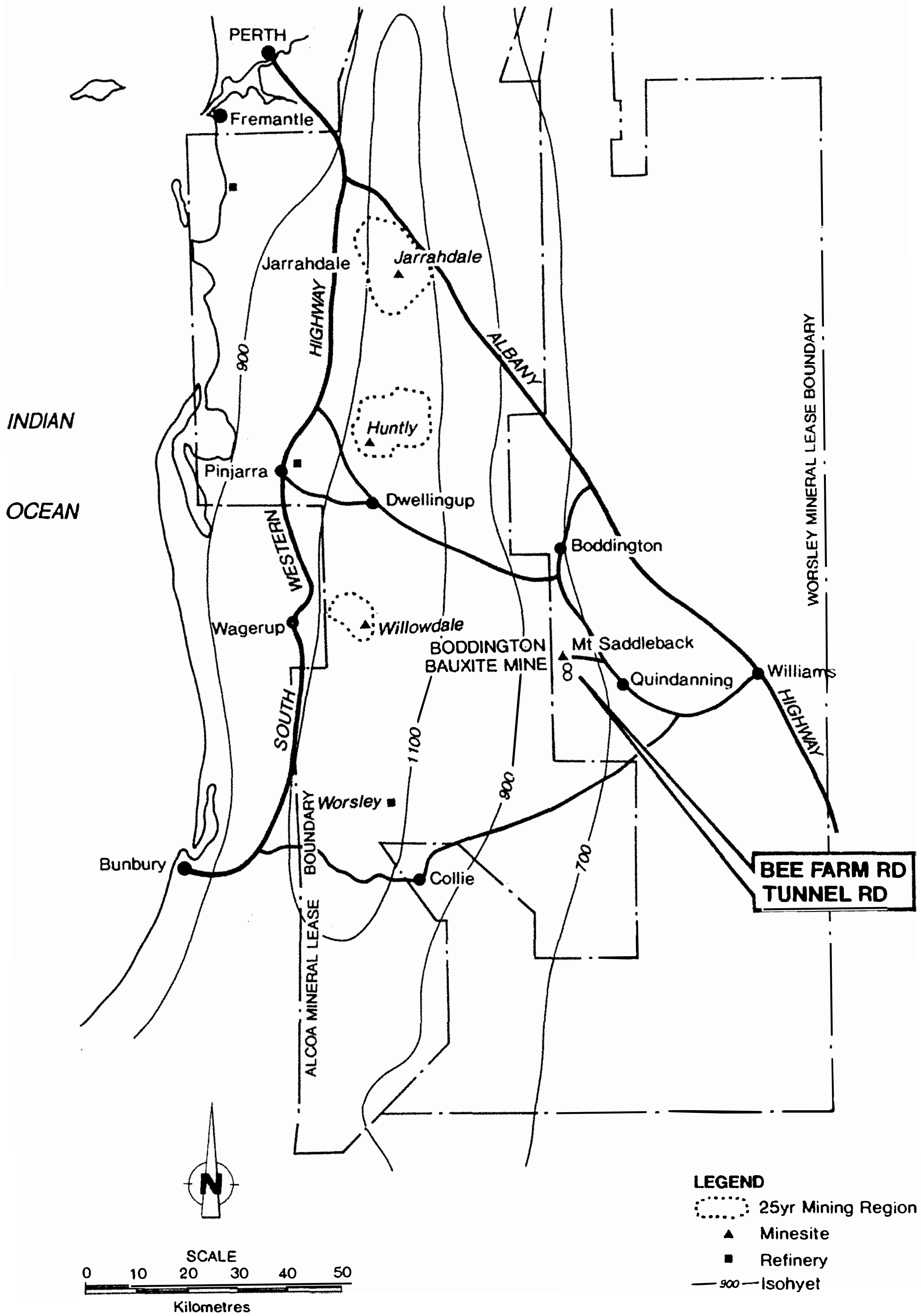

FIGURE 1 LOCATION MAP FOR MT SADDLEBACK PAIRED CATCHMENTS

3. EXPERIMENTAL METHOD

A paired catchment approach was utilized for this study, in which two adjacent catchments were monitored for a calibration period (12 years) prior to mining one catchment. Approximately 10% of Bee Farm Road catchment was cleared for mining during 1986. Mining primarily occurred in the lowest one third of the catchment (Fig. 2), and varied in depth between 3 and 13 metres. Rehabilitation of the mined areas commenced in 1987 and was completed in 1990. Tunnel Road catchment was the control catchment in this study.

The mining process commences with the harvest of millable timber. Remaining timber is heaped and burnt. Topsoil and overburden are then removed in separate stages for use in mine pit rehabilitation. Following blasting the bauxite profile is extracted and the pit shaped and deep ripped to 1.5 metres depth, on the contour, prior to the replacement of overburden and topsoil. The area is then revegetated with eucalypt seedlings and a mixture of indigenous understorey species established from seed.

Gauging stations incorporating sharp crested V-notch weirs were established during 1975 to continuously monitor streamflow. Automatic pumping samplers were installed to collect samples for water quality analysis. These were supplemented with manually obtained samples gathered during instrument inspections.

Pluviometers were installed at the stream gauging sites during 1975. Another pluviometer formed part of a climate station established midway along Bee Farm Road catchment. A rainfall storage gauge at the climate station provided samples for saltfall (chloride ion) analysis.

A network of 41 piezometers across both catchments have been monitored since 1977, initially at monthly intervals and then four times a year, to identify seasonal maxima and minima in groundwater levels. Many of these piezometers, particularly at upslope sites, were not installed to bedrock and failed to intersect the groundwater and others have subsequently 'dried up' as groundwater levels declined during the period of monitoring.

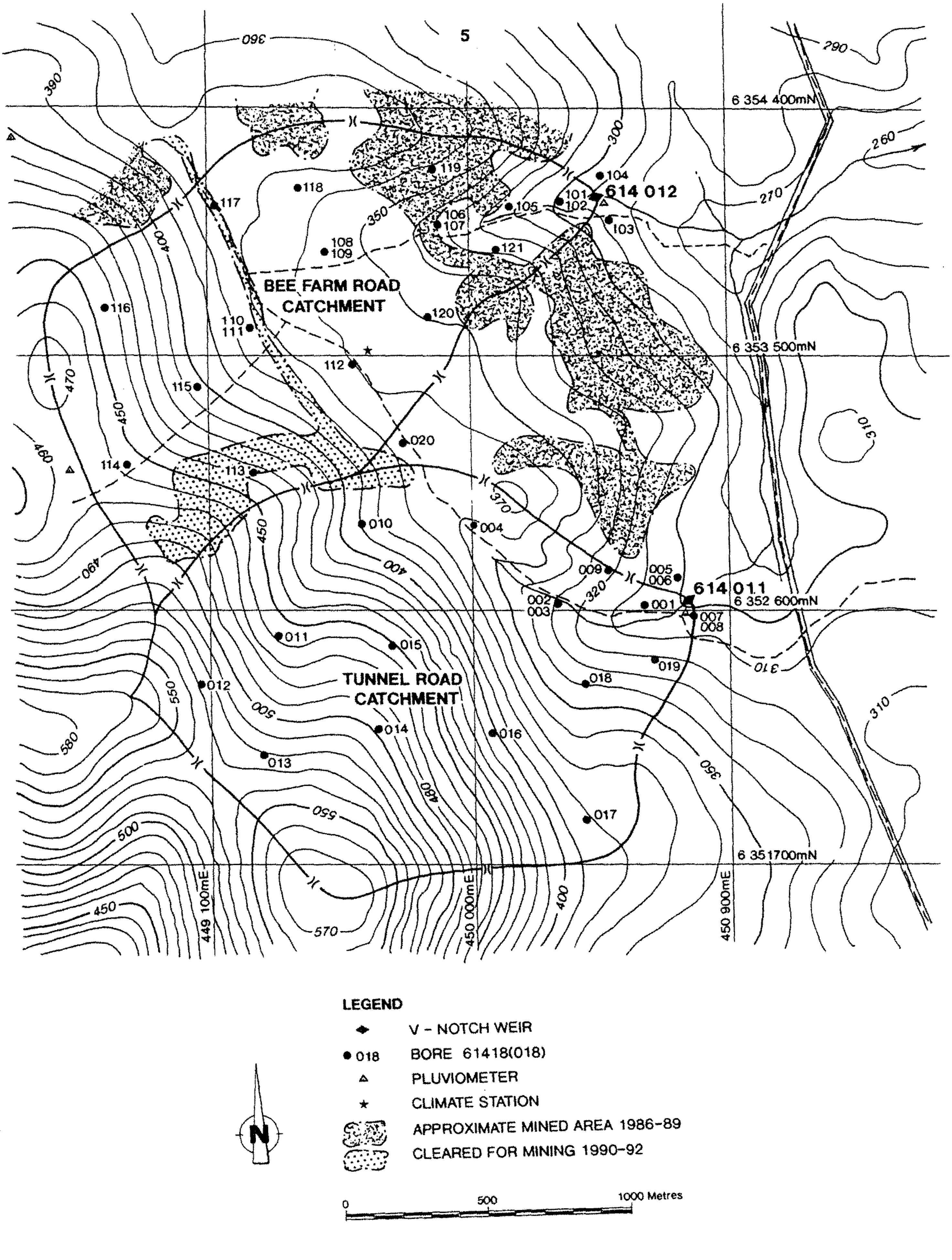

FIGURE 2 BEE FARM ROAD AND TUNNEL ROAD CATCHMENTS

4. RESULTS

The results that follow are based on a water year which commences on the 1st April.

4.1 Rainfall

The study has to date been undertaken during an extended period of below average rainfall. The long term annual average for these catchments was 740 mm, which was exceeded only five times in seventeen years (Fig. 3). The average rainfall during the study period was 680 mm.

The concentration of chloride in the rainfall averaged 3.4 mg L^{-1} (approximately 14 mg L^{-1} TSS) during the study period.

4.2 Groundwater

Analysis of groundwater was based primarily on annual minimum levels in piezometers and has therefore been restricted to those piezometers in which the level was measurable at the minimum. Up to seven piezometers were used in analysis of Bee Farm Road catchment groundwater, and up to seven at Tunnel Road catchment. Most of these piezometers occur at lower elevations across both catchments.

There has been a decline in groundwater levels across both catchments during the study period, most probably in response to the low rainfall which has occurred during this time (Fig. 4 and Fig. 5). Minimum groundwater levels around the outlet to the Bee Farm Road catchment ranged between 5 m and 15 m below the ground surface. Groundwater levels in the valley area of Tunnel Road catchment ranged between 13 m and 18 m below the ground surface.

The mining process commenced with clearing of native vegetation during the summer of 1986. Minimum groundwater levels did not react until 1989. For comparison of

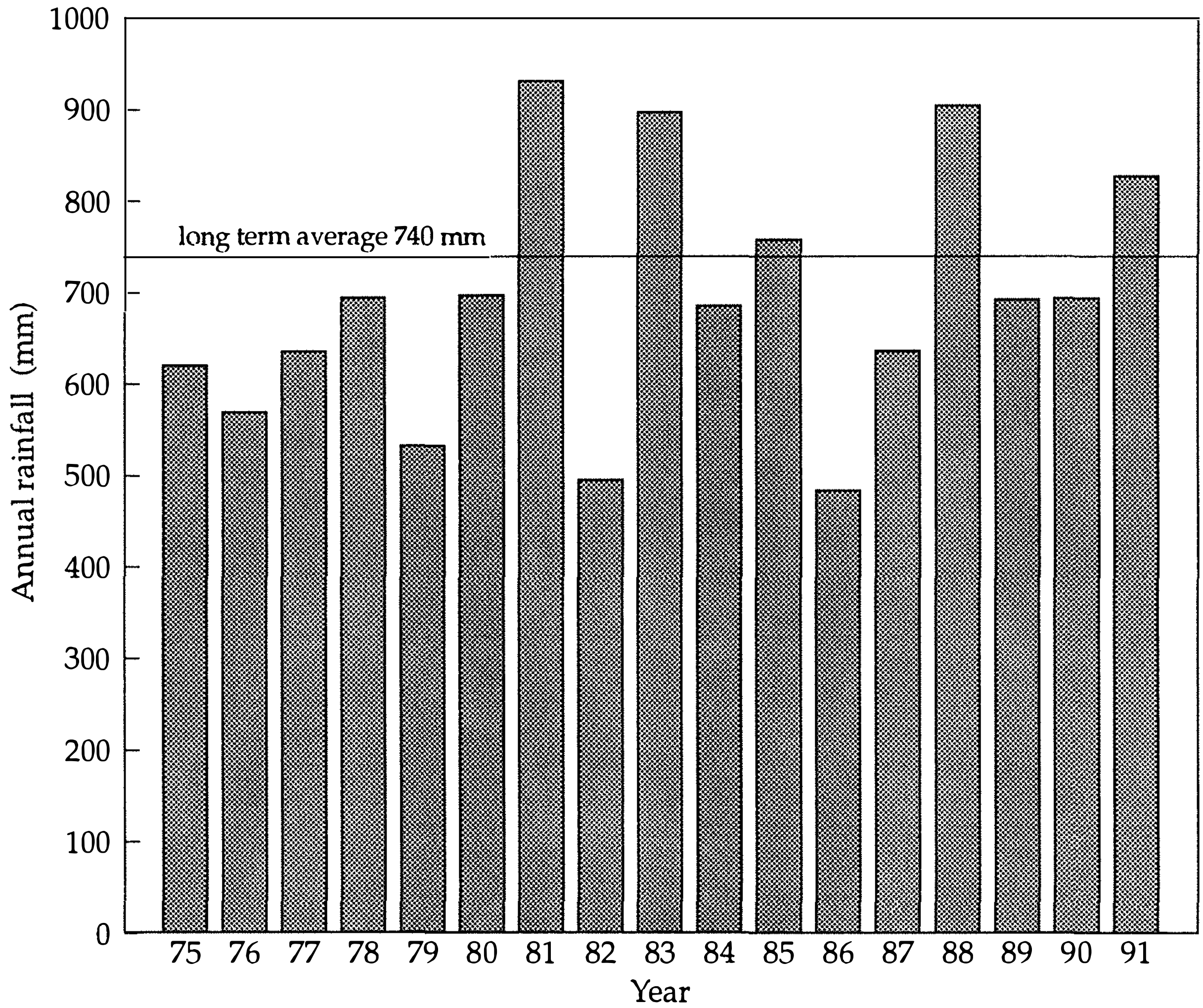

Fig. 3 Bee Farm Road catchment annual rainfall

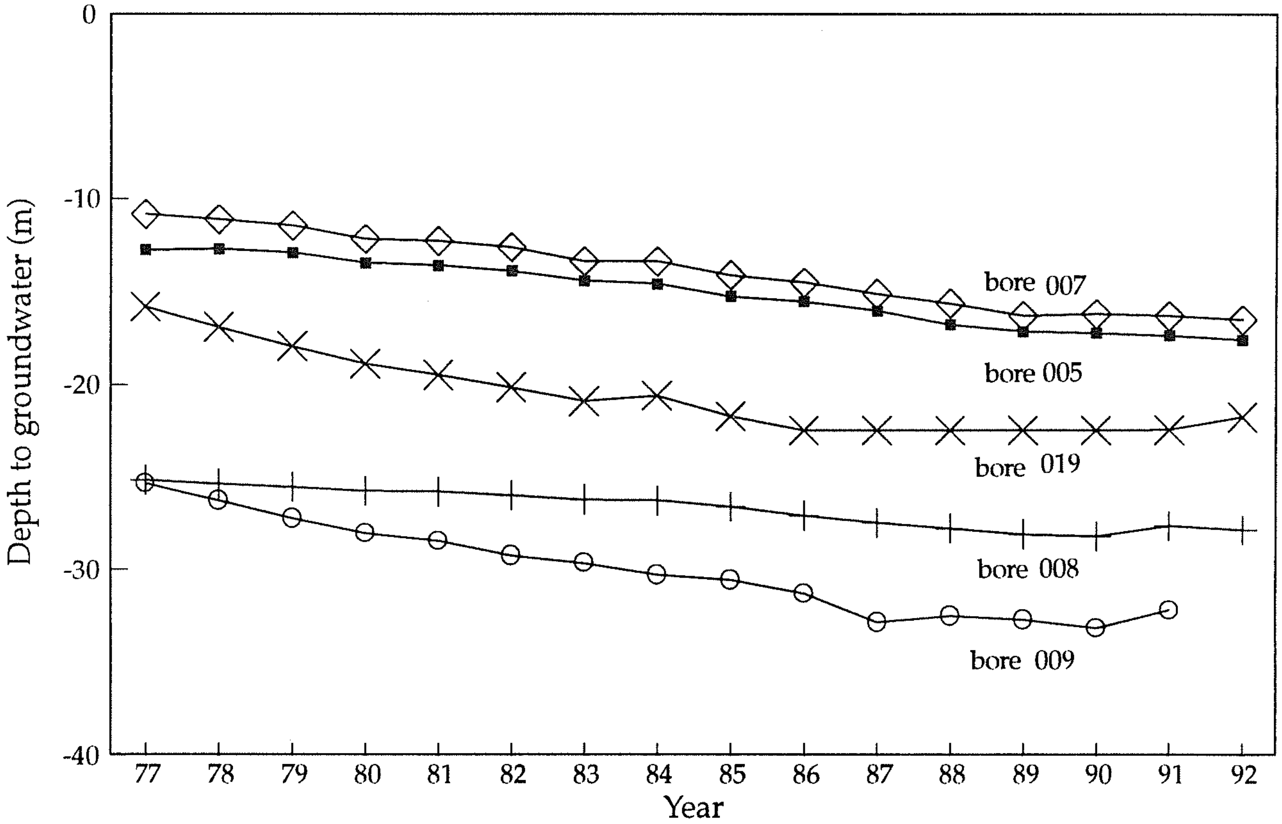

Fig. 4 Tunnel Road catchment groundwater levels

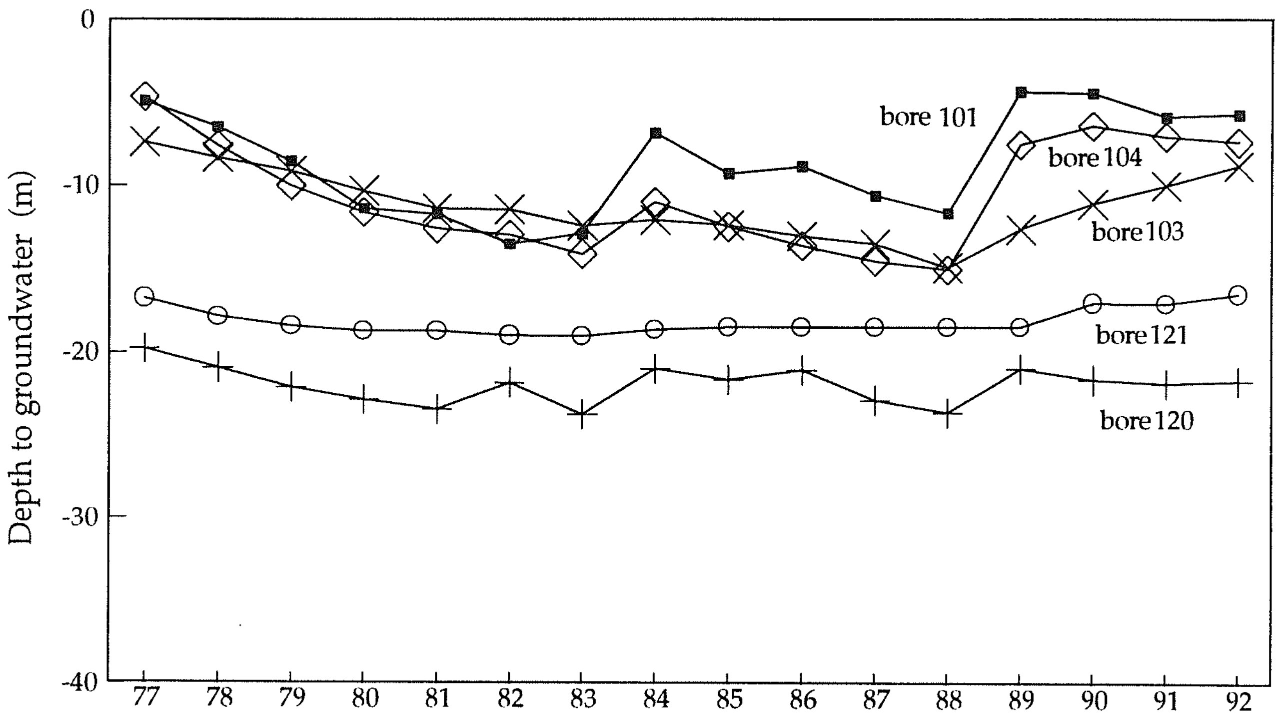

Fig. 5 Bee Farm Road catchment groundwater levels

groundwater levels between Bee Farm Road catchment and Tunnel Road catchment the pre-treatment period was considered to extend to 1988. This provided a longer calibration period which was deemed appropriate in the light of differences in groundwater level trends between the catchments.

Groundwater level behaviour was determined for the pre-treatment and post treatment periods. These calculations were done using 'downslope' piezometers, ie those found at ground elevations less than 310 m AHD. In Tunnel Road catchment these were bores 005 and 007; in Bee Farm Road catchment the bores used were 101, 103 and 104.

The minimum groundwater level of 1988 for piezometer 101 was not recorded and has been estimated for the purpose of these calculations using seasonal trends observed in this piezometer and correlations with adjacent piezometers.

Between 1977 and autumn 1988 the average change in Bee Farm Road catchment groundwater levels downslope was -0.75 m yr^{-1} and in Tunnel Road catchment the average change was -0.40 m yr^{-1}. Individual level changes on Bee Farm Road catchment ranged from 0 m (118) to -10 m (104). Level changes at Tunnel Road catchment varied from +0.41 m (17) to -7.2 m (09) in the same period.

Levels on Bee Farm Road catchment declined at a faster rate than Tunnel Road catchment and were more variable. Several piezometers indicated rises in 1984, against the general trend, with subsequent falls (101, 103, 104, 115, 120). This may reflect the high rainfall during 1983. Limited response to this rainfall was observed at Tunnel Road catchment (Fig. 6), perhaps due to the generally greater depth to groundwater in this catchment.

Downslope water levels on Bee Farm Road catchment rose an average 6.57 m in the period 1988 to 1990 and have remained around these levels in 1991 (average 0.33 m fall) and 1992 (average 0.35 m rise). Groundwater at similar elevations on the Tunnel Road catchment continued to decline - on average 0.84 m between 1988 and 1992.

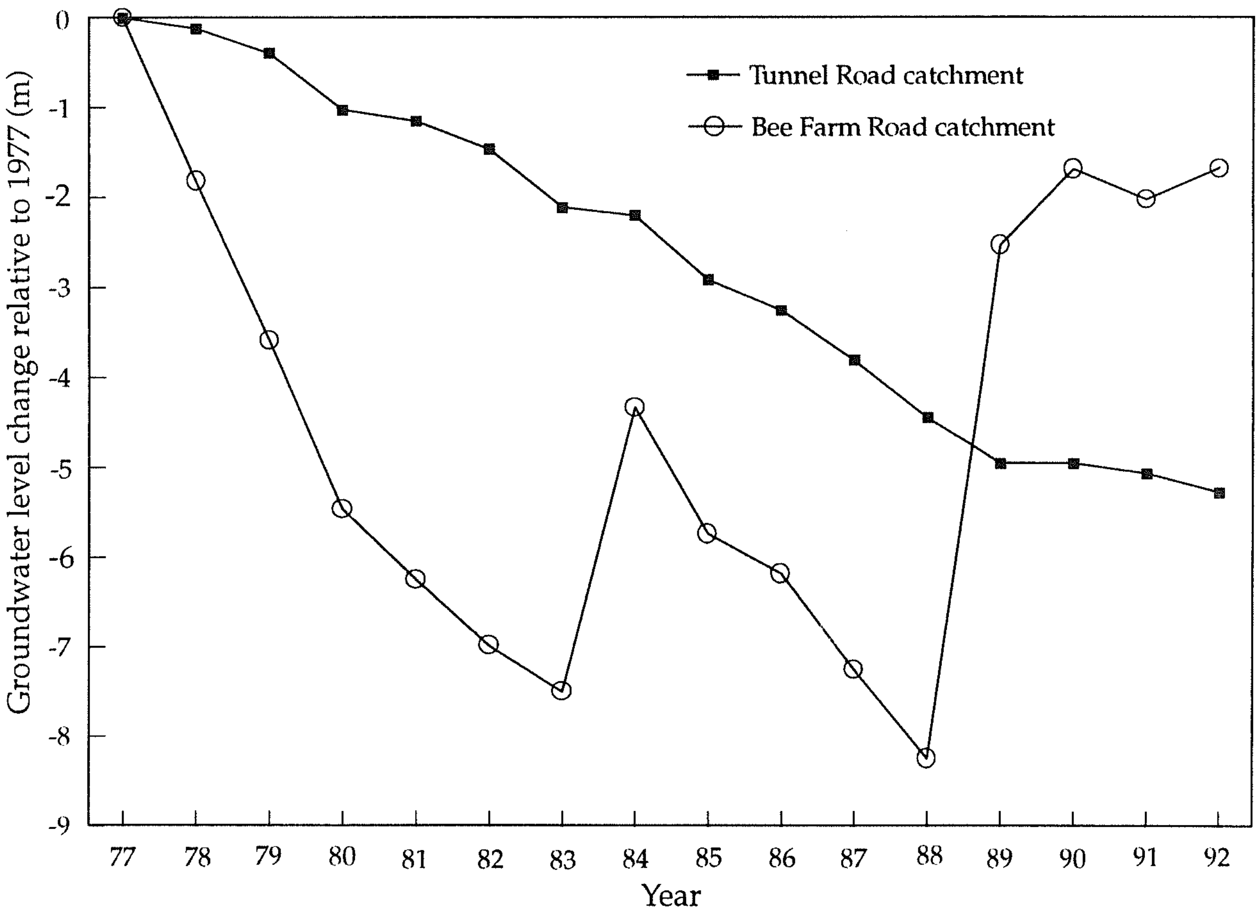

Fig. 6 Change in annual minimum groundwater levels - downslope bores, relative to 1977

Bore 119, which lies within the mined area of the Bee Farm Road catchment and had been dry at the minimum until 1987, rose 2.8 m to May 1991.

A premining correlation in the trend of groundwater levels between the mined and control catchments was used to separate the groundwater response to mining from that due to climatic effects (Fig. 7). Although groundwater levels did not react to mining until 1989, the response in the downslope bores was marked in this year (+6.5 m) and has continued to trend upwards, although at a lesser rate (average +0.5 m yr^{-1}, 1990 to 1992).

The variability in groundwater level behaviour between the treated and the control catchments lowered the confidence with which the mining response was separated from the response to climatic trends.

A second estimate of the groundwater response to mining was made using a premining correlation between the average annual change in groundwater level of the mined catchment and the catchment rainfall of the preceding year (Fig. 7). Using this method a response to mining was identified in the first year following mining (1987, +2.8 m), and continued until 1991, at which time the total rise due to mining was 9.1 m.

Whilst the timing of the mining response determined by each approach differs, there is general agreement in the scale of the groundwater level response. By 1992 the magnitude of the groundwater level rise determined by correlation with the control catchment was 8.0 m and by correlation with rainfall was 8.4 m.

4.3 Streamflow

Streamflow for Bee Farm Road catchment was examined on the basis of annual yields. These were compared to annual yields from Tunnel Road catchment and to annual rainfall totals. Correlations with Tunnel Road were intended to separate changes in streamflow yield attributed to climatic trends from those due to mining.

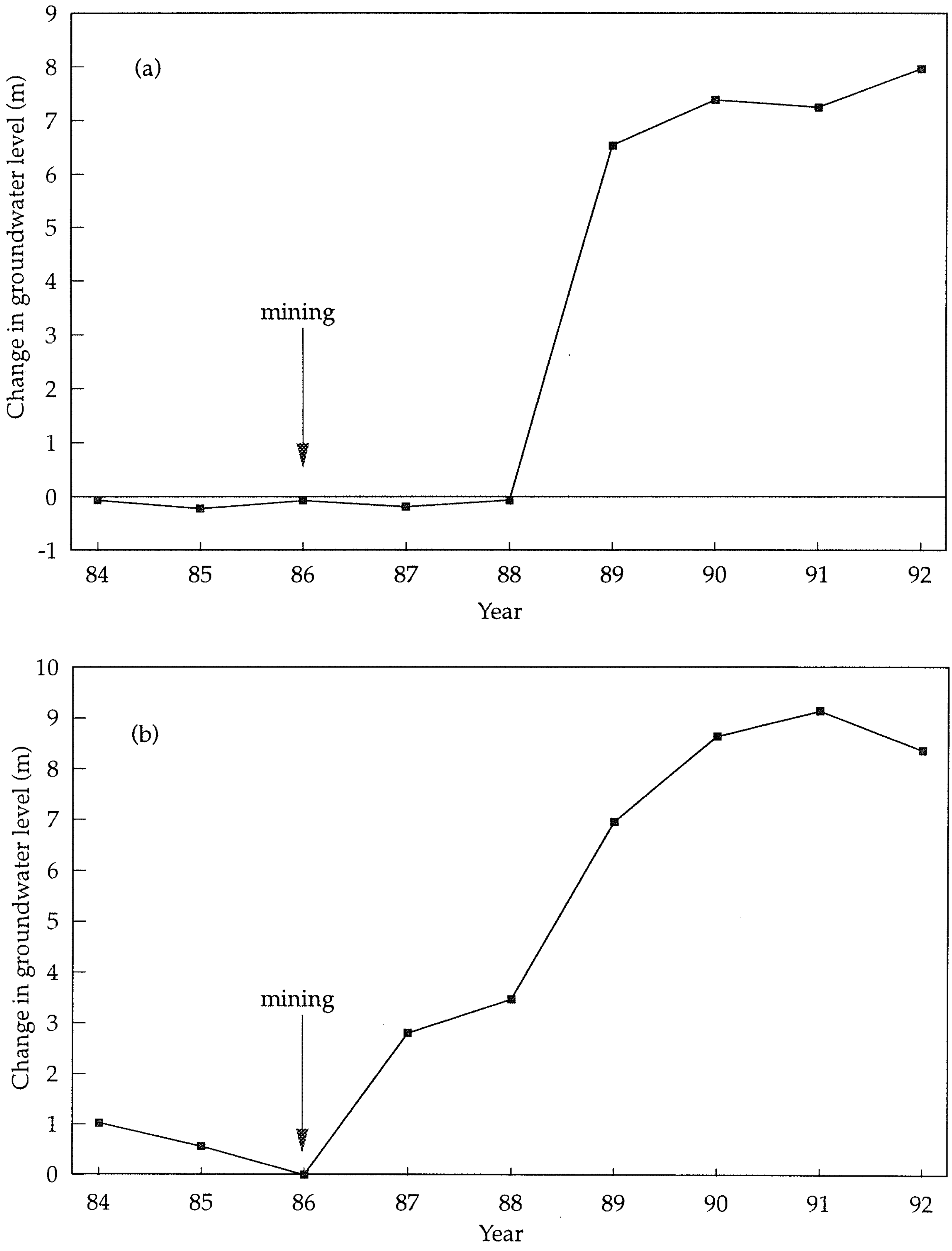

Fig. 7 Downslope groundwater response to mining Bee Farm Road Catchment:-
(a) determined by correlation with control catchment
(b) determined by correlation with rainfall

Streams on both catchments were flowing at the start of monitoring in May 1975, so that 1975 data lacks approximately 6 weeks of low flow record.

Water yield from these catchments was very low. Average streamflow from both catchments was less than 1 mm. This represents less than 1% of rainfall.

Notwithstanding mining induced changes, streamflow characteristics were highly variable during the monitoring period (Fig. 8). The relationship of annual rainfall to streamflow changed significantly during the 17 years of observation. The overall decline in yield corresponds with the reduction in groundwater levels and reflects a decrease to zero in the groundwater contribution to surface flow. In 1975 and 1976 flow at Bee Farm Road occurred throughout extended dry periods, indicating contribution from groundwater. In 1977 flow occurred in five months of late winter and spring only. In 1979 total water yield comprised two discrete flow events in direct response to rainfall. The variation in streamflow characteristics is illustrated by Figure 9.

The streamflow of Bee Farm Road catchment was separated into quick response (assumed surface runoff) and baseflow (shallow subsurface and deep groundwater) components to determine the groundwater contribution to streamflow. A HYDSYS program Hybase, which uses a digital filter technique as described by Lyne and Hollick (1979), was employed for the baseflow separation. Three backward and forward passes were made through the data file of 5 minute values. A filter factor of 0.65 was used.

The results confirm a decline in shallow subsurface and deep groundwater contributions to surface flow (see Table 1), and correspond well with changing stream salinity characteristics observed in this time.

Contribution to baseflow since 1980 appears to be from shallow subsurface flow and not deep groundwater. This applies equally to the increase in baseflows (increase from an average 5% to 16% of total flow) observed after mining. Results obtained from groundwater levels in the downslope bores and stream salinities observed in this time support this.

Year	Streamflow (mm)	Qb/Qt[1] %
75	5.25	82
76	1.36	67
77	0.27	48
78	0.85	34
79	0.0013	0
80	0.0002	0
81	0.0988	10
82	0	-
83	0.154	9
84	0	-
85	0	-
86	0	-
87	0	-
88	0.44	11
89	0.0179	1
90	0.0429	24
91	0.047	29

Table 1 : Baseflow contribution to total flow.

Notes

1. Qb - baseflow component of streamflow
   Qt - total streamflow

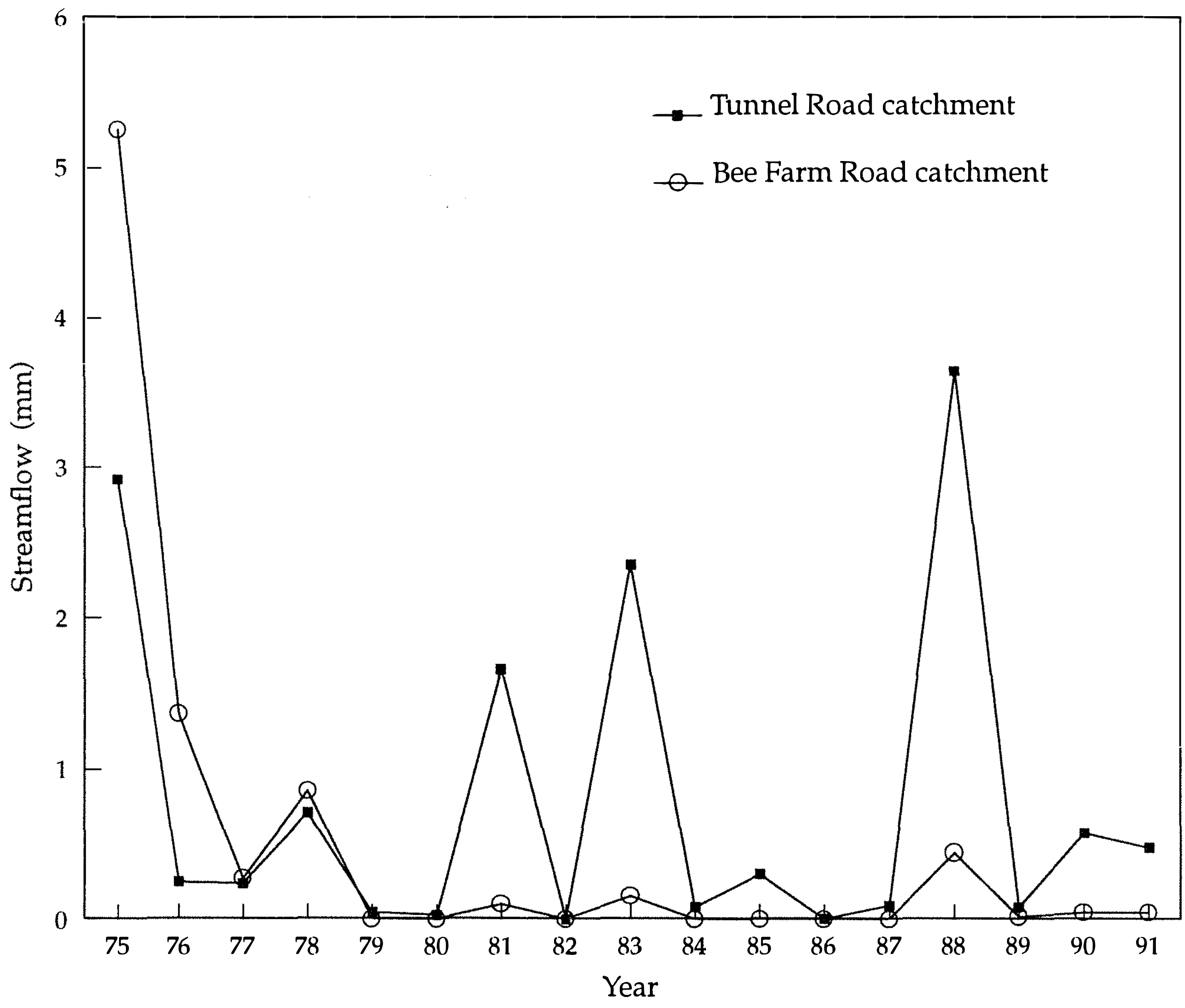

Fig. 8 Mt Saddleback catchments annual streamflow

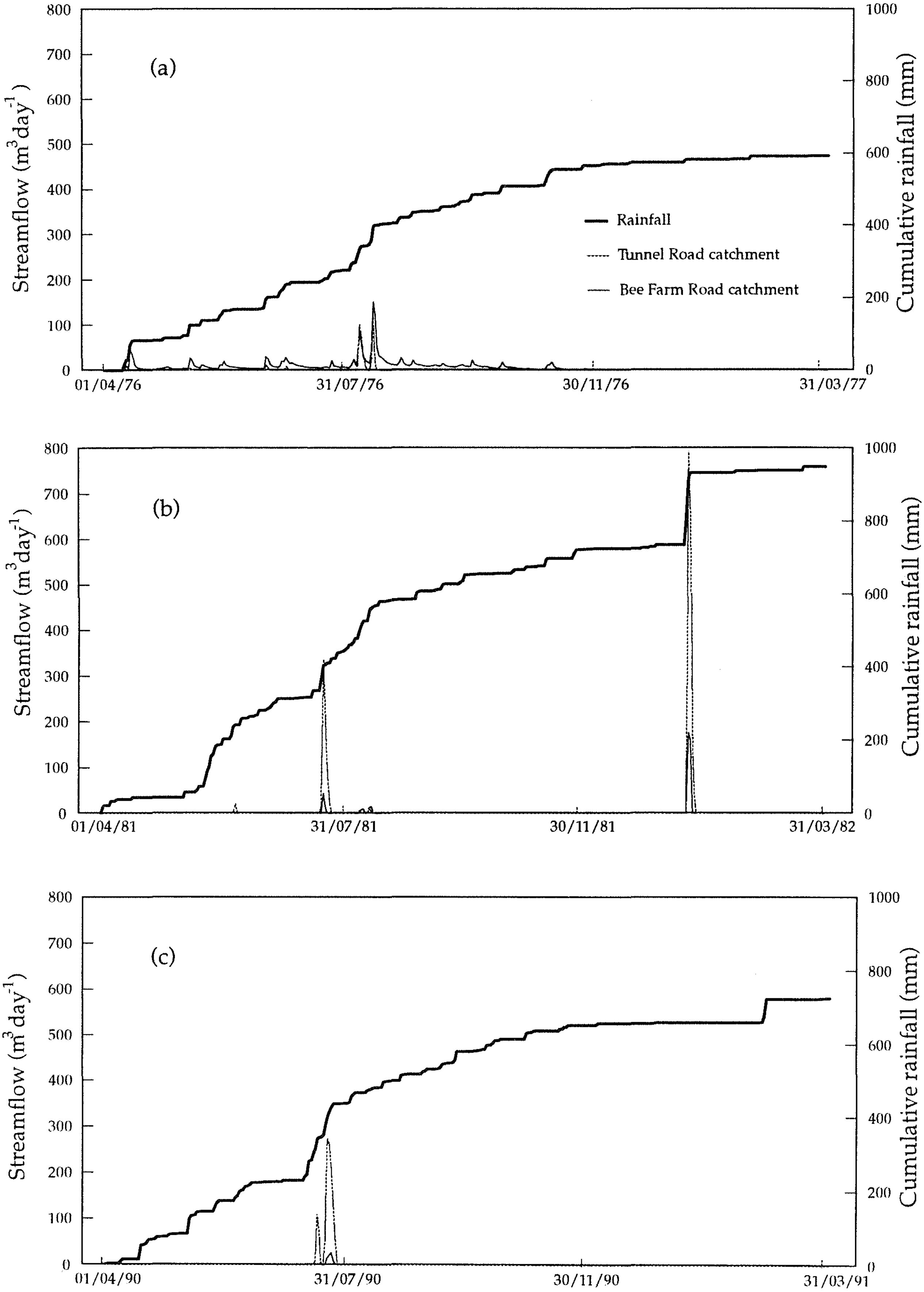

Fig. 9 Streamflow and rainfall for Bee Farm Road and Tunnel Road catchments
(a) 1976; (b) 1981; (c) 1990.

There has been a small increase in water yield due to mining (Fig. 10). The increase was first observed in 1988, despite clearing first occurring during pre-winter 1986. This coincides with observed increases in groundwater. Both 1986 and 1987 were very dry years (annual rainfall 483 mm, 636 mm respectively).

The increase in water yield from Bee Farm Road catchment ranged from 0.01 mm for annual rainfall of 690 mm to 0.2 mm for annual rainfall of 900 mm. This represents increases on premining streamflow of 30% and 90% respectively, as predicted by correlation with the streamflow of Tunnel Road catchment. The increase in yield is not linearly related to annual rainfall.

Mining appears to have lowered the annual rainfall threshold for flow to occur from 750 mm (1981 - 1985) to 670 mm (1986 - 1990). The results of 1991 however, suggest a change towards the pre-mining annual rainfall to streamflow relationship (Fig. 11). This is a broad indication only. Examination of the rainfall to streamflow relationship in greater detail would more appropriately be done at a shorter time scale (perhaps to consider the duration and intensity of storm events) for these catchments.

4.4 Stream Salinity

Stream salinity is described in terms of chloride ion (Cl^-) concentration. A relationship between sample conductivity and Cl^- was established to determine chloride values for the bulk of samples which underwent basic analysis (pH, colour, conductivity and turbidity).

Whilst not providing the detail of continuous water quality observations the samples obtained may be considered a reasonable reflection of real stream conditions, both in absolute and flow weighted terms. The exceptions to this are 1990 and 1991 where few samples were obtained during the limited flow events.

A marked decline in stream salinity occurred at both catchments during the pre-treatment period, reflecting a decreasing contribution of groundwater to surface flow. Bee Farm

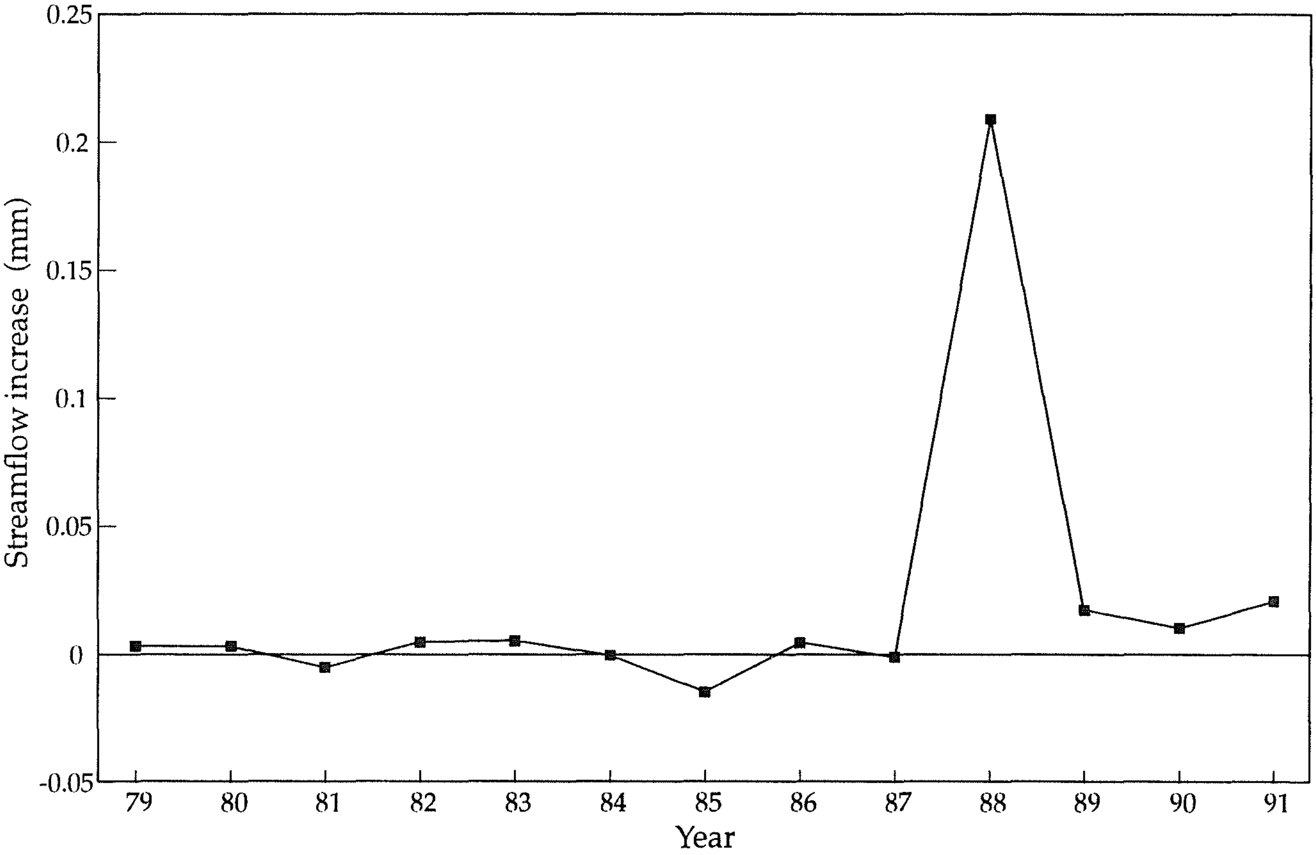

Fig. 10 Bee Farm Road catchment - streamflow response to mining

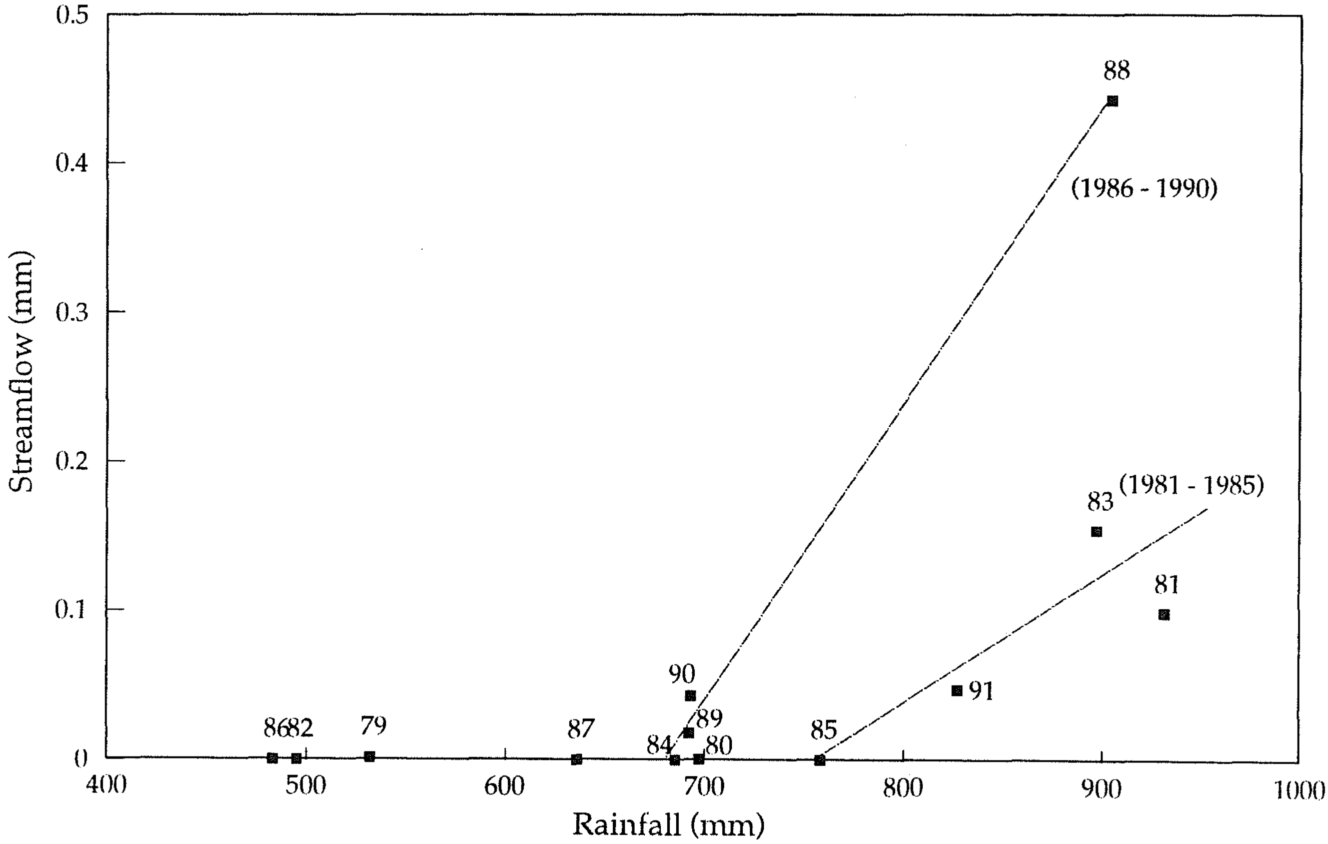

Fig. 11 Bee Farm Road catchment - streamflow to rainfall relationship

Road flow weighted average salinity reduced from an average 475 mg L^{-1} Cl^- for the years 1975 to 1977 to 24 mg L^{-1} Cl^- in 1981. Figure 13 illustrates the variation in flow and salinity encountered during monitoring.

In the two years of flow at Bee Farm Road between 1980 and 1988 (1981 and 1983), salinity averaged 24 mg L^{-1} Cl^-. Post mining the flow weighted average salinity increased to 149 mg L^{-1} Cl^- in 1988 (Fig. 12). Stream yields in 1990 and 1991 were similar (0.043 mm and 0.047 mm respectively) and stream salinity was correspondingly similar (83 mg L^{-1} Cl^- and 62 mg L^{-1} Cl^-).

4.5 Catchment Salt Balances

Salt balances of both catchments were examined in terms of the predominant anion, chloride (Cl^-). A relationship between conductivity and chloride was established to determine chloride output from the catchments via streamflow.

Both catchments have been accumulators of salt for the duration of the study (see Table 2 and Table 3). Since groundwater stopped discharging to the streams both catchments have retained at least 95% of the salt deposited by rain. Mining has had an insignificant effect on the output to input ratio.

The salt balances are based on the assumption that streamflow was the sole mechanism for salt export. The figures however, need to be treated with caution given previous estimates of groundwater underflow from the catchments of 1 to 4 times the magnitude of streamflow (Stokes, 1983).

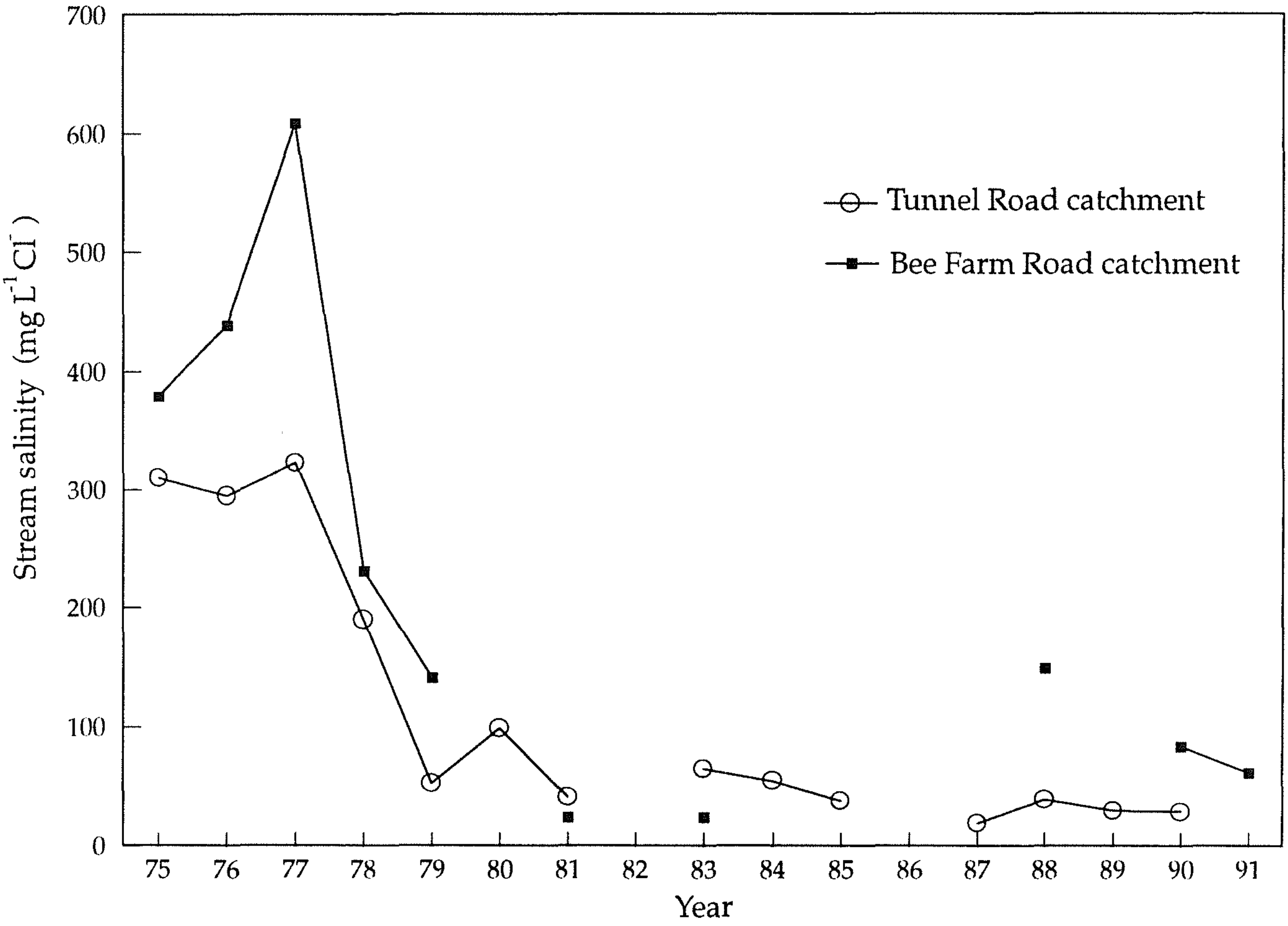

Fig 12 Mt Saddleback catchments - stream salinity

note: no data obtained during 1991 flow at Tunnel Road catchment.

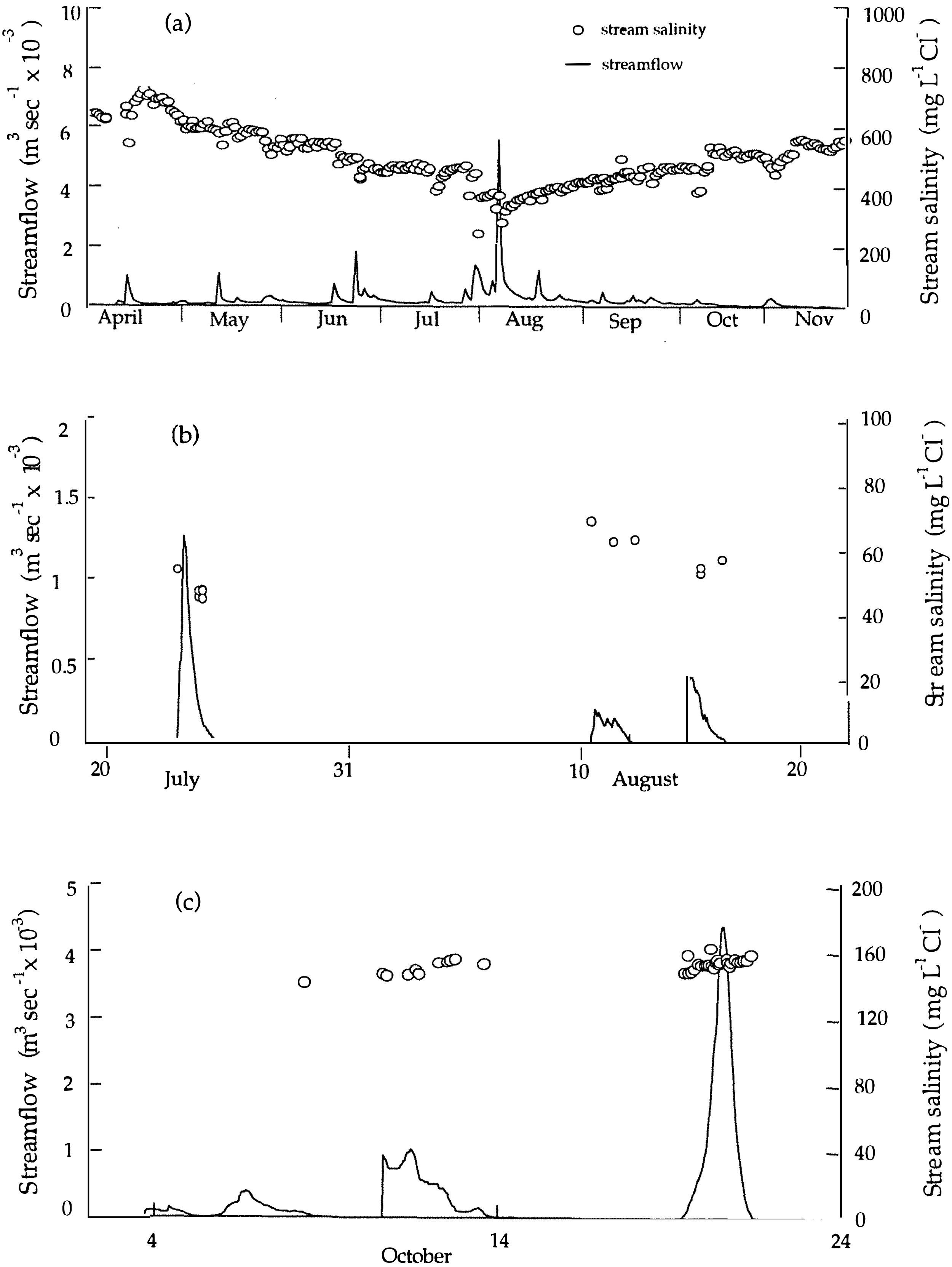

Fig. 13 Streamflow and stream salinity characteristics for Bee Farm Road catchment
(a) 1976; (b) 1981; (c) 1988.

YEAR	RAINFALL INPUT			STREAM OUTFLOW			OUTPUT/ INPUT %
	mm	chloride conc. [1] (mgL^{-1})	saltfall (kg Cl^-)	mm	chloride conc. [2] (mgL^{-1})	saltload (kg Cl^-)	
75	620	3.4	3810	5.2	378	3600	94
76	569	3.4	3500	1.4	439	1080	31
77	635	3.4	3910	0.27	608	300	7.6
78	694	3	3770	0.86	231	360	9.5
79	532	3.8	3660	0.0013	141	0.3	0.009
80	697	4.5	5680	0.0002	n.d. [3]	-	-
81	931	5.7	9600	0.099	23	4.2	0.04
82	495	4.2	3760	0	0	0	0
83	897	4	6490	0.15	24	6.8	0.10
84	685	4.6	5700	0	0	0	0
85	758	3.1	4250	0	0	0	0
86	483	2.9	2540	0	0	0	0
87	636	3.2	3680	0	0	0	0
88	904	4	6540	0.44	149	120	1.82
89	692	2	2500	0.018	0	0	0
90	693	2	2510	0.043	83	6.5	0.26
91	827	3.4	5090	0.047	62	5.3	0.10

Table 2 : Bee Farm Road Catchment Chloride Balance

YEAR	RAINFALL INPUT			STREAM OUTFLOW			OUTPUT/ INPUT %
	mm	chloride conc. [1] (mgL^{-1})	saltfall (kg Cl^-)	mm	chloride conc. [2] (mgL^{-1})	saltload (kg Cl^-)	
75	593	3.4	4170	2.9	310	1870	44.8
76	556	3.4	3910	0.25	294	150	3.9
77	620	3.4	4360	0.24	323	160	3.8
78	697	3	4330	0.71	190	280	6.4
79	526	3.8	4140	0.046	52	5	0.12
80	683	4.5	6360	0.028	99	5	0.09
81	927	5.7	10940	1.7	41	140	1.3
82	489	4.2	4250	0.79	n.d. [3]	-	-
83	880	4	7290	2.35	64	310	4.3
84	679	4.6	6460	0.08	54	9	0.14
85	759	3.1	4870	0.30	38	23	0.48
86	459	2.9	2760	0.0015	n.d. [3]	-	-
87	644	3.2	4300	0.09	19	3	0.084
88	865	4	7160	3.6	39	290	4.09
89	676	2	2800	0.081	29	4	0.17
90	720	2	2980	0.58	29	34	0.012
91	833	3.4	5860	0.48	n.d. [3]	-	-

Table 3 : Tunnel Road Catchment Chloride Balance

Notes.

1. Chloride concentrations determined from gauge M509313 located within Bee Farm Road Catchment. Years 1975 to 1977 and 1991 average chloride concentration from the period of record used.
2. Chloride - conductivity relationships:-
   Bee Farm Road Catchment chloride (mgl^{-1}) = 3.074 x conductivity (m.siem m^{-1}) - 43.74
   Tunnel Road Catchment chloride (mgl^{-1}) = 3.179 x conductivity (m.siem m^{-1}) - 32.66
3. No data collected.

5. DISCUSSION

5.1 Natural Variation in Groundwater Levels, Streamflow and Stream Salinity

Bee Farm Road and Tunnel Road catchments were monitored for 10 years (1975 - 1985) prior to mining Bee Farm Road catchment. During this period rainfall was well below the long term average (740 mm) and groundwater levels, stream yield and stream salinity declined. The reduction in stream yield and stream salinity was attributed to the decline in groundwater levels. It follows the converse may also occur - during extended periods of higher rainfall groundwater levels may rise sufficiently to again discharge to the stream, resulting in higher stream yields and stream salinities.

The 10 year backward moving average annual rainfall at Marradong, 10 km north of the study site was in decline between 1964 and 1986. It has reduced from 815 mm for 1955 - 1964 to 627 mm for 1977 - 1986. Under natural forest conditions groundwater levels have moved in sympathy with rainfall - reflecting diminishing recharge (Fig. 14).

The hydrological results of this trial mining experiment, as with all other trials, should be considered in the context of antecedent climatic conditions as, in this case, a 40 year period of very low rainfall in comparison to the previous 40 years has resulted in relatively low groundwater levels prevailing during the mining trial.

5.2 Groundwater Response to Mining

Marked differences were evident in the behaviour of groundwater levels between Tunnel Road catchment and Bee Farm Road catchment during the pre-treatment period of monitoring. The large depth to groundwater and the unusually steep groundwater gradient (in the order of 8%) may have contributed to the inconsistencies. The groundwater results of this study should be used with caution if applied to other catchments.

To define the groundwater response to mining with more confidence the response was

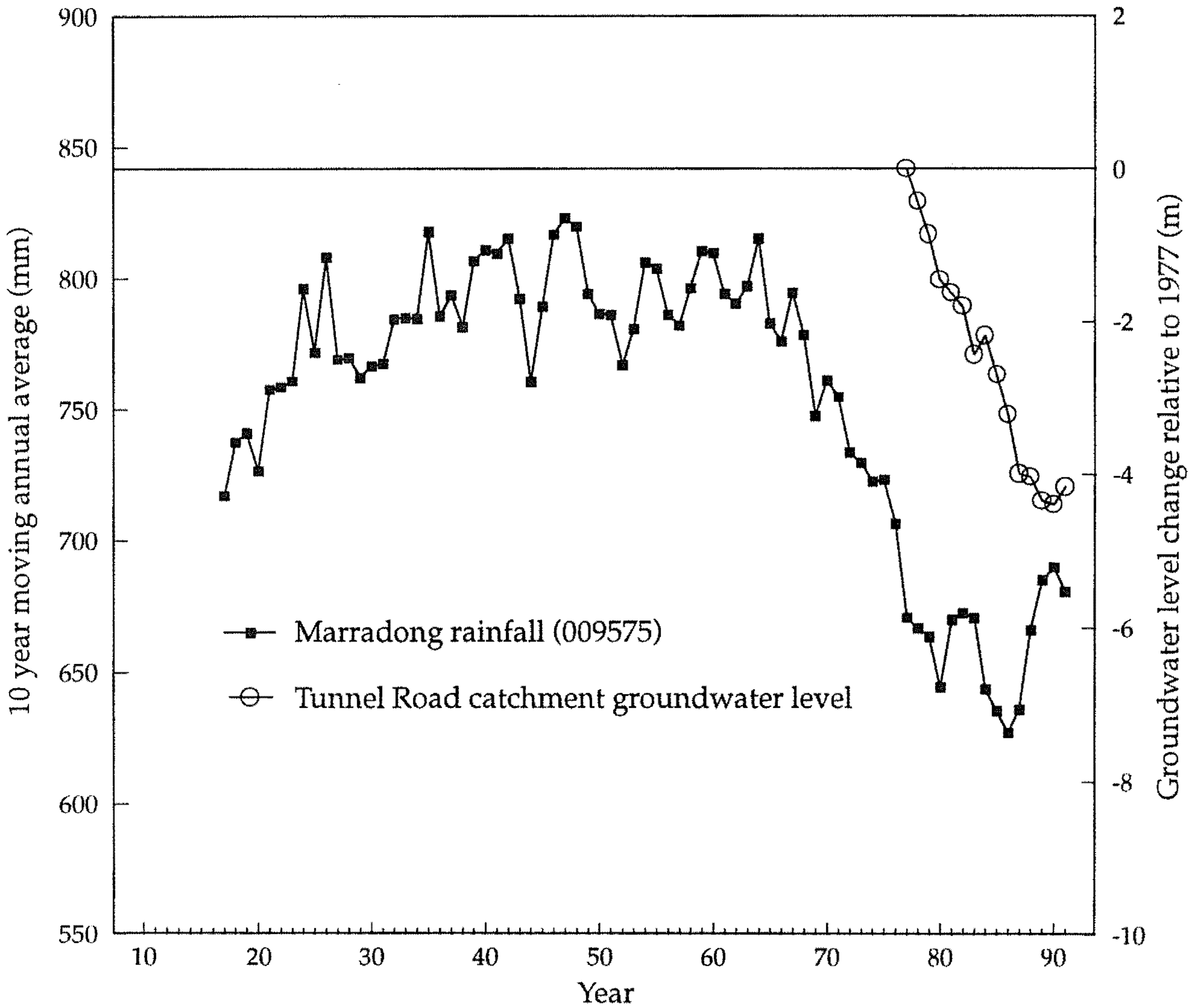

Fig. 14 Long term rainfall and groundwater level trends

determined using two independent methods. Whilst the temporal distribution of the response to mining determined by each approach differed, there was general agreement in the scale of the groundwater level response (Fig 15). By 1992 the magnitude of the groundwater level rise determined by correlation with the control catchment was 8.0 m and by correlation with rainfall was 8.4 m.

Groundwater levels therefore, have risen in the order 8 m in 6 years as a result of mining. This represents an approximate annual rise of 1.2 m since mining commenced.

This is higher than the groundwater response to mining determined for Del Park catchment, in the high rainfall zone (Ruprecht *et al*, 1990), where the maximum response in groundwater levels was 3 - 4 m, attained 4 years after mining. Ruprecht and Schofield (1991) proposed that greater rates of water level rise can be expected when the increased groundwater recharge resulting from clearing is not offset by groundwater discharge to the stream. It is significant that despite the rise in groundwater, the level in only one piezometer (101) has recovered to the levels observed in 1977, which was the first year in a period of declining groundwater that a sustained baseflow did not occur. This suggests groundwater has not discharged to the stream since mining. Streamflow and stream salinity characteristics between 1988 and 1991 support this.

5.3 Streamflow Response to Mining

Bee Farm Road and Tunnel Road catchments are very low yielding catchments. Streamflow averaged 0.65 mm, or 0.1% of rainfall, during the period 1975 to 1991. The results were biased upwards by the sustained flows which occurred in the initial years of monitoring.

The observed increase in streamflow following mining of Bee Farm Road catchment corresponded with the rise in groundwater in the vicinity of the mined area. However, groundwater levels have not attained the levels at which groundwater discharge to the stream was last observed. In May 1977 the depth to groundwater in the valley piezometers averaged 5.6 m; in May 1992 the same piezometers averaged 7.3 m depth to

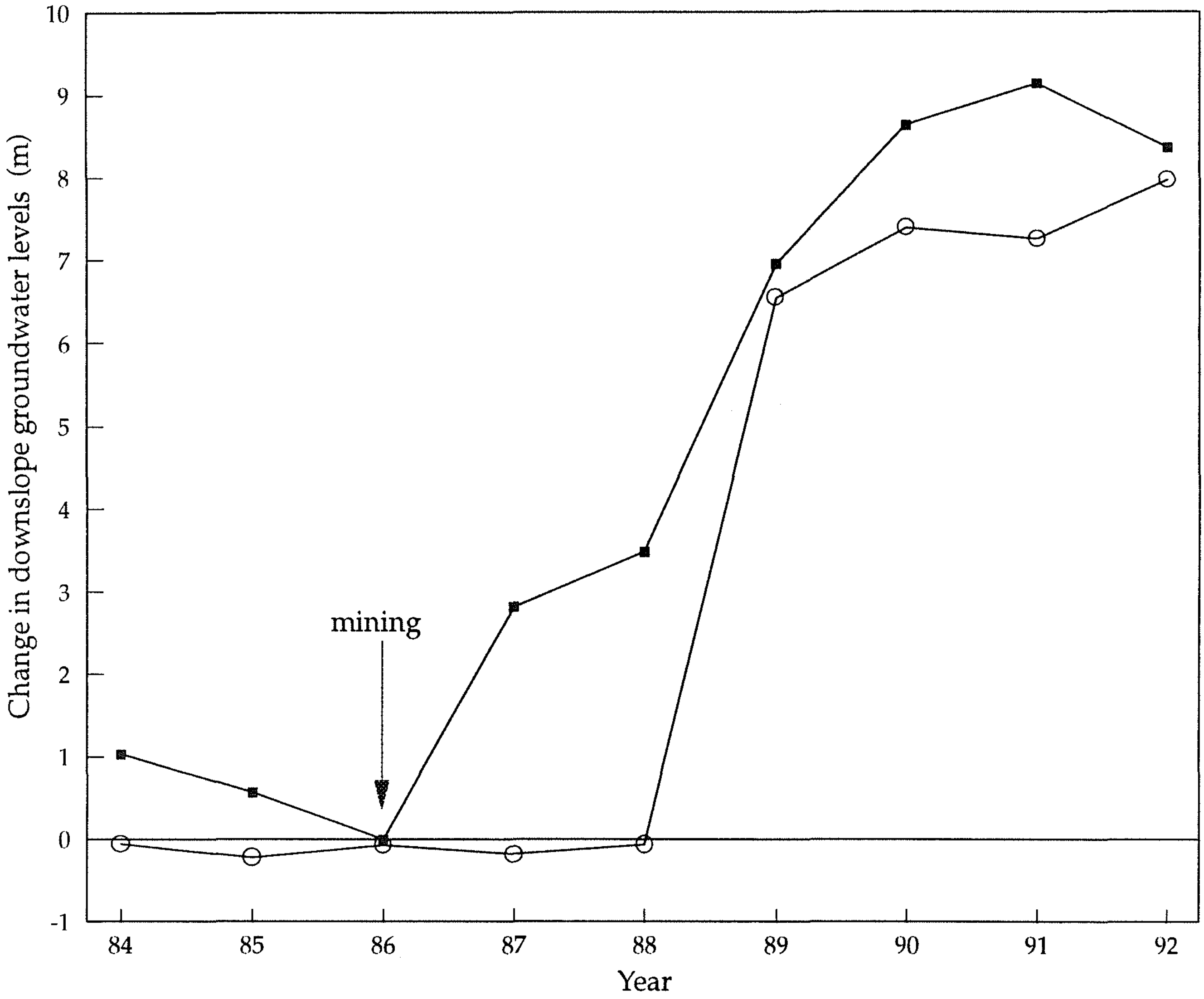

Fig. 15 Comparison of groundwater response to mining determined:-

by correlation with rainfall

by correlation with groundwater levels from control catchment groundwater. Therefore, despite the rise in groundwater levels, it is considered the increased yield is due primarily to greater surface runoff and shallow subsurface flow.

The maximum increase in streamflow observed due to mining, 0.2 mm is considered insufficient to warrant further attention.

5.4 Stream Salinity

The cessation of groundwater discharge to the stream, inferred from the declining groundwater levels, and the lack of sustained low flows from the catchment during periods of no rainfall, is supported by a large reduction in stream salinity, from 149 mg L^{-1} Cl^{-} for the years 1975 to 1977 to 24 mg L^{-1} Cl^{-} in 1981. Following mining stream salinity averaged 98 mg L^{-1} Cl^{-}.

Although groundwater is considered not to have discharged to the stream since mining, groundwater levels have risen sufficiently close to the surface at their maximum to facilitate the upward migration of salt to the zone of subsurface flow. At bore 101 the maximum groundwater level was around 2 m below the surface in 1988 and 1989. The observed increase in salinity post mining is considered the result of subsurface flow mobilizing salt brought nearer the surface by elevated groundwater and capillary action.

Within the mined areas excavation has resulted in zones of significant salt storage being at or near the new ground surface. It is possible lateral subsurface flow from these areas may also contribute salt to surface flow. This may be an alternative or contributory mechanism by which stream salinity increased, but one however, that requires further investigation.

6. CONCLUSIONS

* Under natural conditions, water yield from Bee Farm Road catchment and Tunnel Road catchment was very low, being less than 1% of rainfall. Groundwater levels were significantly more responsive to climatic trends on Bee Farm Road catchment than Tunnel Road catchment.

* Bauxite mining on 10% of Bee Farm Road catchment has resulted in a rise in local groundwater levels and increases in stream yield and stream salinity.

* Variability in groundwater behaviour made it difficult to distinguish the groundwater level response to mining from the reponse to climatic trends. Downslope groundwater levels in the vicinity of the mined area rose in the order of 8 m in six years following mining.

* The increase in stream yield due to mining was negligible. The increase ranged from 0.01 mm for annual rainfall of 690 mm to 0.2 mm for annual rainfall of 900 mm. The maximum response represents a 90% increase in streamflow and 0.02% of rainfall.

* Stream salinity increased by 125 mg L^{-1} Cl^- to 149 mg L^{-1} Cl^- in the first year of flow following mining. In subsequent years the increase above premining values was 50 mg L^{-1} Cl^-.

* These results must be considered in the context of antecedent conditions. This trial was conducted during a period of relatively low groundwater levels due to an extended period of below average rainfall. Had this experiment been conducted under a higher rainfall regime (as in the period 1920 to 1960) the results are likely to have been significantly different.

7. RECOMMENDATIONS

1. Monitoring of rainfall, groundwater levels and quality and streamflow and stream salinity should be continued at least until 1995, at which time the trial should again be reviewed. The review at this time should address the impact of mining an upslope area cleared for excavation during 1992.

2. Stream salinity monitoring should be upgraded to cater for the flashy nature of streamflow.

3. Further investigation into the leaching of salt brought to, or near the surface by excavation of the bauxite profile and, the implications of this for mining in the intermediate rainfall zone, should be conducted.

4. Further investigation into medium to long term variations in catchment hydrological characteristics in response to climatic trends should be conducted so that the results from past, present and future land use trials may be considered in this perspective.

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