67

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J. K. Ruprecht,(1)
G. L. Ainsworth (2)
N. G. Lareu (1)
N. J. Schofield (1)

(1) Water Authority of Western Australia
(2) Alcoa Australia Ltd.

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ABSTRACT

A small (1.3 km^2) experimental forested catchment near Dwellingup, W.A. was partially mined and rehabilitated over the period 1975 to 1979. One objective of the study was to determine the effect of this treatment on groundwater level, which has significance for salinity impacts. Twenty-one per cent of the catchment was cleared and mined from 1975-77 and the area was rehabilitated with the establishment of exotic and native vegetation from 1977-79. Groundwater levels beneath the minepit and downslope of the minepit began to rise (relative to a control) in 1976 and attained a maximum of 3 m by 1980. Subsequently groundwater levels fell to reach near pre-mining levels by 1987. This decline is attributed to the rapid development of a high (70-100%) vegetation cover within six years of replanting. The revegetation was characterised by a very strong understorey component. This study suggests that mining in more salt-sensitive areas could have a transient impact on stream salinity but is unlikely to significantly impact stream salinity in the longer term.

CONTENTS

CONTENTS (Cont'd)

List of Figures

List of Figures (cont'd)

List of Tables

1. INTRODUCTION

Bauxite mining in the Darling Range has the potential to increase stream salinity. Alcoa's mining operation is currently taking place in the high rainfall zone (>1100 mm/yr) where the risk of significantly increasing stream salinity is minimal. However Alcoa plans to extend their mining to lower rainfall areas where soil salt storage is high and the potential to increase stream salinity is greater (Schofield, 1988). Before Alcoa can mine these areas, it has a legal obligation to demonstrate that such mining will not increase stream salinity to the extent that it would be detrimental to water resources (Alcoa, 1978; Steering Committee for Research on Land Use and Water Supply, 1985).

The process leading to stream salinisation following clearing of native vegetation in this region have been clearly described (Peck and Williamson, 1987; Schofield et al., 1988). The clearing of native forests leads to increased groundwater recharge, rise in groundwater levels, dissolution and mobilisation of salts and eventual discharge of salts to streams. In the case of bauxite mining the cleared area is usually revegetated within 2-3 years of clearing and rising groundwaters should be brought under control within a few years of planting.

Previous analyses of the Del Park study gave differing results. Peck (1983) analysed the change in minimum piezometric elevations from 1975 to 1981 for bores affected by mining and for bores in native forest within the Del Park catchment. From 1975 to 1981 a rise of 2.05 m was calculated between the mean of the bores affected by mining and the mean of the bores within native forest, with statistical significance at the 0.1% level.

Hurle and Associates (1983) in analysing the Del Park results, found no clear definition of the significance of bauxite mining in causing annual groundwater level changes. They found that complications arising from mining having taken place during a seasonal trend from decreasing to increasing annual rainfall. Forest thinning in parts of the unmined areas had made it difficult to compare the mined areas with a control area.

This report presents results from the first study of the impact of mining and rehabilitation on groundwater levels over a 10 year period. This study was by necessity carried out in an area of active mining in the high rainfall zone. The results are important to the understanding and prediction of the effects of mining on groundwater levels, stream yield and stream salinity in both high and low rainfall areas.

2. CATCHMENT DESCRIPTION

2.1 Location and Climate

The Del Park catchment is located approximately 100 km south of Perth and 5 km NNW of Dwellingup (Fig. 1). The catchment area is 1.3 km^2 and the stream discharges directly into South Dandalup reservoir (Fig. 1).

The climate of the region is characterised by high winter rainfall and hot, dry summers. The catchment annual rainfall over the period 1975-86 was 1128 mm, 76% of which fell from May to October. The long term annual rainfall (1938-86) at Dwellingup was 1276 mm. The average annual pan evaporation (1969-86) at Dwellingup was 1505 mm.

2.2 Topography and Geology

The Del Park catchment has an approximate elevation of 300 m above sea level, with a hillslope transect typically varying from 277 m to 307 m. Valley slopes are generally moderate with an average inclination of 10%.

The catchment is located within the south western province of the Archaean Yilgarn Block. The bedrock is generally granitic with a large number of intruding sheet-like dykes comprised mainly of dolerite. In situ weathering of the basement rocks has led to the development of a deep lateritic profile.

2.3 Soils

On the middle and upper slopes of the catchment, surface soils of gravelly sands overly caprock. The depth to caprock ranges from 0-2 metres
and averages 0.4 m. Dark organic material is evident to about 0.1 m depth. The caprock may be massive or unconsolidated and is typically about 1 metre thick. Underlying the caprock are typically substantial depths (>10 m) of sandy or silty material which in places becomes more clayey with depth. Where the soils are influenced by a weathered dolerite intrusion,

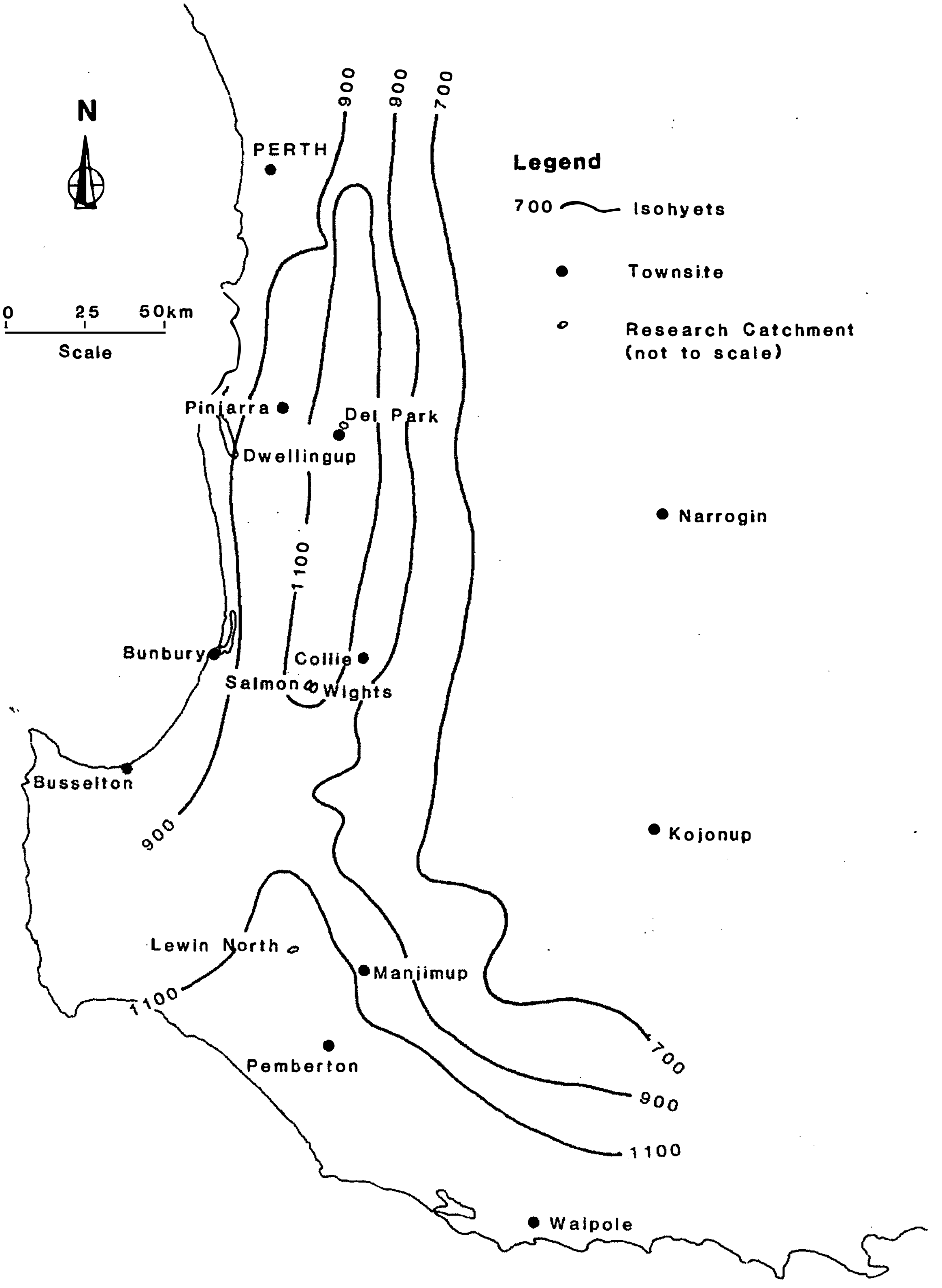


Figure 1 Research Catchments in the Jarrah Forest

a distinctive clay horizon occurs between one and three metres below which the soils are predominantly silty.

2.4 Vegetation

The Del Park catchment vegetation prior to mining consisted of native jarrah forest. The native jarrah forest within the catchment consisted predominantly of jarrah (Eucalyptus marginata) and marri (E. calophylla) on the middle and upper areas and bullich (E. megacarpa) and yarri (E. patens) on the lower slope. The middlestorey is dominated by bull banksia (Banksia grandis) and in some areas by sheoak (Allocasuarina fraseriana).

The forest density of a hillslope transect within mining area C (see Fig. 2) of the catchment, described in detail by Ruprecht et al. (1987), was calculated in terms of basal area (29 m^2 ha^{-1}), projected canopy cover (45%) and leaf area index (1.4). From these measurements the hillslope was categorised as medium density jarrah forest.

In 1977, area C was salvage logged in preparation for mining. This resulted in an estimated reduction of leaf area index of 10% (Ruprecht et al. 1987).

2.5 Mining History

Mining area A at Del Park underwent a mining operation from mid-1975 to mid-1979 (see Table 1). The mining process involved clearing of the native forest, strip mining of the top 4-5 m and subsequent revegetation. Mining area B was cleared for mining in mid-1976 and rehabilitated by mid-1979 (Table 1, Fig. 2).

Table 1 Mining history at Del Park Catchment

Mining area	Clearing	Mining	Rehabilitation
A	3-4Q[1] 1975	2Q/1976 -1Q/1977	2Q/1977 -2Q/1979
B	2Q/1976 3Q/1977	3Q/1977 -3Q/1978	3Q/1978 and 2Q/1979

(1) Q denotes quarter ie. 1Q is Jan-Mar, 2Q is Apr-Jun, 3Q is July-Sep and 4Q is Oct-Dec.

3. VEGETATION MONITORING

3.1 Method

Two sites at the Del Park catchment were assessed. Area B, rehabilitated in 1978/79, is located on the east side of Del Park Road (reference E4724). On the west side of Del Park Road, Area A (reference E4723 and E4727) was rehabilitated in 1977 and 1979 (Fig. 2).

A total area of 22.5 ha of rehabilitated bauxite mined area was surveyed. To assess the vegetation, line transects located 50 m apart were traversed. At 50 m intervals along each transect, an area 10 m in radius (314 m²) was monitored. A total of 96 of these 314 m² sites were assessed. At each of these monitoring points the following data were collected:

TREES

- tree species;
- diameter at breast height (DBH) of each main tree stem
- height of the tallest tree of each species
- the basal area for each tree species calculated using the diameter measurement;

UNDERSTOREY SPECIES

the number of each species was estimated by recording the most physically dominant plants only;
the mean height of the most dominant species;

COVER

visual assessment of the proportion of area covered by understorey foliage;
a 'densiometer' was used to estimate foliage cover above 1.3 m and at ground level, at 4 points. The foliage cover above 1.3 m in height gave an estimate of tree canopy cover;

aerial photos taken annually since 1978 were used to monitor cover over time. Physical barriers within the two sites, such as a haul road and a conveyor line were used as divisions, and numbered 1, 2, 3, 4, 5 (Fig. 2).

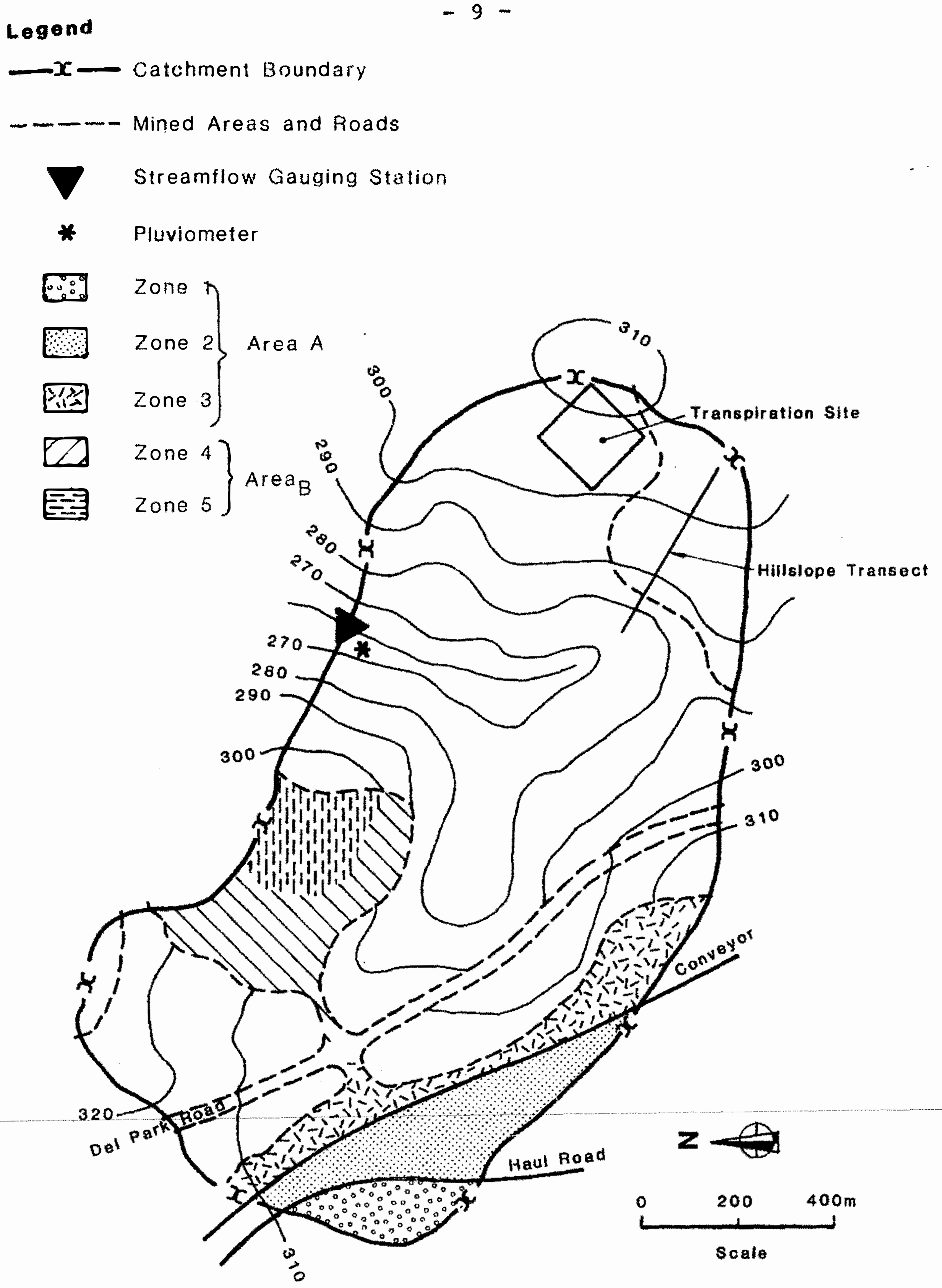


Figure 2 Catchment Plan of Del Park Catchment with Vegetation Mapping Areas

4. GROUNDWATER MONITORING AND ANALYSIS

4.1 Observation Bore Network

A total of 74 groundwater observation bores were installed within the Del Park catchment by Commonwealth Scientific and Industrial Research Organisation (CSIRO) in 1974. The location (see Fig. 3) of the observation bores was based on three grid networks (see Table 2 for listing):

(a) A 200 m square grid across the whole catchment

(b) A 100 m square grid within and downslope of mining areas A and B

(c) A 100 m square grid within and downslope of logged area C

The networks (a), (b) and (c) were installed by CSIRO and Alcoa of Australia Ltd (Alcoa) using a 75 or 150 mm auger. The holes were cased with 40 mm OD PVC pipe with the bottom 3 or 6 m slotted depending on the depth of saturation. The bores typically did not have a sand pack, due to the unconsolidated material collapsing as the auger was withdrawn. A bentonite seal was in most cases installed in the surface soils surrounding the observation bore.

The observation bores were typically monitored on a monthly basis from 1975 to 1980 by CSIRO. In 1981 the frequency of observation was reduced to 3-monthly. Measurements of groundwater level and water quality sampling were reported by Peck et al. (1982) up to 1981. From November 1981 to January 1983 most observation bores were not monitored. In February 1983, Alcoa commenced recording of groundwater levels within Del Park catchment. The frequency of monitoring was typically monthly but for some bores was 3 - monthly. The location of the bores within the catchment are shown in Fig. 3.

Table 2 Groundwater observation bores used in the analysis

WAWA Bore No.	CSIRO No.	Alcoa No.	Natural Surface before	Natural Surface after	Depth (m)	Material at base of bore
Mining area A						
51	2895	E4723-3	309.61	309.61	25.96	Rock
55	2785	E4723-22	308.23	302.69	19.09	Rock
56	2884	E4723-7	306.63	302.58	21.07	Clay
57	2765	E4723-8	302.94		29.07	Rock
60	2784	E4723-11	312.98	306.98	19.94	Rock
66	2883	E4723-18	314.71	307.01	19.69	Rock
Mining area B						
22	2726	E4724-15	299.0	291.97	34.80	Rock
38	2736	E4724-14	297.06	294.09	35.70	Rock
40	2716	E4724-16	301.02	297.01	34.20	Rock
44	2738	E4724-26	313.30	309.79	26.30	Rock
Downslope of area A						
47	2842	E4728-25	288.34		21.06	
48	2843	E4828-16	272.63		36.51	Rock
58	2874	E4723-9	296.38		13.93	Clay
68	2873	E4723-20	302.15		38.94	Clay
69	2743	E4723-21	294.13		17.42	Clay
71	2862	E4728-23	300.94		21.06	Clay
73	2853	E4728-15	279.75		15.65	Clay
74	2723	E4728-14	279.12		12.03	Clay
75	2863	E4728-13	282.53		12.19	Clay
76	2744	E4723-15	291.84		15.63	Clay
77	2734	E4724-23	280.37		8.45	Clay
Downslope of B						
34	2844	E4724-21	277.16		23.00	Clay
35	2725	E4724-19	288.77		17.56	Clay
36	2864	E4724-18	284.28		10.45	Clay
37	2745	E4724-17	287.87		10.45	Clay
79	2714	E4724-25	273.52		12.60	Clay
81	2854	E4724-20	289.89		46.4	Clay
Control area						
2	2635	F4725-20	299.99		30.60	Rock
3	2625	F4725-21	305.16		37.00	Rock
31	2835	E4724-13	272.08		17.64	Clay
867	2665	E4728-11	271.88		10.39	Clay
869	2645	E4728-19	293.65		33.52	Rock
871	2834	E4724-22	271.17		13.98	Clay
872	2814	F4725-19	306.15		42.6	Rock

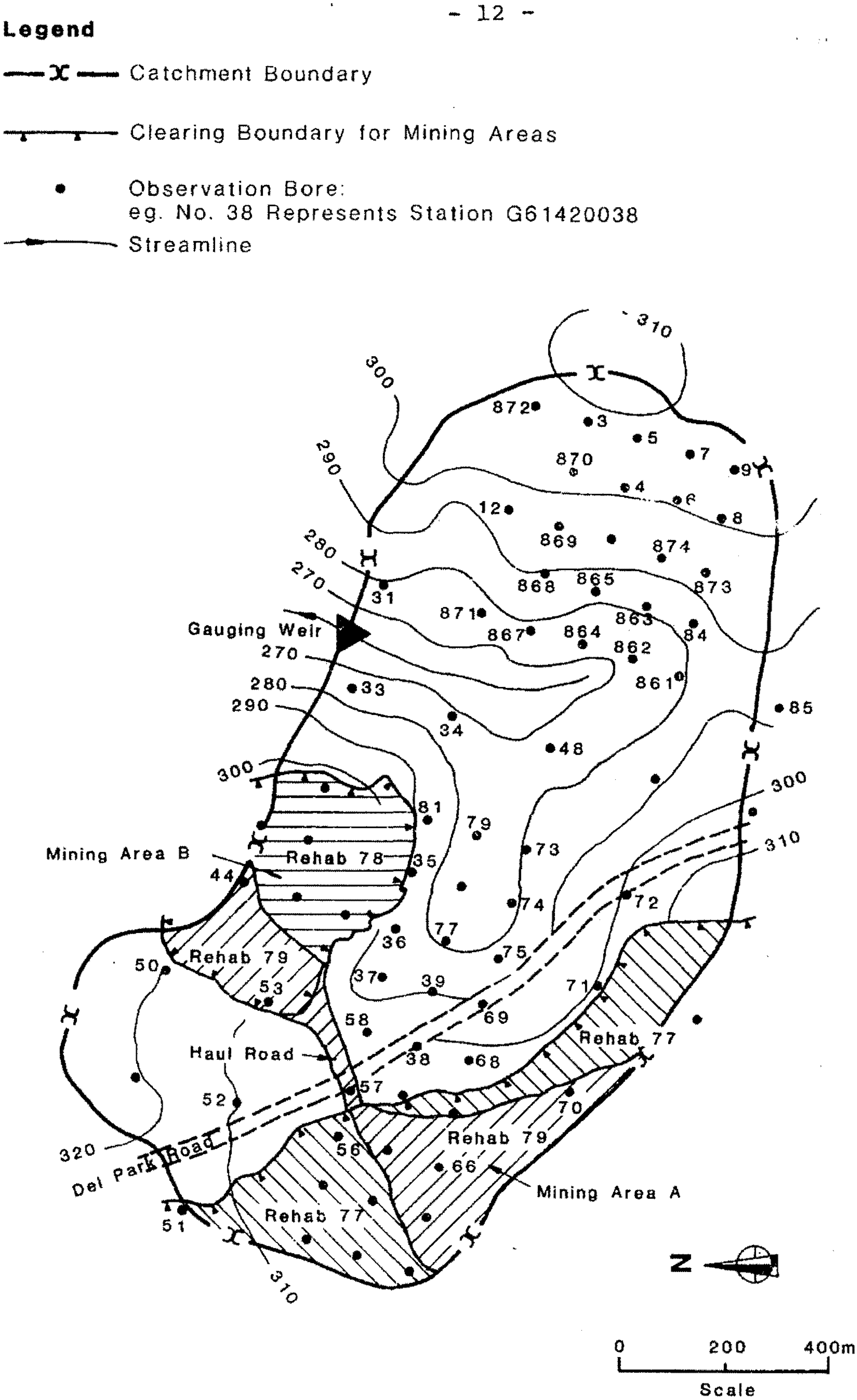


Figure 3 Catchment Plan of Del Park Catchment with Groundwater Monitoring Network

4.2 Analysis

The groundwater level change over time at an observation bore has a delayed and dampened response to the climate and in particular rainfall. This groundwater level response to the climate varies with depth of unsaturated zone, soil properties, vegetation type and density, and catchment surface and bedrock topography. For observation bores within and downslope of mining there is a groundwater level response to mining in addition to the groundwater level response to the climate.

In order to identify the mining groundwater level response, the climatic groundwater level response needs to be subtracted from the total groundwater level response. The method used in this analysis was to compare minimum groundwater levels relative to 1975 for observation bores within and downslope of mining areas A and B to observation bores within a control area.

Variations in the distribution and amount of rainfall strongly influence the maximum groundwater level for a given year. The minimum groundwater level is not affected to the same extent and thus better represents changes in the groundwater storage from year to year. Consequently, the basic analysis conducted for this study was the comparison of annual minimum groundwater levels.

To summarise the groundwater response the yearly minimum water levels of all bores within the following categories were averaged:

(a) Mining area A
(b) Mining area B
(c) Downslope of mining area A
(d) Downslope of mining area B
(e) Control area

5. RESULTS

5.1 Vegetation Response

5.1.1 Tree species

(a) Mining area A

The rehabilitated catchment area for mining area A was 9.3 ha. A total of 691 trees were measured in this area. Forty six sites were assessed which gave a total sampled area of 1.44 ha. The average stocking rate was 480 trees/ha. Ten different species were identified (Table 3).

Table 3: Abbreviation and common name for tree species identified within mining area A

Abbreviation	Species	Common name
EUCACC	E. accedens	powder bark wandoo
EUCCAE	E. caesia	gungurru
EUCCAL	E. calophylla	marri
EUCFOR	E. forrestiana	fuschia mallee
EUCLAE	E. laeliae	Darling Range ghost gum
EUCMAC	E. maculata	spotted gum
EUCMAR	E. marginata	jarrah
EUCRES	E. resinifera	red mahogany
EUCSAL	E. saligna	Sydney blue gum
EUCWAN	E. wandoo	wandoo

The number of each species is shown in Fig. 4 and Table 4. The most dominant species were E. maculata (38.5%) followed by E. accedens (16.2%), E. resinifera (15.6%) and E. wandoo (14.3%). A large proportion of eucalypts monitored had multiple stems. Tree heights ranged from approximately 2 m to 12 m.

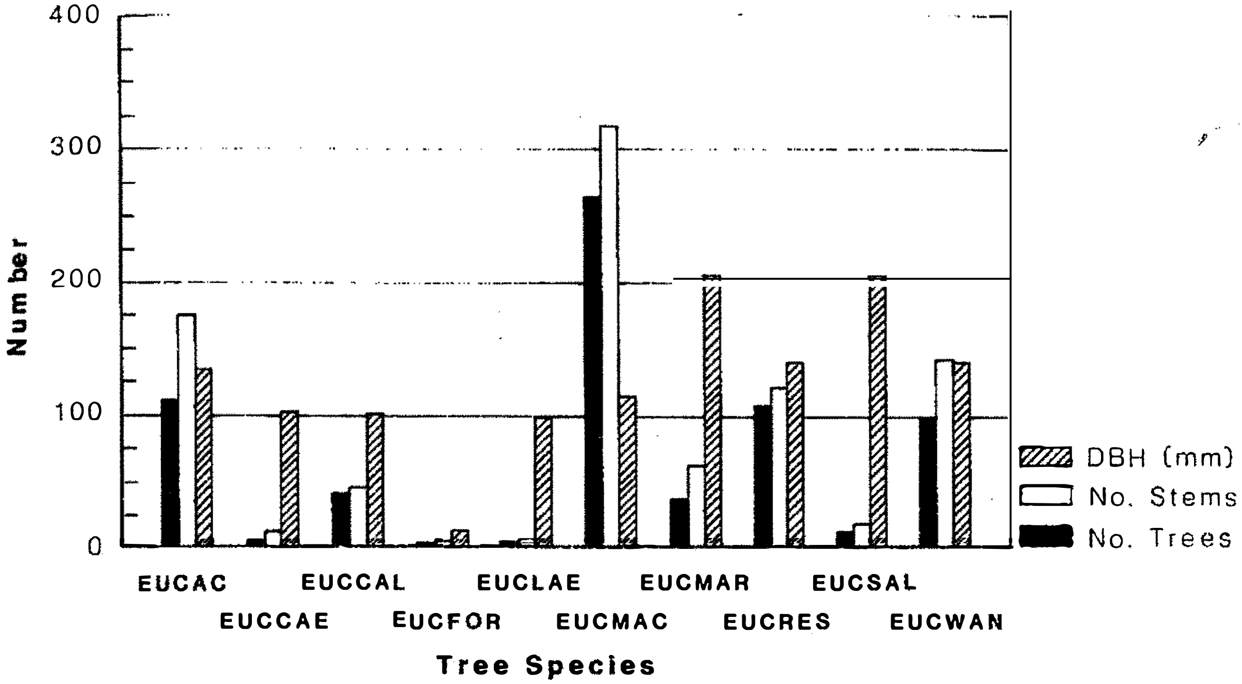


Figure 4 Tree Species Distribution for Mining Area A

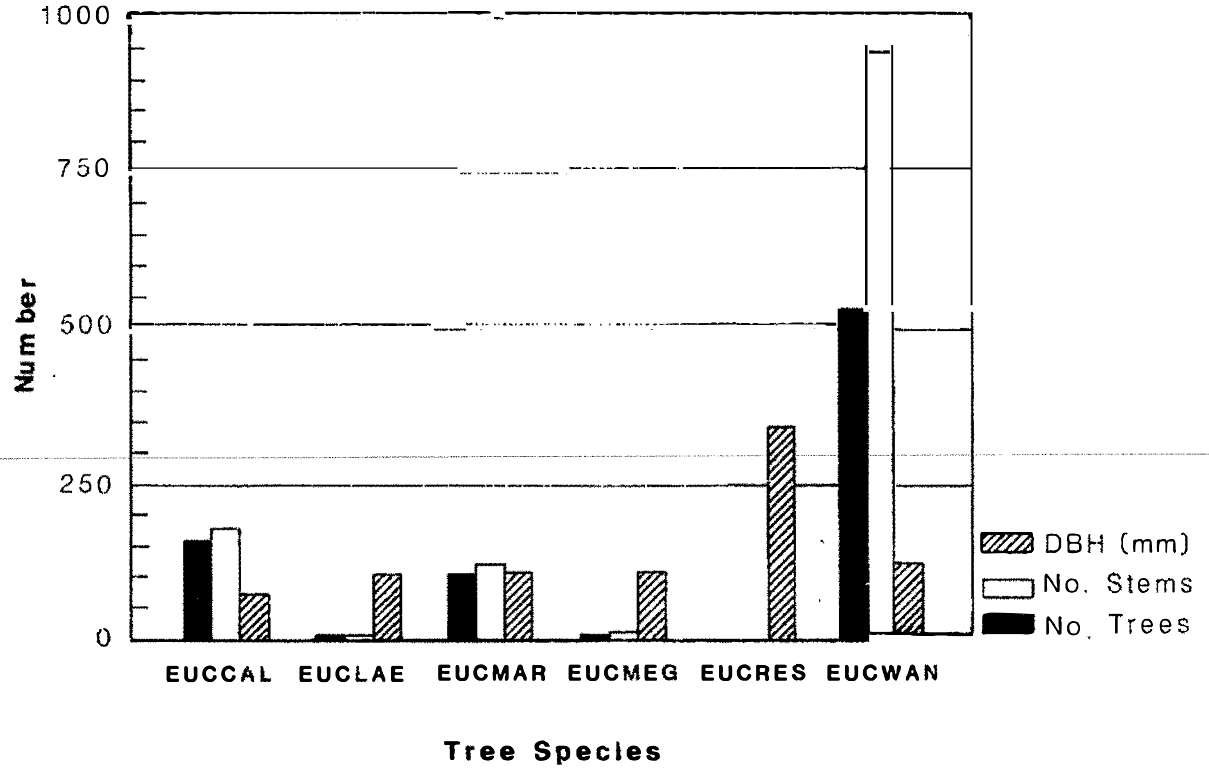


Figure 5 Tree Species Distribution for Mining Area B

Most species had a mean DBH between 10 and 15 cm (Fig. 4, Table 4). *E. marginata* and *E. saligna* however, were significantly larger having a mean diameter of 20.6 cm and 20.5 cm respectively.

The basal area for the trees monitored at this location totalled 6.56 m^2ha^{-1}. Species basal area is shown in Table 4.

Table 4 Species diameter and basal area for area A

Species	No. Trees	No. Stems	Mean DBH (cm)	Median DBH (cm)	STD	Max.	Min.	Basal Area (m^2ha^{-1})
EUCACC	112	175	13.5	12.8	5.0	25.0	3.1	1.06
EUCCAE	6	13	10.3	10.8	1.6	11.8	7.3	0.06
EUCCAL	42	46	10.2	8.5	6.4	28.7	2.2	0.4
EUCFOR	2	3	1.4	1.4	0.6	1.9	1.0	0.02
EUCLAE	3	5	9.9	9.8	0.2	10.2	9.8	0.03
EUCMAC	266	318	11.6	11.8	4.1	24.4	1.6	2.53
EUCMAR	39	64	20.6	23.1	9.5	35.1	4.1	0.37
EUCRES	108	122	14.1	15.7	7.5	30.0	1.0	1.02
EUCSAL	14	21	20.5	21.2	5.5	27.4	12.1	0.13
EUCWAN	99	143	14.1	15.4	6.3	26.9	1.6	0.94
	691	910	12.62		6.3	35.1	1.0	6.56

(b) Mining area B

The rehabilitated catchment area for mining area B was 13.2 ha. A total of 50 sites were assessed, which represented a total area of 1.57 ha. 813 trees were recorded giving a stocking rate of 517 trees ha^{-1}. Six different species were identified (Table 5). The average height of the tallest trees was 9.6 m. Six tree species were identified.

Table 5 Abbreviation and common name for tree species identified within mining area B

Abbreviation	Species	Common Name
EUCCAL	E. calophylla	marri
EUCLAE	E. laeliae	Darling Range ghost gum
EUCMAR	E. marginata	jarrah
EUCMEG	E. megacarpa	bullich
EUCRES	E. resinifera	red mahogany
EUCWAN	E. wandoo	wandoo

E.wandoo was the dominant species (65%) (Fig. 5). Many of these had multiple stems. Diameter distribution was similar between species. The solitary E. resinifera tree had a DBH of 34.3 cm. The basal area totalled 5.3 m^2 ha^{-1} (Table 6).

Table 6 Species diameter and basal area for area B

Species	No. Trees	No. Stems	Mean DBH (cm)	Median DBH (cm)	STD	Max.	Min.	Basal Area ($m^2 ha^{-1}$)
EUCCAL	159	180	7.2	5.9	0.4	27.9	0.5	1.02
EUCLAE	5	5	10.4	10.1	1.6	15.9	6.6	0.03
EUCMAR	106	121	10.8	10.3	0.5	25.1	0.9	0.60
EUCMEG	9	11	11.1	12.1	1.1	15.2	4.5	0.06
EUCRES	1	1	34.3	34.3		34.3	34.3	0.006
EUCWAN	531	947	12.6	13.1	0.3	28.9	0.8	3.4
	811	1265	11.3		6.0	34.3	0.5	5.2

5.1.2 Understorey species

The dominant understorey species in Area A were Acacia drummondii, Bossiaea aquifolium, Mirbelia dilatata, Acacia pulchella, Calothamnus quadrifidus, Kunzea baxterii, Acacia myrtifolia and Acacia saligna (see also Species List Appendix 1).

The frequency of each of these species is shown in Figure 6. The mean height of the understorey ranged from 2.6 m in Area A to 3.0 m in Area B. Albizia lophantha which had senesced and collapsed was not included in Fig. 6.

Percentage area cover was estimated using three methods (Table 7). The visual estimate of understorey cover in Area A was 68% of which 78% was alive and 22% was dead. Area B had 70% cover with 81% alive and 19% dead. In Area A the hand-held densiometer gave 84% mean cover from ground level and 65% at 1.3m. The mean cover at ground level in Area B was 85%, at 1.3 m above the ground the mean cover was 73%.

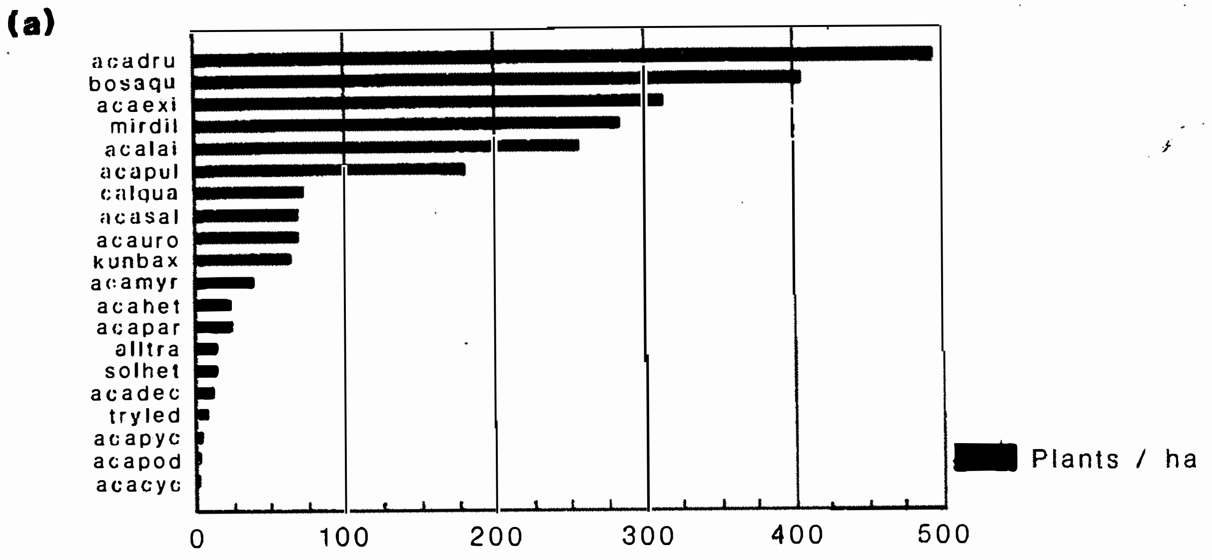
Total cover estimates using aerial photographs from 1978 to 1989 show a gradual increase in cover over time (Fig. 7). Divisions 1 and 5 had much higher cover than zones 2, 3 and 4. Because of the dense understorey in zone 1 and 5, the understorey was slashed in 1985 in an experiment on fire hazard control. This significantly reduced the cover although there has been a rapid recovery, particularly in area 5 (see Fig. 2 for divisions).

Table 7 Comparison of three methods estimating vegetation cover in 1989.

	Method	VISUAL ESTIMATION	DENSIOMETER	AERIAL PHOTOGRAPHS
% Cover	Area A	68%	84%	77%
% Cover	Area B	70%	85%	83%

5.2 Rainfall

The annual rainfall for Del Park catchment based on a daily read rain gauge at Dwellingup (5 km NNW of Del Park) was below average prior to study and through the period of study. However this was not statistically significant ($p < 0.10$, t-test, $n = 58$). The annual rainfall for the rain gauge at Dwellingup is shown in



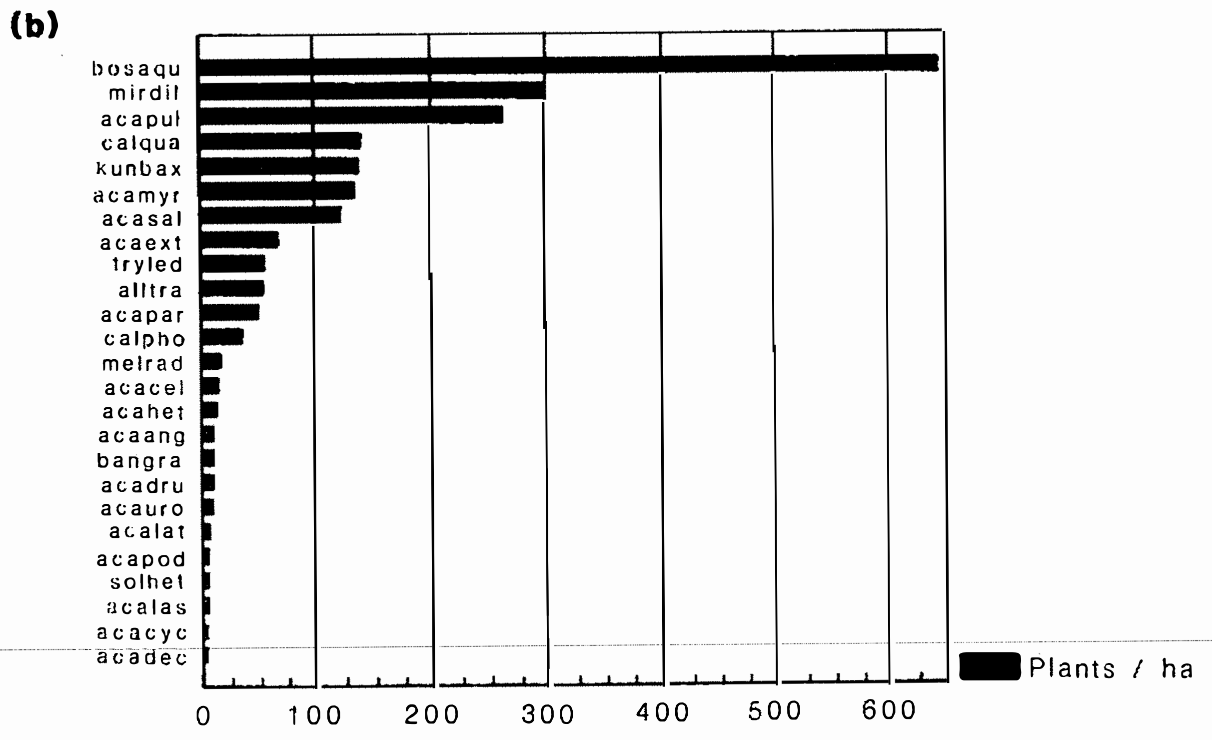
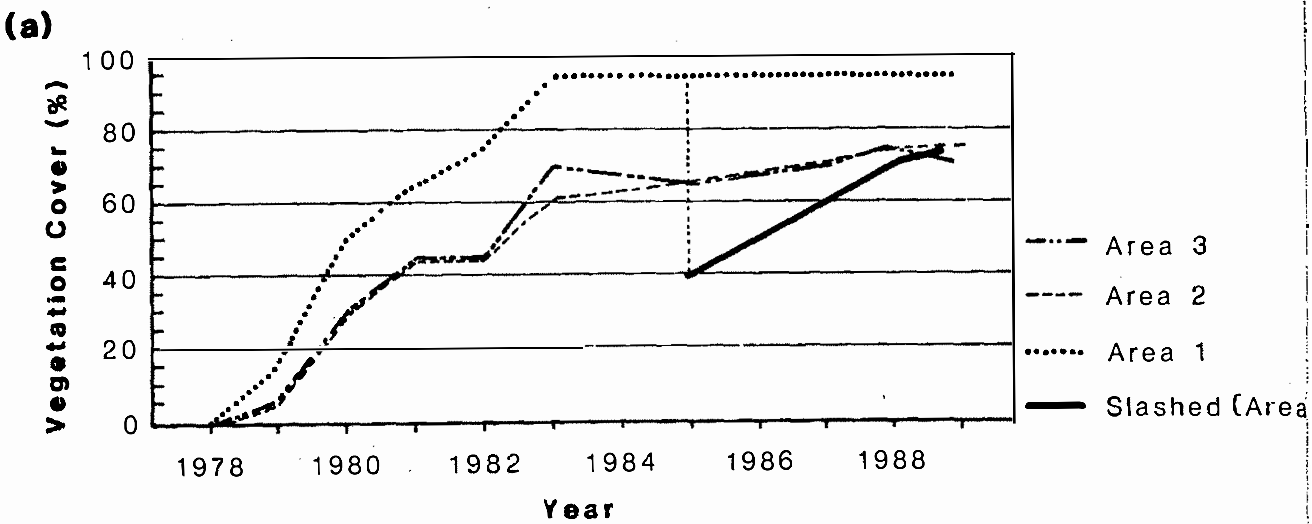


Figure 6 Understory Species Distribution for (a) Mining Area A : (b) Mining Area B



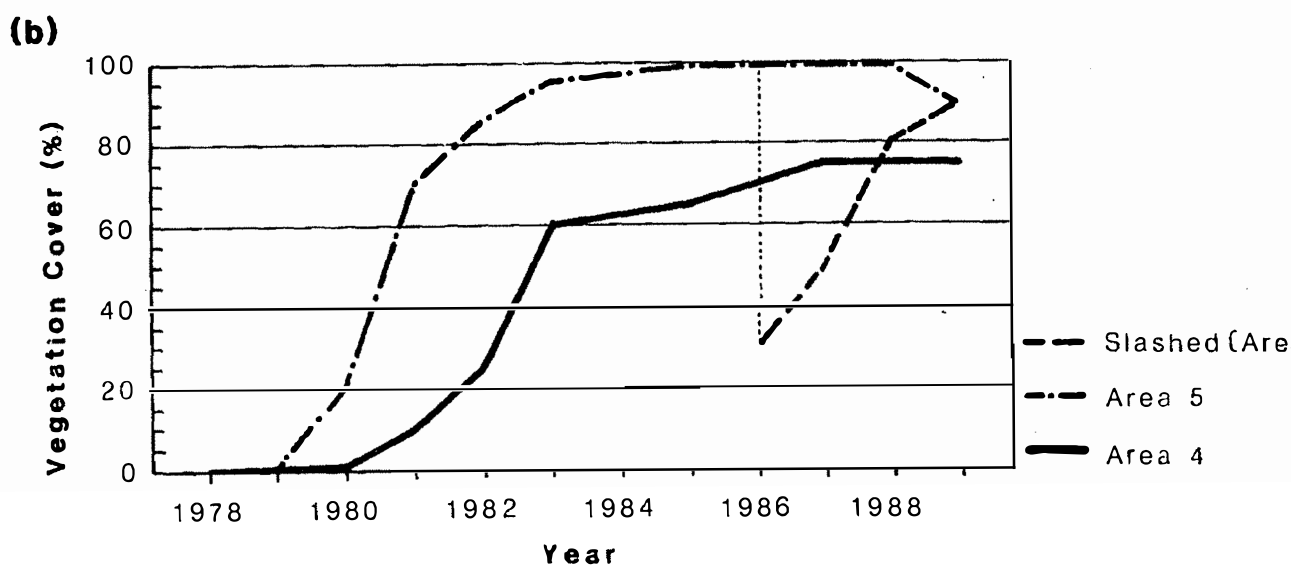


Figure 7 Vegetation Cover Response for (a) Mining Area A : (b) Mining Area B

Fig. 8. Based on an 11 year moving average there would appear to be stationary record from 1934 to 1968, followed by a transition from 1969 to 1974. From 1975 to 1988 there would appear to be another stationary period of record, 10% below the 1934 to 1968 record.

The decline in rainfall in recent years in the south-west is well documented (Pittock, 1983; Broadbridge, 1988; and Schofield, 1990). However it is still uncertain whether this is a temporary period of low rainfall, the commencement of a declining trend in rainfall on whether a new 'quasi-equilibrium' has been reached at a reduced annual rainfall. Whatever the implications this study was undertaken under a period of below average rainfall just after a declining period of rainfall. The last period of sustained above average rainfall occurred 7-12 years (1963-1968) prior to the commencement of this study.

5.3 Selection of Control

In order to take into account climatic variation the response from the mining areas was compared to a control area. However because of the very short period of pre-mining data there was some difficulty in determining the most appropriate control set. Over the period of study there was below average rainfall at the study site, while at other sites within the south-west there was still a declining trend in annual rainfall (Borg et al., 1987a).

Four sites which had native forest vegetation before and during the period of study were: Del Park control area; Banksiadale; Salmon Catchment; and Lewin North in the Southern forest (see Figure 1 for location). The groundwater response from a typical observation bore within each site is plotted in Fig. 9. This figure highlights the regional variation in groundwater levels. The influence of topography, soils and vegetation together with the local climate can mean significantly different groundwater responses are observed. Consequently, despite the concerns that the Del Park control may have some influence from the mining and adjacent forest thinning, it was still considered the most appropriate control. It is clear from Fig. 9 that Del Park

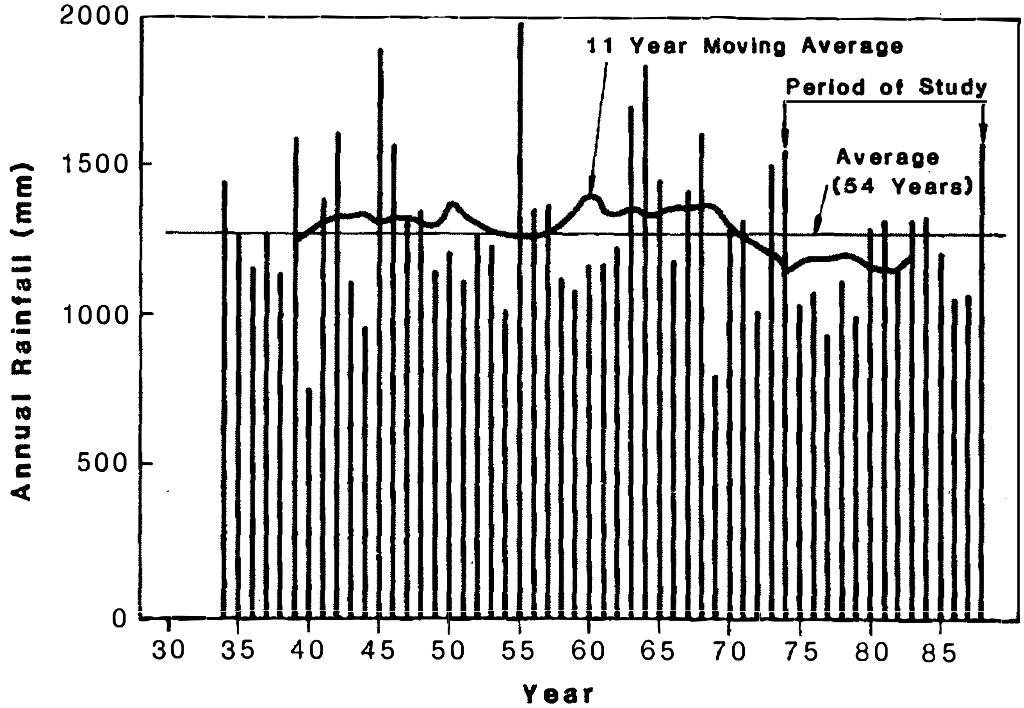


Figure 8 Annual Rainfall for Dwellingup (009 538)

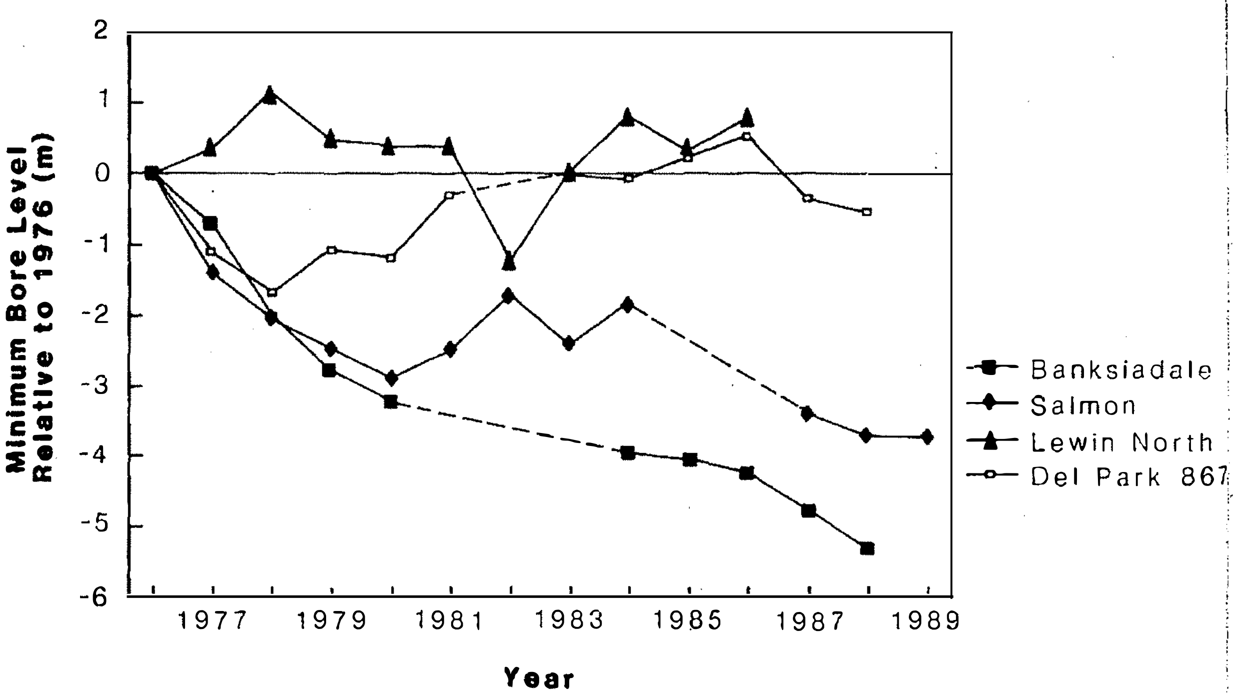


Figure 9 Comparison of Control Bores

control is a conservative control and may underestimate the response of groundwater levels to bauxite mining.

The control set for Del Park was split into two groups (above and below 290 m AHD contour line) to check whether the landscape position influenced the groundwater response. The two groups had very distinct groundwater responses to the rainfall record. However due to the relatively low depth to groundwater (<10 m) over most of the bores in the analyses, the control set was amalgamated for all the analysis except for downslope of mining area B. For downslope of mining area B the control set of below 290 m AHD was used, due to all the bores downslope of mining area B being below 290 m AHD and the subsequent better fit with this group.

5.4 Groundwater response within mining areas

The comparisons between the control set and mining areas A and B are shown in Fig. 10. Clearing for mining area B did not occur until late 1976 (see Table 1) and consequently there was good fit for 1975 and 1976 within the control set. By subtracting the mining response from the control response the groundwater change due to mining is shown in Fig. 11.

The maximum groundwater responses were 2.5 m and 3.1 m for mining areas A and B respectively, while 8-9 years after mining groundwater responses were down to 0.08 m and 0.67 m for mining areas A and B respectively. The groundwater response for 1987 for both mining areas was higher than for 1985 and 1986. This may be a response to the understorey thinning undertaken in both mining areas in 1985.

5.5 Groundwater response downslope of mining areas

The annual minimum groundwater level relative to 1975 is shown in Fig. 12 and 13, downslope of mining areas A and B respectively. The control set in native forest had reduced by nearly 3 m relative to 1975. The groundwater response to mining is depicted

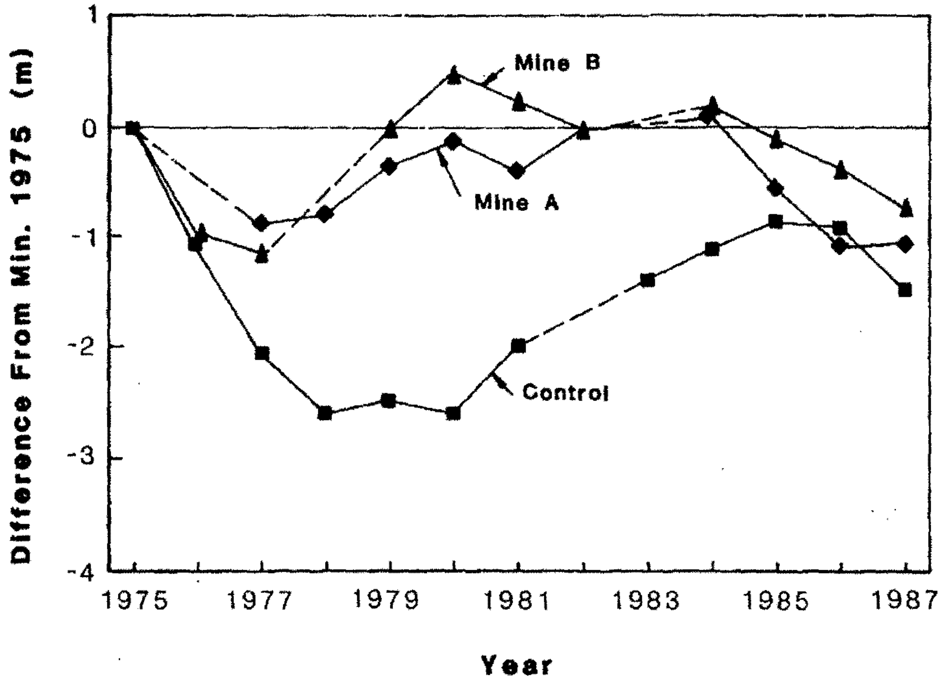


Figure 10 Changes in Minimum Groundwater Level for Mining Areas A & B, and Control Area

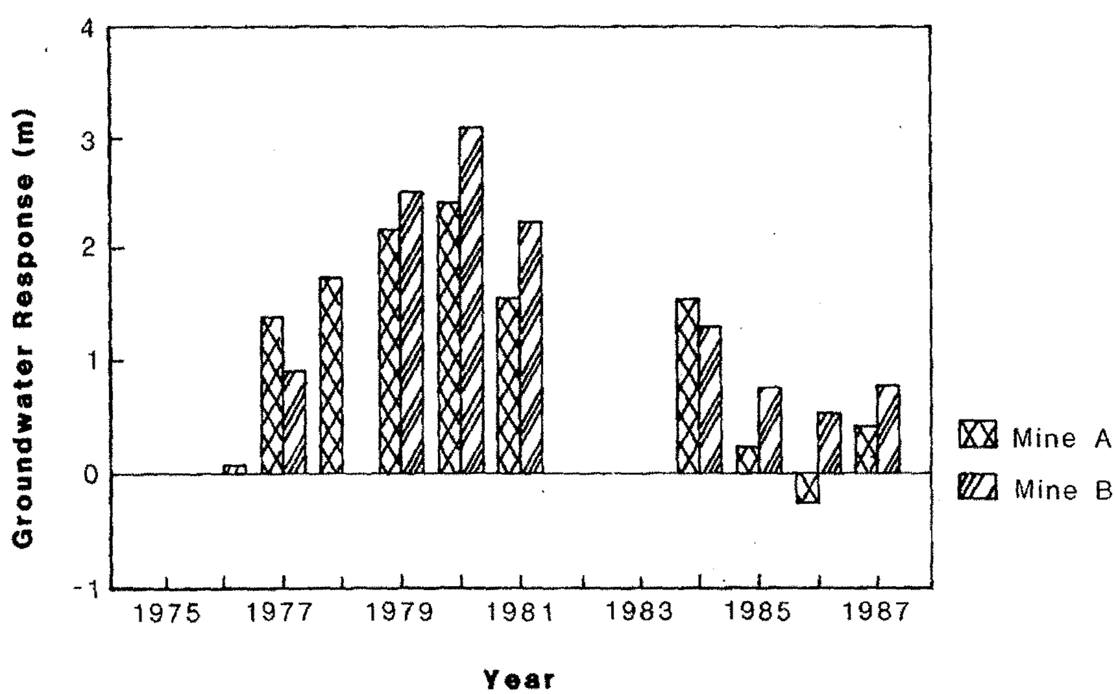


Figure 11 Groundwater Response to Mining Within Mining Areas A & B

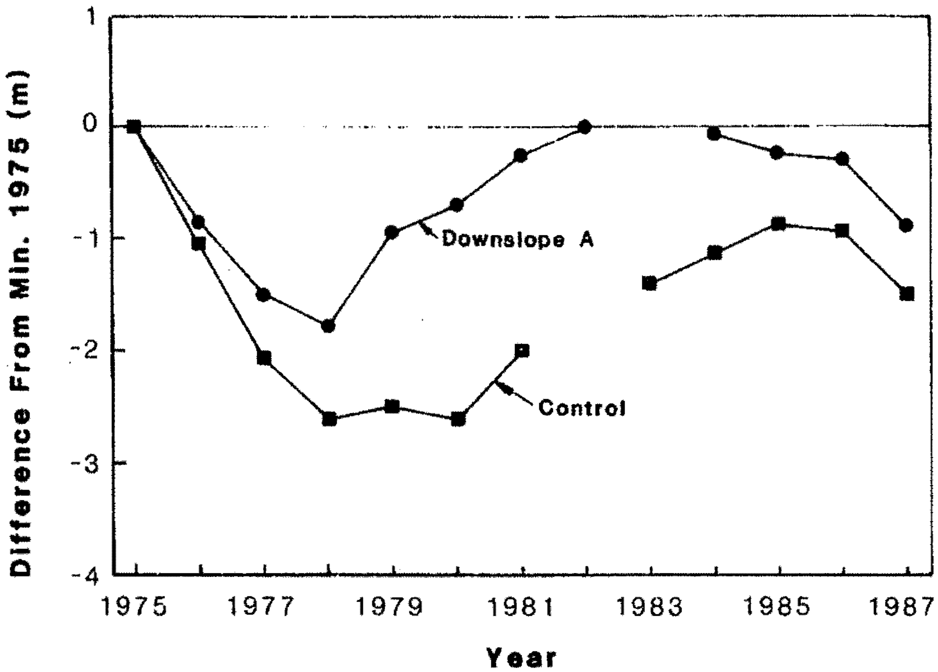


Figure 12 Changes in Minimum Groundwater Level Downslope of Mining Area A and Control Area

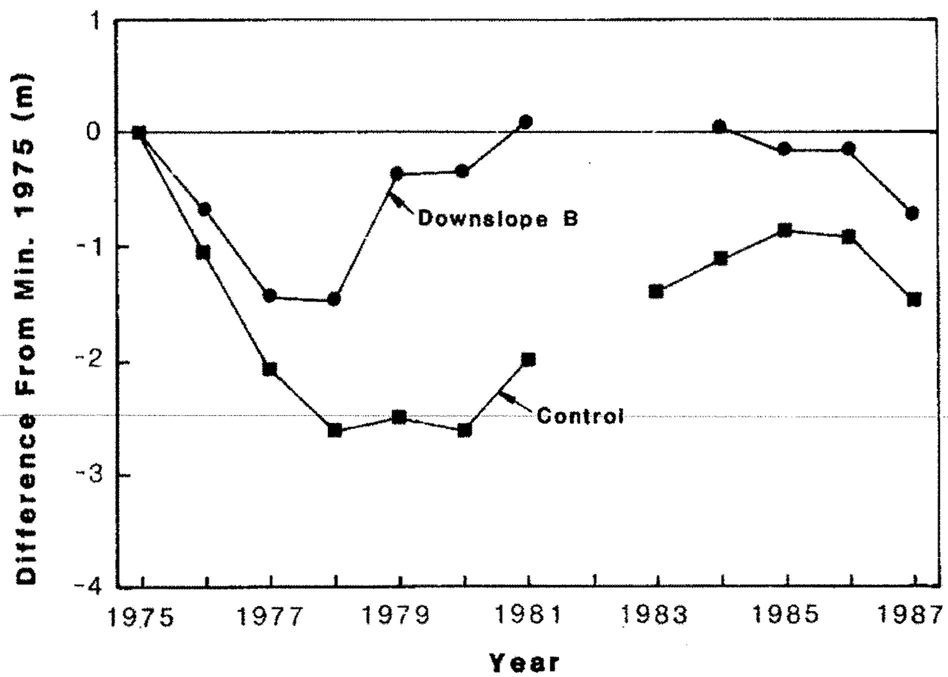


Figure 13 Changes in Minimum Groundwater Level Downslope of Mining Area B and Control Area

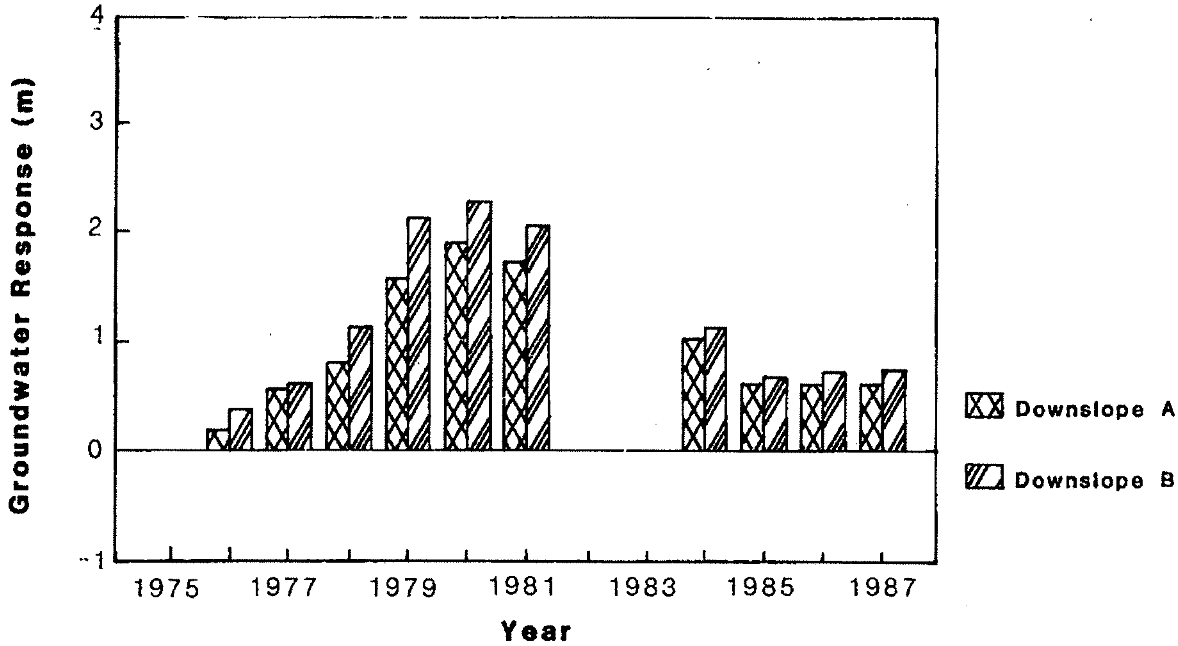


Figure 14 Groundwater Response to Mining Downslope of Mining Areas A and B

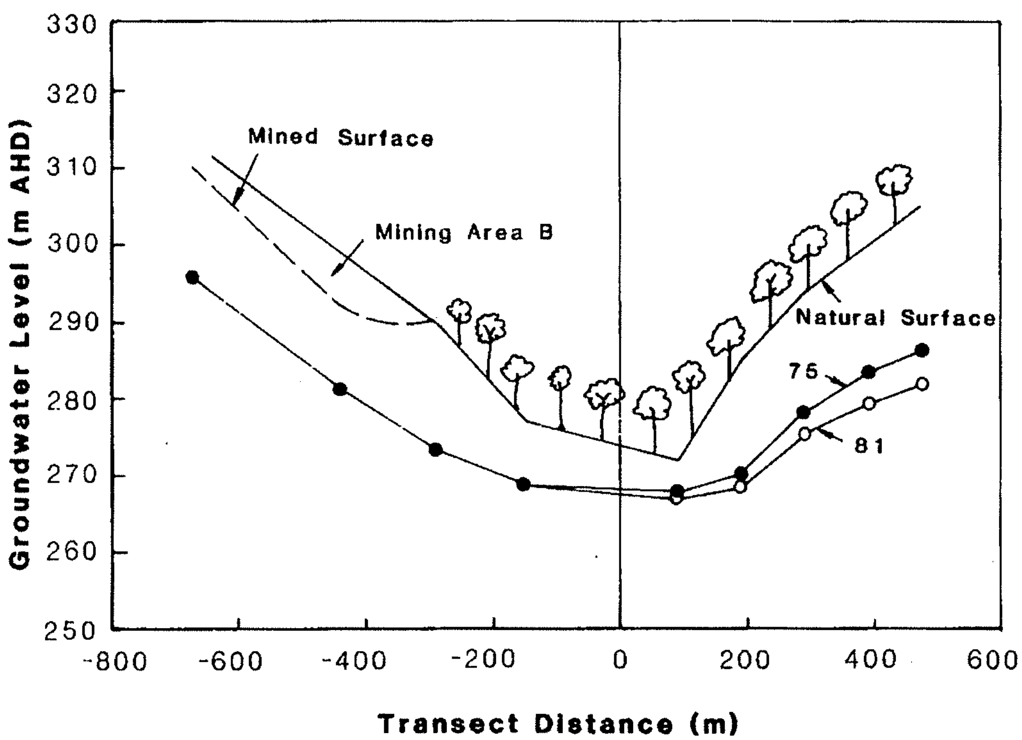


Figure 15 Transect Across Del Park Catchment

in Fig. 14 for downslope of mining areas A and B. This figure shows the maximum groundwater response was approximately 2 m. This maximum groundwater response was sustained for approximately 3 years, from 0 to 2 years after rehabilitation.

Seven to eight years after rehabilitation the groundwater response downslope of both mining areas had stabilised to approximately 0.6 - 0.7 m .

5.6 Transect analysis

The response of the groundwater potentiometric surface under mined/rehabilitated and control areas is illustrated by a catchment transect in (Fig. 15). The groundwater level on the native forest control side the mined side fell over the period 1975 to 1981, the maximum fall being 4.3 m at the upslope location. The groundwater levels on the mined side have, however, remained at approximately the same level.

6. DISCUSSION

Vegetation response

Eleven eucalypt species were identified in the survey. The majority had been planted, with the exception of *E. marginata* and *E. calophylla* which were encroaching on the rehabilitated areas from the surrounding forest. *E. megacarpa* (bullich) was invading on the lower slopes of Area B. Some dominant understorey species had also invaded from the forest, particularly *Bossiaea aquifolium.*

E. wandoo and *E. accedens* typically had multiple stems, originating either from the base or often at a 1/4 to 1/3 of the tree height. Heights of trees were variable, depending on the degree and type of understorey present. Trees in areas with very thick understorey, 3-5 m high, were suppressed during the early growth stages.

Some legume species (*A. decurrens, A. cyclops, A. saligna, A. paradoxa, Albizia lophantha*) in the two study areas which are now 10-12 years old, showed definite signs of senescence and collapsing. This is a normal characteristic of these species. The natural senescence of the understorey could be seen in the sequence of aerial photos taken over consecutive years. In 1988 the cover was estimated at 100% for area 5 (Figure 7), while the following year cover had dropped to around 90% indicating that some species had reached full maturity and were senescent.

Because of the high fire risk posed by this tall dense understorey a mechanical slasher was used in 1985 to cut down and flatten some areas of understorey. This study has shown that in the long term slashing is ineffective as a method of fire control due to the rapid regeneration that occurs.

Forest rehabilitation compared to forest regeneration due to logging

The rehabilitation of the mining areas A and B was rapid with respect to foliage cover. Five years after rehabilitation, the foliage cover ranged from 60 to 95%. Compared to a major study of groundwater response to logging and subsequent regeneration in the southern forest of Western Australia (Borg et al., 1987a; Borg et al., 1987b; Borg et al., 1988; Stoneman et al., 1988) the total cover in the bauxite mined areas was on average 13% (range 0 to 35%) above the regeneration from logging at five years. However the tree cover was estimated to be 9-20% less in the mining rehabilitation compared to logging regeneration.

The rehabilitated forest in mining areas A and B had attained an average of 6 m^2 ha^{-1} basal area after 10 years. In comparison, regrowth basal area, from jarrah forest sites, 10 years after logging in the southern forests (Stoneman et al., 1988) was 22.6 m^2 ha^{-1}.

Groundwater response to mining and rehabilitation

The minimum groundwater levels were found to increase by approximately 2.5 m to 3.1 m in the first four years after mining. This increase in minimum groundwater level gradually reduced to 0.1 to 0.7 m after 7-8 years mining for mining areas A and B respectively.

The reason for the increase in minimum groundwater level is considered to be due primarily to the lack of vegetation either intercepting or transpiring water. However the reduction in depth to groundwater due to the mining process, and the changed soil profile with no caprock and deep ripping may have had some influence on the groundwater response. As the rehabilitated vegetation grows transpiration and interception increase so that groundwater recharge decreases.

This study confirms that a discernible response to mining was able to be identified. The groundwater level rises were higher than estimated by Peck (1983). Due to the difficulty in determining a reliable control set, the estimates of groundwater rise are conservative and could conceivably be higher.

Groundwater response due to mining compared to forest management

The maximum increase in groundwater level due to bauxite mining was considered to be approximately 2.5 m to 3.1 m. This compares to an average rise in groundwater level of 3 m from clearfell logging in the southern forests of Western Australia (Borg *et al.,* 1987a; Martin, 1987) and 4 m from forest thinning in an experimental catchment in the northern jarrah forest (Ruprecht *et al.,* in prep.).

After ten years the groundwater rise due to logging in the southern forests was still substantial (0.5 m to 2.5 m, Borg et *al.,* 1988). Within the mined areas of Del Park, the groundwater rise was minimal (0.1 to 0.7 m) after 10 years.

Significance of this study to future mining and stream salinity management

This study has shown that groundwater levels can rise by 3-4 m in the first four years following clearing and mining but then decline when vegetation is well established. After 10 years groundwater levels have almost returned to pre-mining levels. This has occurred in high rainfall areas where groundwater responses are most rapid and with an early revegetation approach which has since been substantially improved. Taking account of the broad local experience in related studies, this study supports the argument that future mining and rehabilitation in high salt sensitive areas may have a transient impact on stream salinity but is unlikely to significantly impact stream salinity in the longer term.

7. CONCLUSIONS

- Groundwater levels rose by 3-4 m, relative to a control, in the first four years following bauxite mining, and then declined to near pre-mining levels by 10 years.

- Groundwater responses downslope of the minepit were similar to those within the minepit area.

- The decline in groundwater levels was attributed to the rapid development of a dense vegetation cover on the mined and cleared areas. Cover had reached close to its maximum (70-100%) within six years.

- The revegetated area was characterised by high density understorey but low density (6 m^2 ha^{-1} basal area) overstorey at 10 years.

- This groundwater response in this study suggests that mining in lower rainfall, high salt storage areas would at most lead to a transient increase in stream salinity.

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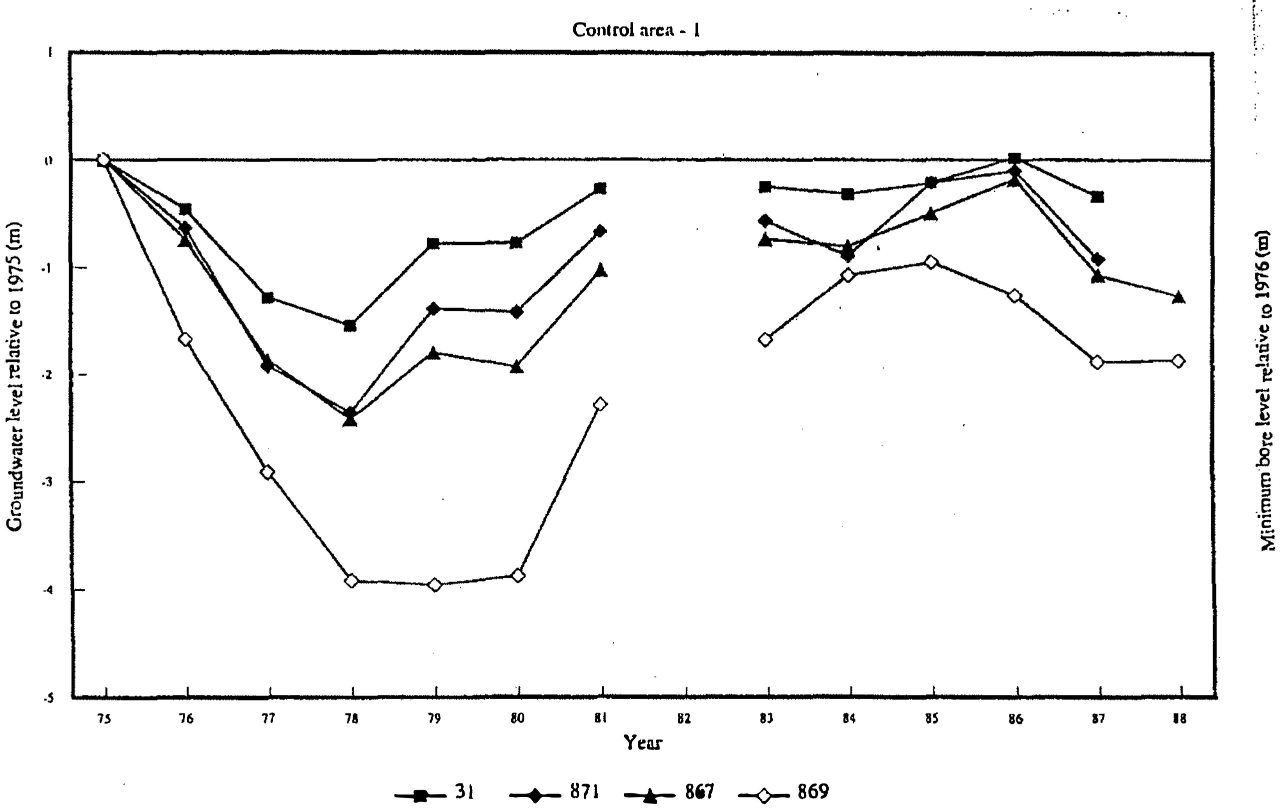
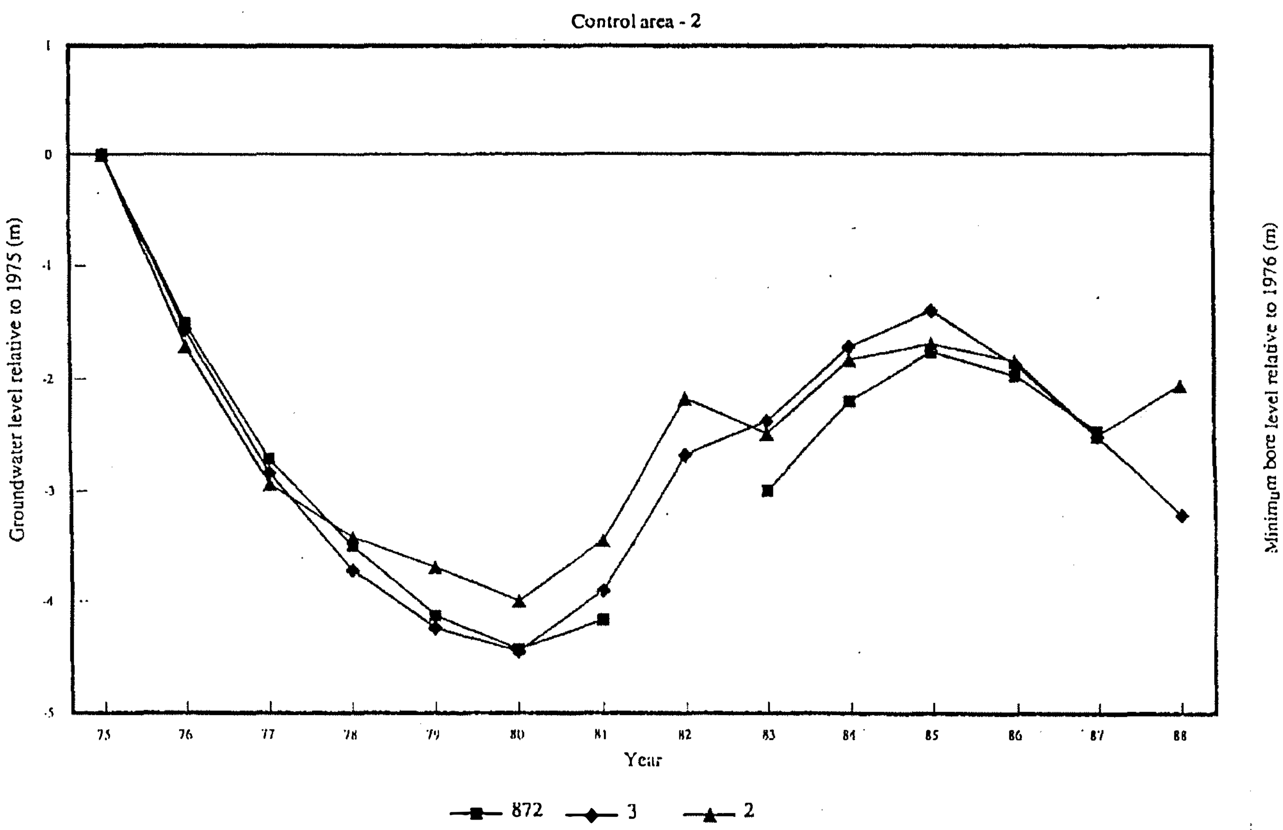
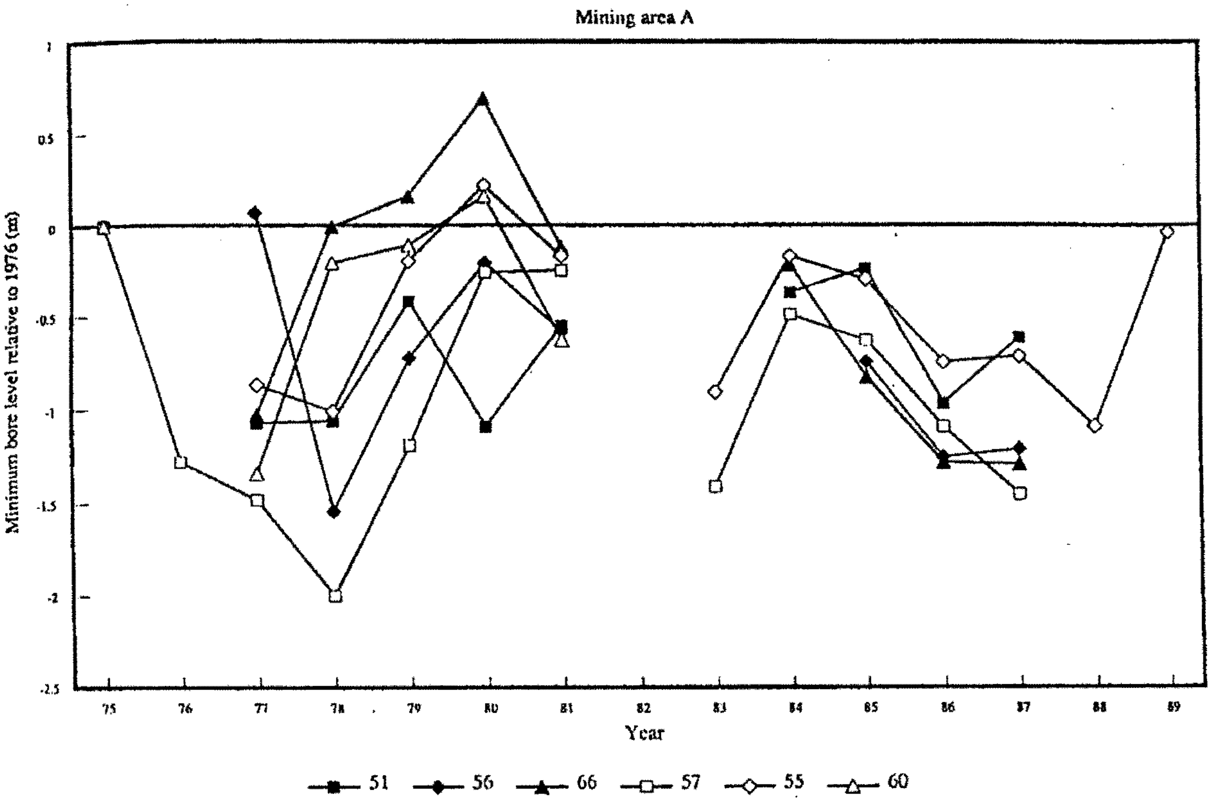
APPENDIX I Species list of understorey found within area A

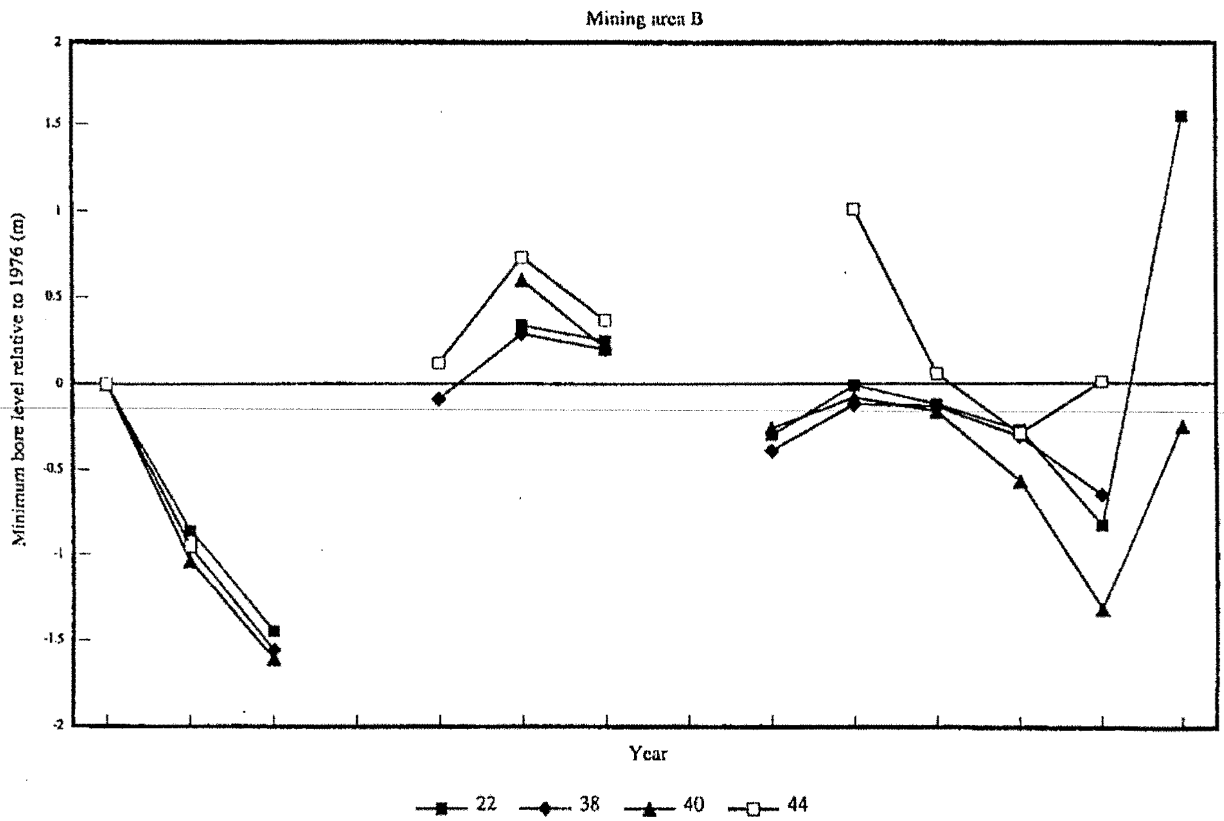
ABBREVIATION	UNDERSTOREY SPECIES FOUND BOTANICAL NAME
acaang	Acacia angustifolium
acacel	Acacia celastrifolia
acacyc	Acacia cyclops
acadec	Acacia decurrens
acadru	Acacia drummondii
acaext	Acacia extensa
acahet	Acacia heteroclita
acalas	Acacia lasiocarpa
acalat	Acacia lateriticola
acamyr	Acacia myrtifolia
acapar	Acacia paradoxa
acapod	Acacia podalyriifolia
acapul	Acacia pulchella
acapyc	Acacia pychantha
acasal	Acacia saligna
acauro	Acacia urophylla
allfra	Allocasuarina fraseriana
bangra	Banksia grandis
bosaqu	Bossiaea aquifolium
calpho	Callistemon phoeniceus
calqua	Calothamnus quadrifidus
kunbax	Kunzea baxteri
melrad	Melaleuca radula
mirdil	Mirbelia dilatata
perell	Personnia elliptica
solhet	Sollya heterophylla
tryled	Trymalium ledifolium

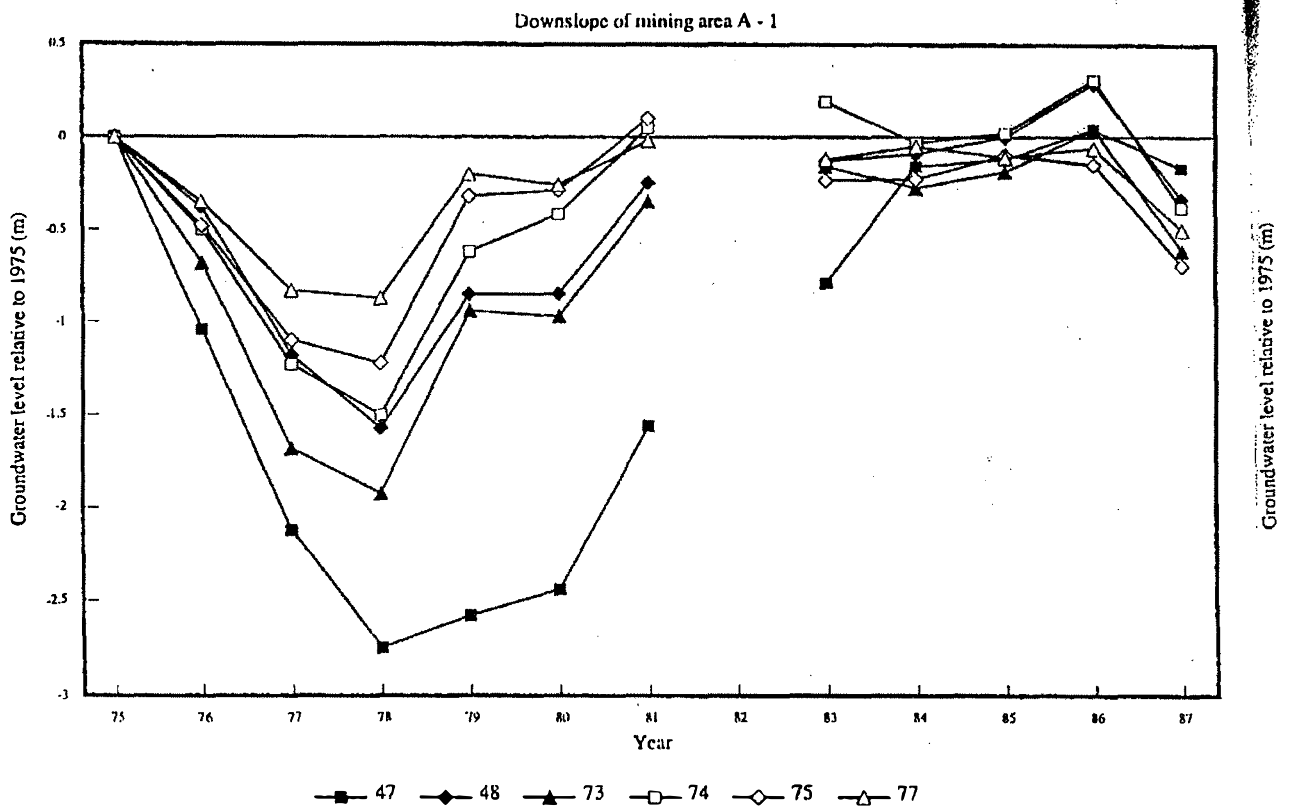
APPENDIX II   Minimum groundwater levels relative to 1975 for observation bores used in the analysis

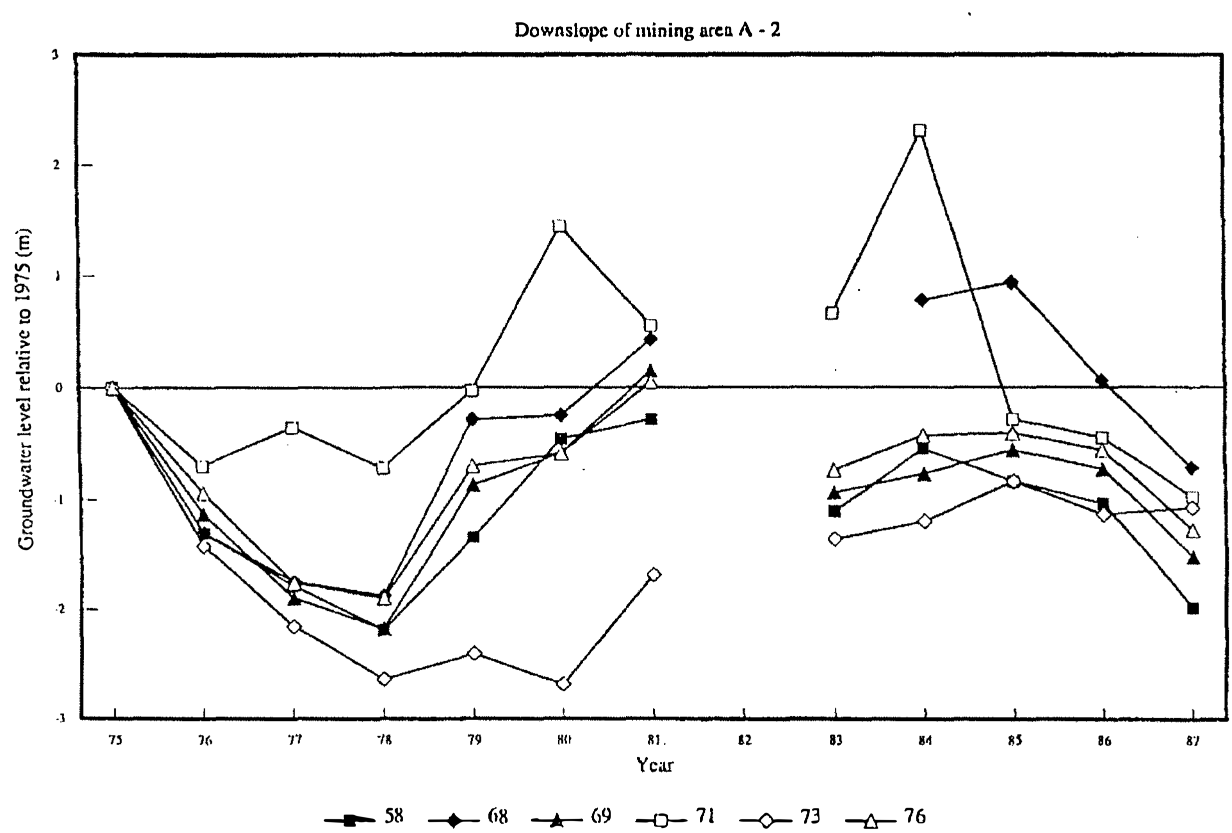

Control area - 1
Groundwater level relative to 1975 (m)
Minimum bore level relative to 1976 (m)
Year
31
871
867
869

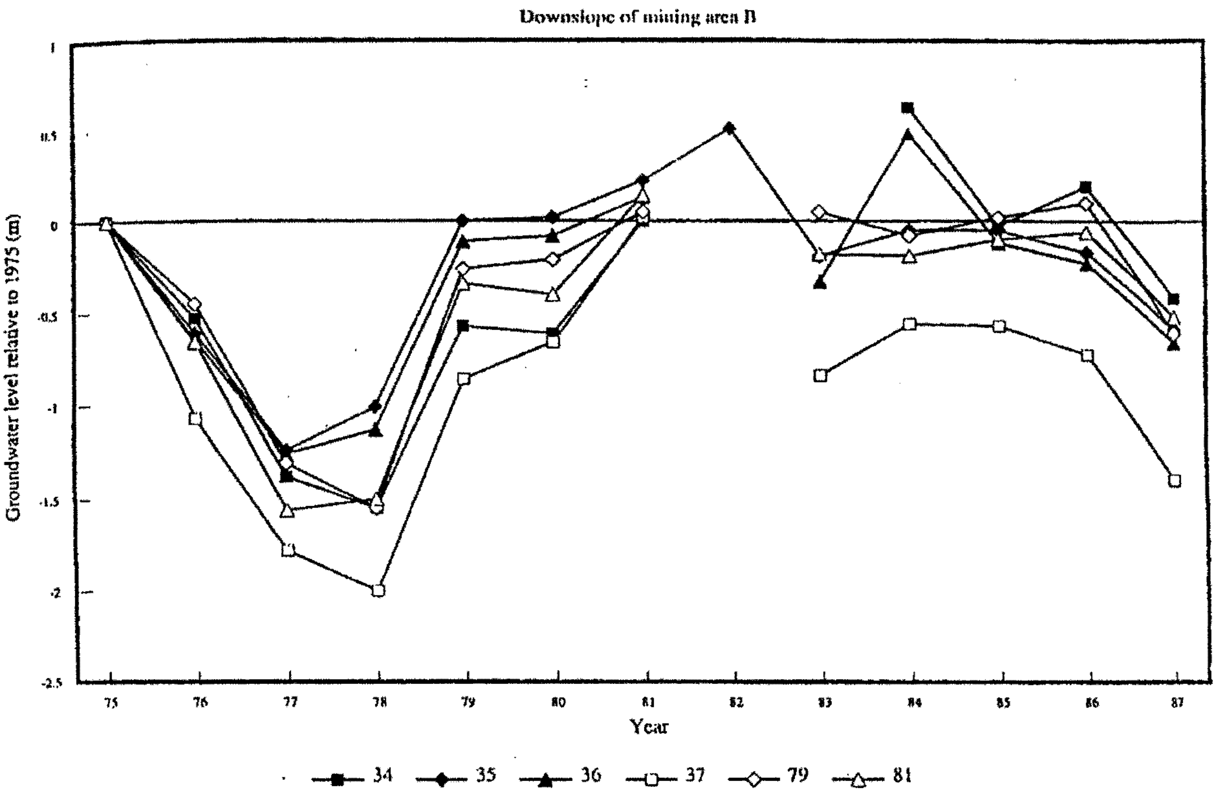

Control area - 2
Groundwater level relative to 1975 (m)
Minimum bore level relative to 1976 (m)
Year
872
3
2


Mining area A
Minimum bore level relative to 1976 (m)
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
Year
51
56
66
57
55
60


Mining area B
Minimum bore level relative to 1976 (m)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
Year
22
38
40
44


Downslope of mining area A - 1
Groundwater level relative to 1975 (m)
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
75
76
77
78
79
80
81
82
83
84
85
86
87
Year
47
48
73
74
75
77
Groundwater level relative to 1975 (m)


Downslope of mining area A - 2
Groundwater level relative to 1975 (m)
3
2
1
0
-1
-2
-3
75
76
77
78
79
80
81
82
83
84
85
86
87
Year
58
68
69
71
73
76


Downslope of mining area B
Groundwater level relative to 1975 (m)
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
75
76
77
78
79
80
81
82
83
84
85
86
87
Year
34
35
36
37
79
81