Groundwater Level and Salinity Response at Stene's Farm Arboretum Site in the Darling Range of Western Australia

by M. A. Bari, N. J. Schofield and D. W. Boyd

Report No. WS 76

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SUMMARY

Stream and groundwater salinities have increased in the south-west of Western Australia due to the replacement of deep-rooted, native, perennial vegetation with shallow-rooted annual agricultural crops and pastures. The process involved a decrease in evapotranspiration leading to a rise in groundwater tables accompanied by the dissolution and transport of salts to the streams. Research began in 1970s to reverse the process by lowering the groundwater table with partial reforestation of the cleared land.

One important partial reforestation strategy is high density plantation of the valley floor covering typically >50% of the cleared land. This strategy, termed extensive planting, has been carried out operationally in the eastern Wellington Dam catchment covering some 6000 ha to 1990. This report describes the groundwater level, groundwater salinity and soil salinity response at Stene's Farm (~700 mm yr^{-1} rainfall) arboretum site in the Darling Range of Western Australia. The groundwater level and salinity data are analysed for the period 1980 to 1989.

During the study period (1980-89), the minimum groundwater level beneath the arboretum declined 7.3 m compared to the pasture control and 5.5 m relative to ground level. The rate of reduction was fairly uniform which may be attributable to the continuous crown growth of the plantations. The maximum groundwater level dropped 7.8 m relative to pasture and 5.8 m relative to ground level.

The annual changes in minimum groundwater level were compared with the annual rainfall of the preceding year. The results implied if the annual rainfall was less than 605 mm over the pasture site, the minimum groundwater level would decline in the following year. Similarly, the minimum groundwater level would decrease beneath the arboretum site if the preceding year's rainfall was less than 865 mm. During 1980-89 annual rainfall was 8% lower than the long term average. The results indicated

the minimum groundwater level would have risen under pasture and would have fallen under the arboretum if long term average rainfall conditions had occurred.

Groundwater salinity beneath the arboretum reduced by 10% during the study period. Under pasture the groundwater salinity reduction was 40%. The trend of declining water table and decreasing groundwater salinity should significantly reduce stream salinity with time.

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1. INTRODUCTION

Stream salinisation as a result of agricultural development has been recognised as a major problem in the south-west of Western Australia (Schofield et al., 1988; Schofield and Ruprecht, 1989). Prior to the agricultural development, all divertible surface water resources were believed to be fresh. It is generally accepted that the replacement of native deep-rooted vegetation to shallow-rooted crops and pasture increased the stream salinity (Peck et al., 1983).

Research began in 1970s to rehabilitate the salt-affected catchments. Partial reforestation of the already cleared land was found to be most promising. During the late 1970s, a number of experimental sites were established with various reforestation strategies embracing different layouts and densities of trees. One of them was the Stene's Farm arboretum site where the valley floor and lower slopes were planted at a high density. This strategy is totally discharge control and aims to lower the groundwater table in the vicinity of the streamline and so prevent groundwater solute discharge to streams. This strategy, termed extensive planting, has been carried out operationally on the Wellington Dam catchment since 1979, with planting covering 6000 ha of farmland to date (Schofield et al., 1989).

The Stene's Farm arboretum site is located in the Wellington Dam catchment. The reforestation, consisted of 63 species of eucalyptus and two species of pinus covered 70% of the farmland. Earlier, less detailed hydrological analyses of the data of this site were reported by Bell et al.(1988); and Schofield et al. (1989). This report presents the most in-depth and up-to-date analysis of the data from this site and is an important contribution to the assessment of extensive planting reforestation strategy to salinity control. The results are compared with that of valley planting site also established at Stene's Farm (Bari et al., 1991a).

2. SITE DESCRIPTION

2.1 Location

The experimental site is located in the Darling Range, approximately 40 km North of Collie (Fig. 1). It lies within the predominantly forested Wellington Dam catchment. The control catchment is situated about 3 km east-north-east of the catchment (Fig. 1).

2.2 Site History and Layout

The experimental site has two parts : the arboretum site and control site (Fig. 1). Both sites comprise part farmland (pasture), native forest and reforestation. Clearing of the native forest for pasture development took place during the early 1960s. In 1976 the site was purchased by the State Government as part of a programme to reforest farmland within Wellington Dam catchment to control the inflow salinity to Wellington reservoir.

About 31% of the control site was cleared leaving very little native vegetation on the valley floor. In the 1976-78 period, strip reforestation was carried out on the lower slopes covering about 14% of the cleared area. The groundwater control bores are located upslope of the reforestation (Fig. 1).

The arboretum site has a catchment area of 284 ha (Fig. 2). A tributary of the Bingham River flows through the catchment. Clearing took place on the lower slopes of the site covering 35% of the catchment. The arboretum and bore network were established in 1979. In 1980 depth to minimum groundwater level varied from 1.0 m to 19.5 m (Appendix A). The average groundwater salinity was 4900 mg L^{-1} Total Soluble Salts (TSS). Saline seeps were evident on the upper valley reaches of the catchment.

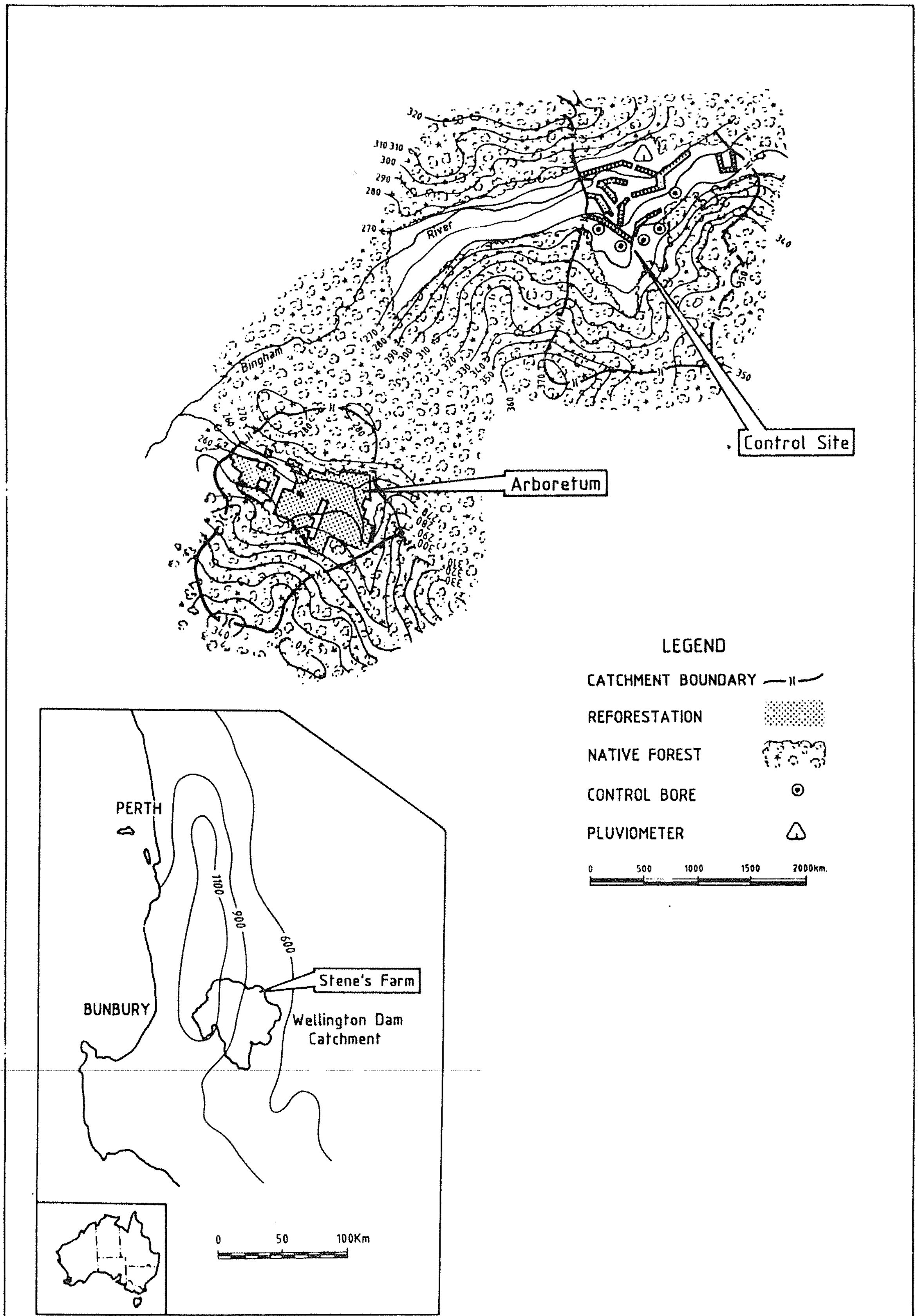


Figure 1 Location of the study area

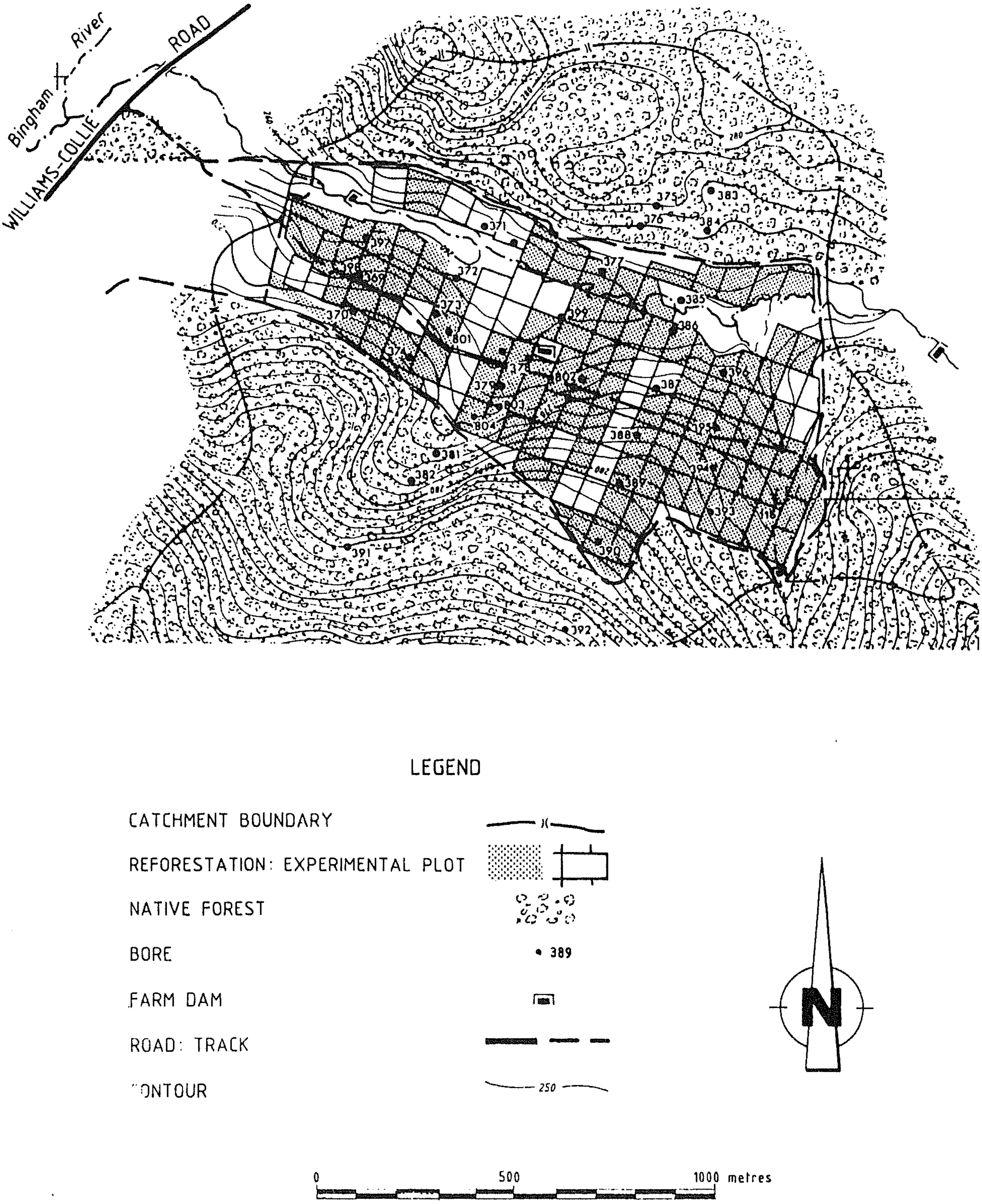


Figure 2 Reforestation layout and hydrometric network

2.3 Climate

The Wellington catchment area has a Mediterranean climate with cool, humid, wet winters and hot, dry summers. About 80% of the total annual rainfall occurs in winter. The long term average (1926 to 1988) rainfall of the experimental site is 713 mm yr^{-1}. The annual average pan evaporation of the catchment is 1600 mm (Luke et al., 1988). Temperatures range from a maximum in excess of 40°C, which occurs in January to February, to a minimum of less than 0°C in June or July.

2.4 Topography

The elevation of the control site varies from 271 m AHD to 374 m AHD. The mean slope of the catchment is 3.8%.

The topography of the arboretum site is illustrated in Fig. 2. The upslope forested portion of the catchment is slightly steeper than the reforested zone. Most of the bores are located in the reforested portion where ground slope averages 4% (Fig. 2).

2.5 Soil and Geology

The surface soils of both sites are highly permeable and the rainfall intensity rarely exceeds the infiltration capacity of the soil (Sharma et al., 1987; Ruprecht and Schofield, 1989). Soil types in this area are typical of the eastern Collie catchment (Bettenay et al., 1980). The soil and geology of the control site is similar to that of the arboretum site. Sand and sandy clays are common near the soil surface, while the subsoil has a variable sandy clay matrix. The depth of weathering of this site is more than 20 m.

The soil profile of the arboretum site mainly consists of shallow silty sands to clay gravels of variable thickness overlying a sandy clay subsoil. The depth of weathering is more than 20 m. The geological cross-section of the valley is shown in Fig. 3.

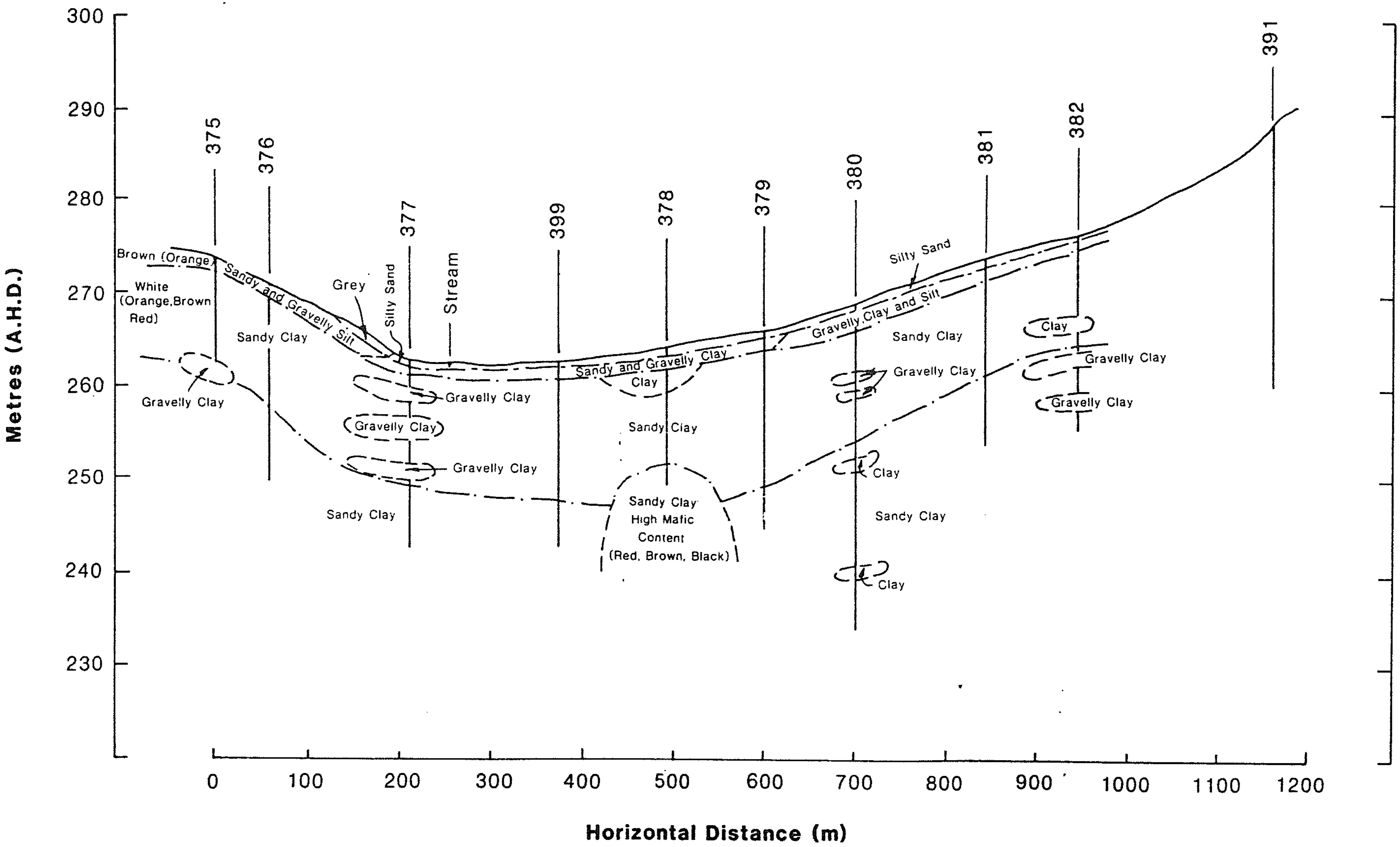


Figure 3 Geological cross-section of the arboretum site

2.6 Vegetation

On the lower slope of the control site 14% of the cleared area was reforested. Two species of pinus and eleven species of Eucalyptus were planted during the period 1976-78.

In the past the cleared area of the arboretum site had germination of annual rye grasses (Lolium spp), barley (Hordium marinum) and other grasses. A total of 63 species of Eucalyptus and two species of pinus were planted in 1979 (Appendix A), details of which are given in section 4. The upslope native vegetation is dominated by jarrah (E. marginata) with the principal sub-dominants being marri (E. calophylla) and wandoo (E. wandoo).

3. EXPERIMENTAL OBJECTIVES

3.1 Plantation

The major objectives of the reforestation strategy were to lower the groundwater levels significantly in a relatively short period of time (~ 10 years) and to determine the water use of different species of eucalypts. The water use potential of eucalypts are described in detail by Hookey et al. (1987).

3.2 Hydrology and Salinity

The objectives of the groundwater monitoring programme were to:

(i) identify the initial groundwater table conditions prior to reforestation treatment;

(ii) determine groundwater table seasonal variations and longer term trends beneath pasture;

(iii) determine the effect of reforestation on groundwater level;

(iv) identify the groundwater flow direction and any change due to the reforestation treatment;

(v) determine spatial and temporal variability in groundwater salinity and the effect of reforestation on groundwater and soil salinity; and

(vi) determine changes in solute distribution through the soil profile in response to reforestation.

4. PLANTATION ESTABLISHMENT AND MANAGEMENT

4.1 Plantation Establishment and Layout

In 1979, 63 eucalypt species and two pine species were planted in the cleared area (Fig. 2). The site was divided into 123 plots of approximately 0.5 ha area. Each plot was planted with single species to provide an inner core which was reasonably representative of forest. The initial stem density of all plots was 625 stems per hectare.

4.2 Plantation Management

There was no thinning or pruning at the study site. On the plots badly affected by salt and waterlogging, tree survival was poor. By 1988 stem density varied from nil to 600 sph (stems per hectare), with an overall average of 340 sph (Appendix A).

4.3 Crown Cover

Crown cover is defined as the percentage of the ground area covered by the vertical projection of the vegetation canopy on the ground surface. Measurements of crown cover of the trees at the arboretum site were taken on the 11th of December, 1987 using a crownometer similar to the one described by Montana and Ezcurra (1980). Crown cover varied from 14% to 66% with an average of 39% (Appendix A).

5. HYDROLOGICAL DATA COLLECTION

5.1 Rainfall

Rainfall records were taken from the pluviometer M509374 located approximately 3.5 km north east of the catchment (Fig. 1). For periods of missing rainfall, data from the nearest pluviometer (M509337) were transposed using the correlation developed by Bari et al. (1991b). Annual rainfall was determined for the hydrological water year (1st April to 31st March). The long term average rainfall (1926-86) at this study site had been estimated at 722 mm yr^{-1} (Hayes and Garnaut, 1981; Bell et al., 1990). The long term average, extended up to 1988 by including the pluviometer data, is 713 mm yr^{-1}.

5.2 Groundwater Monitoring

The groundwater bore networks for the control and arboretum sites are shown in Fig. 1 and Fig. 2 respectively. The pasture control bores are located at the upper mid-slope of the control site (Fig. 1). These bores were drilled to the bedrock and their slotted length varied from 6 m to 18 m (Table 1a).

At the arboretum site 31 bores were installed, which included a transect across the valley. The bores are fairly evenly spaced over the reforested area (Fig. 2). All but one bore have a screen length of 3 m (Table 1b).

Monitoring for water level and salinity began in 1979. Piezometer levels and salinity were measured approximately once a month. Salinity was determined from the samples collected within the screen area of the bores. Pumped samples were taken from all bores towards the end of the study. Salinity (Total Soluble Salts, TSS) of collected samples were determined by using the relationship between the TSS (mg L^{-1}) and electrical conductivity (m Sm^{-1}) developed by Bari et al. (1991b).

Table 1a : Details of observation bores - control site

S.W.R.I.S. Bore Number	Drillers Bore Number	Commencement of Operation	Bore Classif-ication	Top of Inner Tube (AHD)	Natural Surface Level (AHD)	Bottom of Tube (AHD)	Length of Slotting (m)	Length of Inner Tube (m)	Height of T.O.I.T. Above N.S.L. (m)	Depth of B.O.T. Below N.S.L. (m)
61218008	8-76	01/06/1976	Pasture	295.767	295.090	274.677	18.00	21.09	0.677	20.413
61218009	9-76	01/06/1976	Pasture	291.092	290.400	274.432	14.00	16.66	0.692	15.968
61218038	22-77	30/07/1977	Pasture	284.607	284.020	266.807	6.00	17.80	0.587	17.213
61218044	29-77	30/07/1977	Pasture	287.460	286.860	271.960	8.50	15.5	0.600	14.900
61218045	30-77	30/07/1977	Pasture	285.512	284.880	269.012	11.00	16.50	0.632	15.868

T.O.I.T. :Top of inner tube

B.O.T. :Bottom of tube

N.S.L. :Natural surface level

Table 1b : Details of the observation bores - arboretum site

S.W.R.I.S. Bore Number	Drillers Bore Number	Commencement of Operation	Bore Classif- ication	Top of Inner Tube (AHD)	Natural Surface Level (AHD)	Bottom of Tube (AHD)	Length of Slotting (m)	Length of Inner Tube (m)	Height of T.O.I.T. Above N.S.L. (m)	Depth of B.O.T. Below N.S.L. (m)
61218369	1.2/79A	09/05/1979	Reforest	266.740	266.260	236.300	3.00	30.440	0.480	29.960
61218370	1.3/79	09/05/1979	Reforest	271.032	270.550	246.092	3.00	24.940	0.482	24.458
61218371	2.1/79	09/05/1979	Reforest	261.723	261.240	245.893	3.00	15.830	0.483	15.347
61218372	2.2/79	09/05/1979	Reforest	262.069	261.500	249.849	3.00	12.220	0.569	11.651
61218373	2.3/79	09/05/1979	Reforest	267.098	266.600	253.608	3.00	13.490	0.498	12.992
61218374	2.4/79	09/05/1979	Reforest	271.810	271.320	253.770	3.00	18.040	0.490	17.550
61218375	3.1/79	09/05/1979	Forest	273.639	273.130	260.039	3.00	13.600	0.509	13.091
61218376	3.2/79	09/05/1979	Forest	271.067	270.580	254.557	3.00	16.510	0.487	16.023
61218377	3.3/79	09/05/1979	Reforest	262.636	262.120	242.406	4.00	20.230	0.516	19.714
61218378	3.5/79	09/05/1979	Reforest	263.650	263.190	247.420	3.00	16.230	0.460	15.770
61218379	3.6/79	09/05/1979	Reforest	265.806	265.290	253.536	3.00	12.270	0.516	11.754
61218380	3.7/79	09/05/1979	Reforest	269.031	268.500	234.401	3.00	34.630	0.531	34.099
61218381	3.8/79	09/05/1979	Forest	273.610	273.080	257.350	3.00	16.260	0.530	15.730
61218382	3.9/79	09/05/1979	Forest	276.414	275.900	257.274	3.00	19.140	0.514	18.626
61218383	4.1/79	09/05/1979	Forest	272.319	271.850	254.759	3.00	17.560	0.469	17.091
61218384	4.2/79	09/05/1979	Forest	270.901	270.410	254.181	3.00	16.720	0.491	16.229
61218385	4.3/79	09/05/1979	Reforest	263.429	262.900	251.469	3.00	11.960	0.529	11.431
61218386	4.4/79	09/05/1979	Reforest	263.021	262.250	252.381	3.00	10.640	0.771	9.869
61218387	4.5/79	09/05/1979	Reforest	270.056	269.540	256.416	3.00	13.640	0.516	13.124
61218388	4.6/79	09/05/1979	Reforest	275.084	274.550	256.864	3.00	18.220	0.534	17.686
61218389	4.7/79	09/05/1979	Reforest	281.649	281.180	260.489	3.00	21.160	0.469	20.691
61218390	4.8/79	09/05/1979	Reforest	288.063	287.530	267.873	3.00	20.190	0.533	19.657
61218391	3.10/79	09/05/1979	Forest	290.849	290.330	262.099	3.00	28.750	0.519	28.231
61218392	4.10/79	09/05/1979	Forest	305.055	304.530	285.155	3.00	19.900	0.525	19.375
61218393	5.4/79	09/05/1979	Reforest	275.908	275.370	259.068	3.00	16.840	0.538	16.302
61218394	5.3/79	09/05/1979	Reforest	274.007	273.470	257.307	3.00	16.700	0.537	16.163
61218395	5.2/79	09/05/1979	Reforest	271.165	270.680	254.705	3.00	16.460	0.485	15.975
61218396	5.1/79	09/05/1979	Reforest	167.104	266.580	252.104	3.00	15.000	0.524	14.476
61218397	1.1/79	09/05/1979	Reforest	261.619	261.080	249.459	3.00	12.160	0.539	11.621
61218398	1.2/79B	17/05/1979	Reforest	266.779	266.270	252.169	3.00	14.610	0.509	14.101
61218399	3.4/79	17/05/1979	Reforest	262.207	261.680	253.207	3.00	9.000	0.527	8.473

6. DATA ANALYSES AND INTERPRETATION OF RESULTS

6.1 Rainfall

During the study period (1980-89), rainfall varied between 473 mm yr^{-1} and 910 mm yr^{-1} and averaged 655 mm yr^{-1}. The long term average (1926-88) rainfall was 713 mm yr^{-1}. The 1980-1989 average rainfall was 8% lower than the long term average. Only three years (1981, 1983 and 1988) had rainfall higher than the long term average. Most of the rainfall (more than 80%) occurred in winter, between May to October.

6.2 Groundwater Levels Beneath Pasture Control

Hydrographs of the control bores show high seasonal variation in groundwater level. There is also a trend of increasing groundwater level (Fig. 4). The variation in the annual maximum groundwater levels is more than the variation in annual minimum.

The variation in yearly minimum groundwater level relative to 1980, averaged for the five bores, is shown in Fig. 5. Groundwater levels increased in 1982, 1984 and 1989 due to above average rainfall in preceding water year. There was a rise in minimum groundwater level of 1.8 m between 1980 and 1989.

Similarly, the maximum groundwater level showed rises in 1981, 1983 and 1988; and falls in other years (Fig. 6). Between 1980 and 1989, there was a rise of 2.0 m in maximum groundwater level.

To determine the effect of annual rainfall variation, a linear regression of the change in mean minimum groundwater level relative to the previous year's annual rainfall was derived by Bari et al. (1991a). On the basis of the regression, annual minimum groundwater levels would rise 431 mm yr^{-1} under long term average rainfall conditions; and would be stable if the preceding year's rainfall was 605 mm.

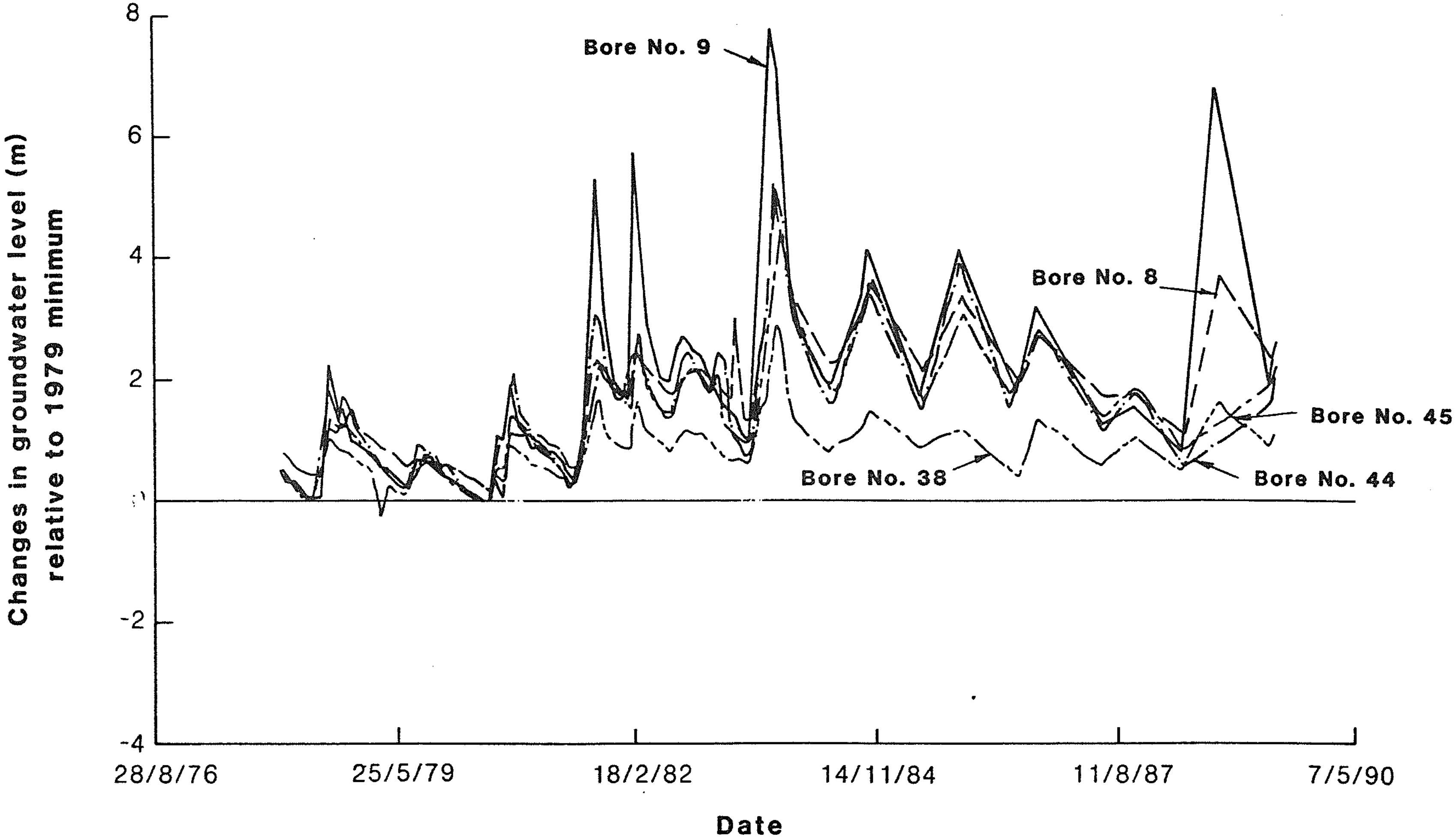


Figure 4 Groundwater hydrographs of pasture control bores

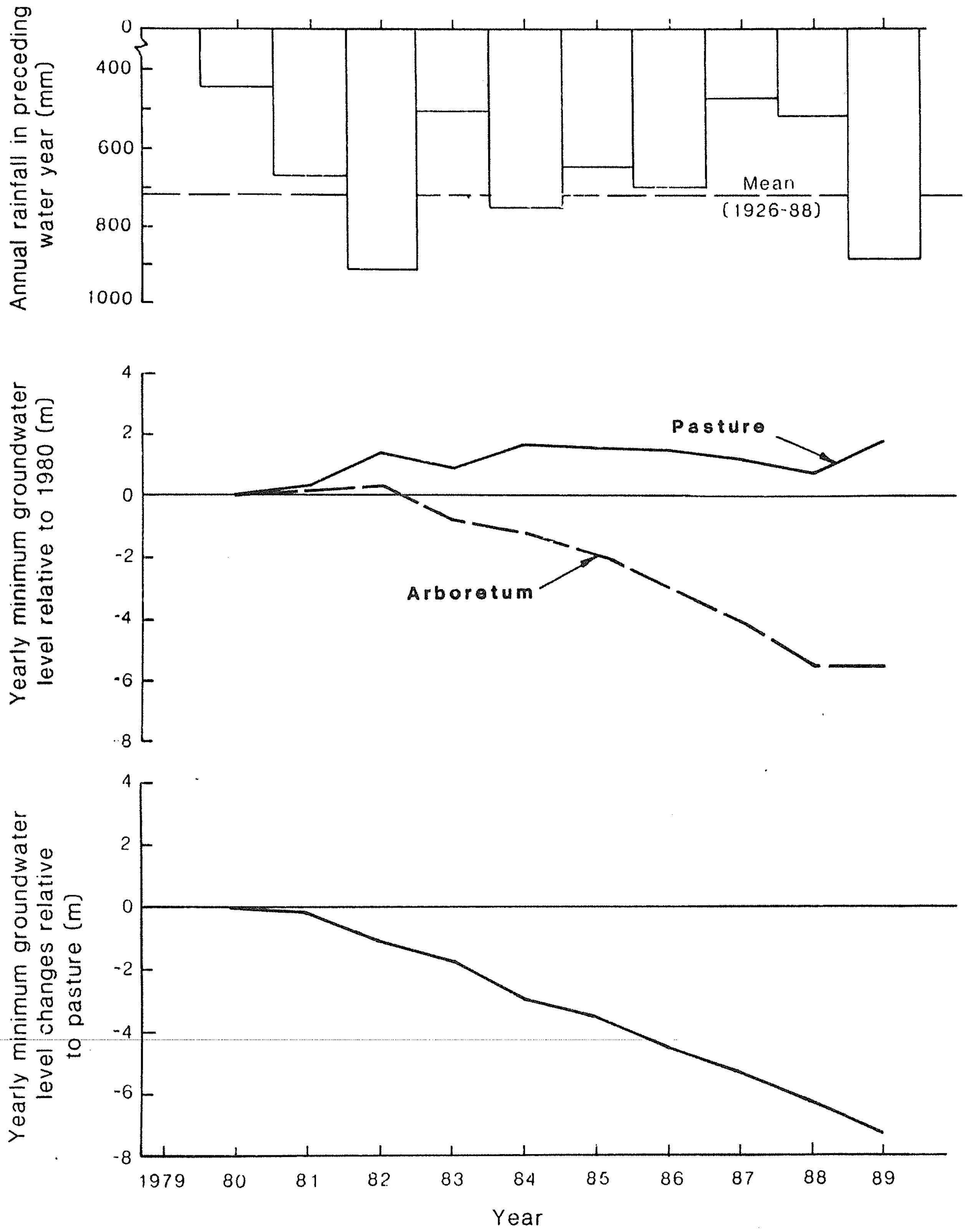


Figure 5 Annual rainfall and minimum groundwater level at the arboretum site

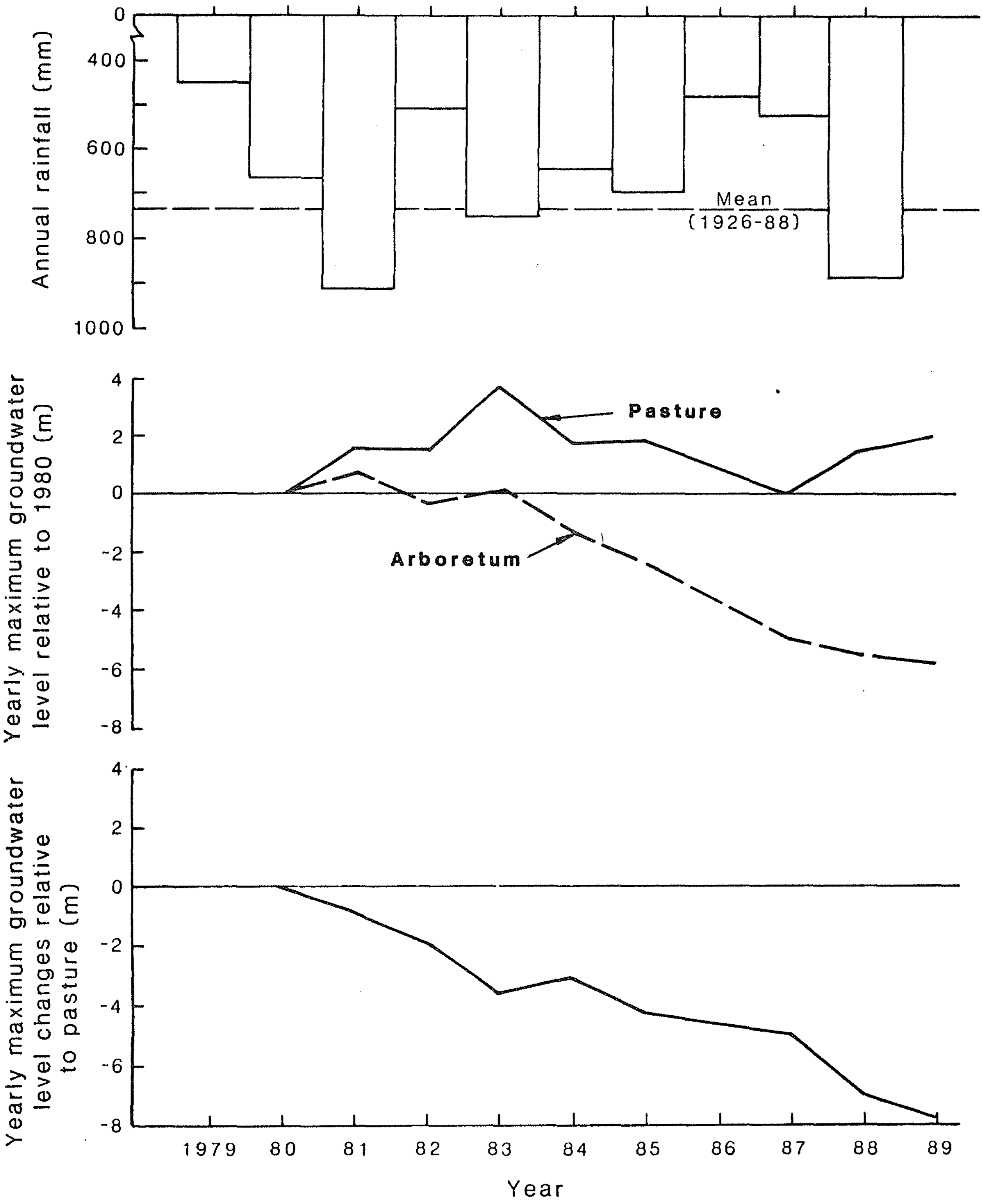


Figure 6 Annual rainfall and maximum groundwater level at the arboretum site

6.3 Groundwater Level Response to Reforestation

Trees planted on cleared agricultural sites have the potential to decrease the vertical recharge to the aquifer system by increasing transpiration and interception loss (Eastham et al., 1988; Schofield, 1990). Analyses of annual minima and maxima and comparisons to the control site were carried out to determine the effects of reforestation on groundwater levels. A typical representation of groundwater level fluctuations of bores beneath pasture and arboretum sites is shown in Fig. 7.

6.3.1 Minimum Groundwater Level

The annual minimum groundwater levels of all bores at the arboretum site are shown in Table 2a. Fig. 5 shows that the high rainfall in 1981 (910 mm) resulted in groundwater levels rising beneath the control and arboretum sites during 1982. In the following year rainfall was very low (497 mm). Groundwater levels declined at both sites (Fig. 5). From 1984 to 1987 annual rainfall, ranging from 470 mm to 693 mm, was lower than long term average. During this period, the decline in groundwater level beneath the arboretum site was near-linear relative to pasture bores. Above average rainfall was recorded in 1988. As a result the water table rose beneath pasture and arboretum sites. Over the study period the minimum groundwater level beneath reforestation declined 5.5 m relative to the ground surface and 7.3 m relative to the control site.

Contours of the reduction in minimum groundwater level are shown in Fig. 8a. The reduction varied across the site, being greatest in the valley floor and least below the upper midslopes.

6.3.2 Maximum Groundwater Level

The annual maximum groundwater levels of all bores are given in Table 2b and the variation in maximum groundwater level is shown in Fig. 6. In 1981, groundwater level under pasture rose by 1.6 m

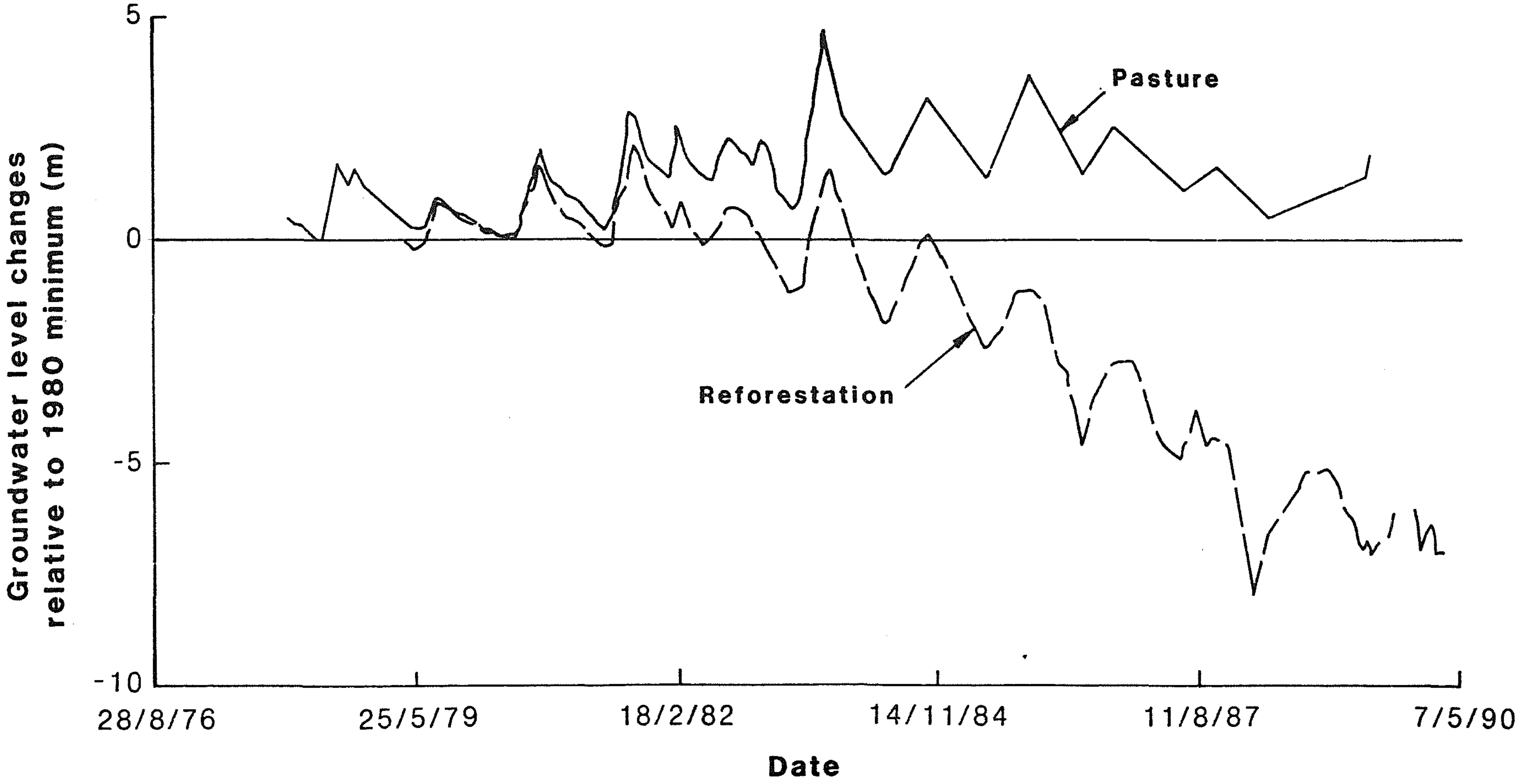


Figure 7 Typical groundwater hydrographs of pasture and arboretum bores

Table 2a: Yearly minimum groundwater level (m, AHD) for observation bores -- arboretum site

Bore No.	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
G61218369	258.670	258.680	259.510	258.090	258.030	257.140	256.240	255.040	253.440	254.140
G61218370	259.362	259.412	260.172	258.592	258.372	257.282	256.222	254.932	253.382	253.732
G61218372	259.549	259.469	259.729	258.519	257.999	257.509	256.409	255.369	253.429	253.969
G61218373	260.628	260.388	260.718	258.898	258.228	257.498	256.278	255.148	254.218	254.398
G61218374	260.830	261.360	261.750	260.000	259.460	258.590	257.430	256.110	255.190	255.210
G61218377	259.236	259.206	259.326	258.666	258.316	257.736	257.116	256.136	255.006	254.536
G61218378	261.530	261.370	261.390	260.340	259.660	259.100	256.910	256.650	253.600	254.550
G61218379	262.166	262.036	262.116	260.846	260.136	259.456	258.436	257.206	255.756	255.306
G61218380	262.351	262.261	262.391	261.131	260.531	259.761	258.861	257.631	256.481	256.031
G61218386	260.061	259.531	259.461	258.561	257.871	257.711	256.831	255.971	254.901	254.321
G61218388	264.094	264.354	264.274	263.244	263.144	261.884	260.584	259.384	257.384	258.084
G61218389	266.249	266.739	266.759	266.039	265.899	264.879	263.649	262.449	261.149	259.389
G61218393	264.808	265.058	264.808	264.728	264.718	264.108	263.308	262.408	261.708	261.208
G61218394	265.487	265.607	265.247	264.447	264.307	263.267	262.257	261.057	260.107	259.507
G61218396	260.334	260.164	260.154	259.284	258.634	258.154	257.374	256.304	255.024	254.604
G61218397	254.989	257.979	258.539	257.289	256.889	256.569	255.329	254.319	252.589	253.419
G61218398	258.729	258.749	259.569	258.109	258.019	257.039	256.199	255.029	253.479	254.029
G61218399	260.657	260.517	260.537	259.657	259.097	258.517	257.527	256.407	254.757	254.557

Table 2b: Yearly maximum groundwater level (m, AHD) for observation bores --- arboretum site

Bore No.	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
G61218369	260.840	262.920	260.890	262.000	259.660	258.650	257.140	255.940	256.100	255.810
G61218370	261.582	264.042	261.962	262.952	260.202	258.902	257.182	255.882	255.532	255.622
G61218372	261.139	261.819	260.719	261.419	260.109	259.329	257.919	256.119	256.009	255.449
G61218373	263.208	264.458	262.298	263.288	260.948	259.708	257.848	256.098	255.998	255.748
G61218374	263.940	264.890	263.230	263.890	261.570	260.280	258.540	257.210	256.410	256.680
G61218377	260.586	261.116	260.216	260.966	259.906	259.226	257.796	256.836	256.186	255.746
G61218378	263.180	263.650	262.350	263.080	261.660	260.430	258.850	257.750	256.450	256.110
G61218379	263.966	264.586	263.306	263.796	262.106	260.806	259.256	258.106	257.356	257.176
G61218380	264.061	264.581	263.511	263.891	262.311	261.071	259.641	258.431	257.631	257.641
G61218386	261.471	261.681	260.471	261.391	260.311	259.621	257.801	256.621	256.951	255.821
G61218388	265.724	265.984	265.254	265.084	264.354	262.254	261.854	260.534	258.984	258.974
G61218389	267.189	267.699	267.539	267.069	266.859	265.869	264.649	263.449	261.949	261.869
G61218393	265.318	265.548	266.348	265.308	265.126	264.178	263.988	263.208	262.558	261.908
G61218394	266.417	266.467	266.157	265.507	265.187	263.477	263.117	262.007	260.757	260.557
G61218396	262.334	262.374	261.174	261.894	260.634	259.684	258.104	257.104	257.584	256.904
G61218397	259.339	259.869	259.369	260.009	258.869	258.209	257.169	255.719	255.719	255.519
G61218398	260.969	263.079	260.949	262.059	259.699	258.639	257.179	255.979	255.879	255.729
G61218399	261.867	262.192	261.417	261.997	260.997	260.007	258.507	257.207	256.407	255.887

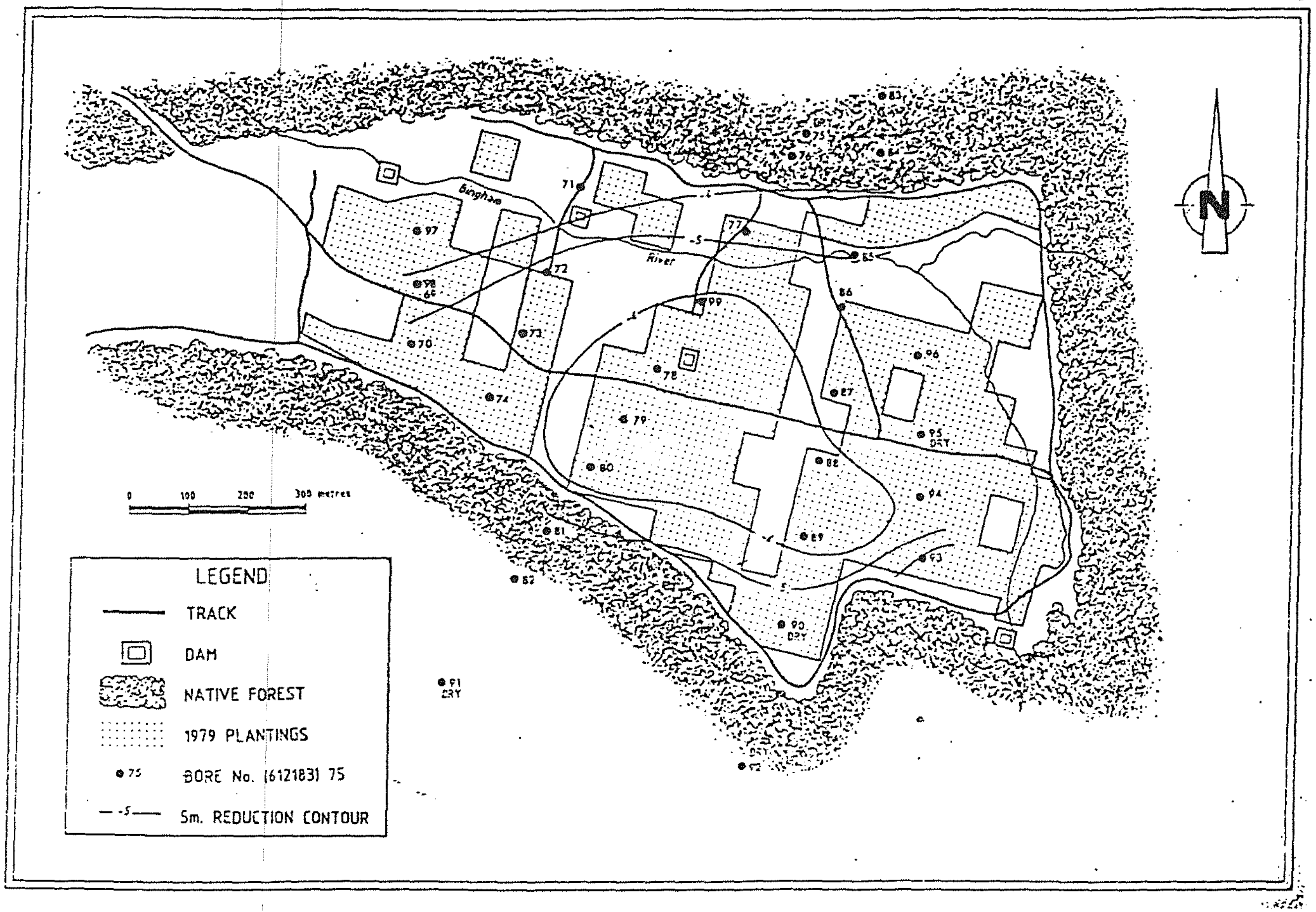


Figure 8a Contours of the reduction in minimum groundwater level

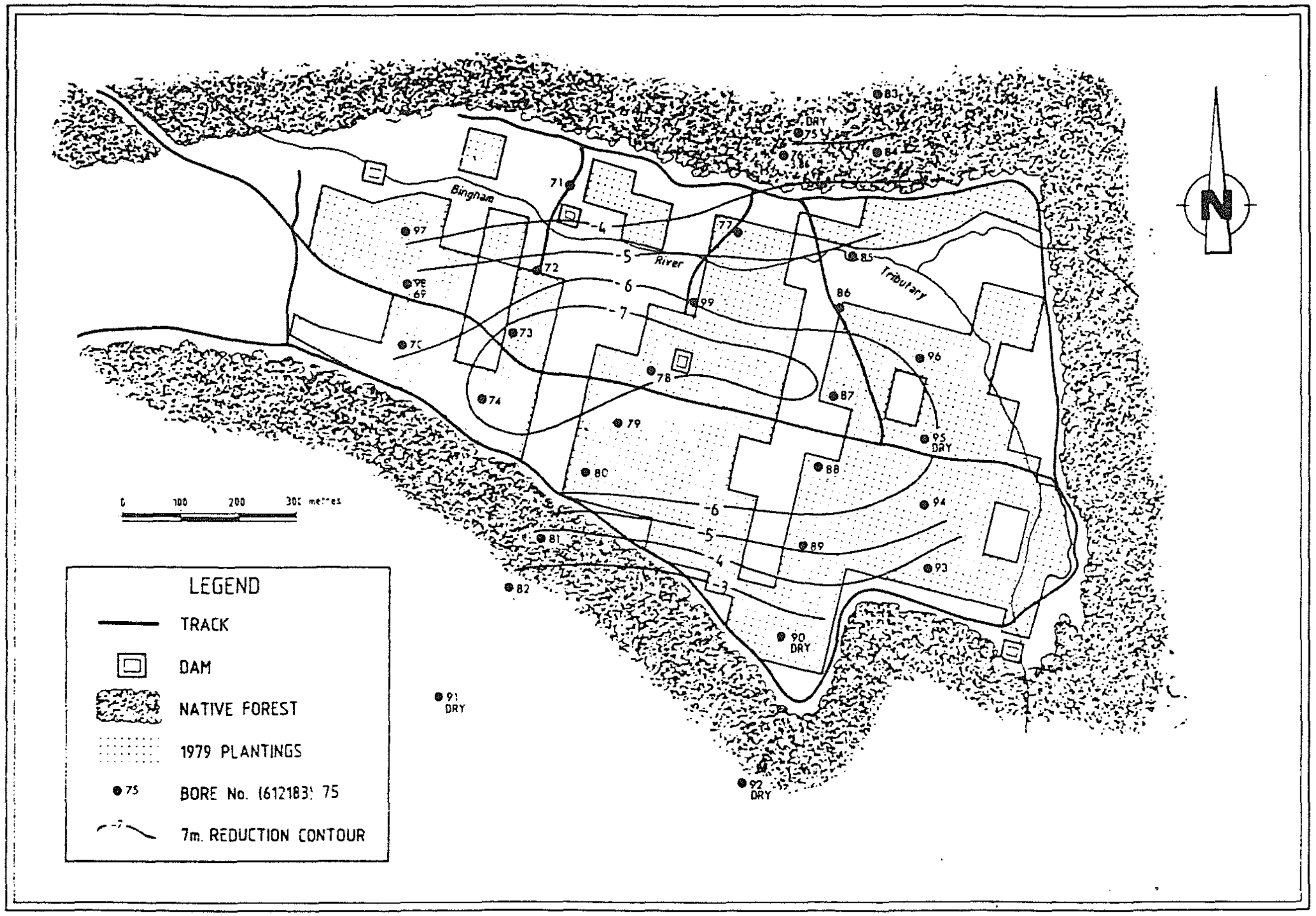


Figure 8b Contours of the reduction in maximum groundwater level

following an above average rainfall year (910 mm). But under the reforestation, the maximum groundwater level rose by 0.76 m. Annual rainfall was very low in 1982. The maximum groundwater level under pasture was steady and declined beneath reforestation. In 1983, the groundwater level at the control site rose by 2.1 m, but at the arboretum site the increase was 0.47 m. This marked decline of 1.63 m relative to pasture was not repeated in following years. Indeed the groundwater level steadily declined relative to pasture for the period 1984-87 (Fig. 6). At the end of the study period, the maximum groundwater reduction was 5.8 m relative to the ground surface and 7.8 m relative to pasture.

Contours of the reduction in maximum groundwater level are shown in Fig. 8b. Like the minimum, the reduction of maximum groundwater level varied across the site, being greatest in the valley floor and least below the upper midslopes.

6.3.3 Comparison of Minimum and Maximum Groundwater Level Reduction

In Fig. 9 the reductions in yearly minimum and maximum groundwater levels relative to the pasture are shown. Both the minimum and maximum groundwater levels had a near-linear decline over the study period. However, the reduction in minimum groundwater level was more uniform than the maximum.

6.3.4 Regression Analyses

Linear regressions were developed to predict the changes in minimum and maximum groundwater levels under different annual rainfall conditions.

The minimum groundwater level occurs in autumn. This level is strongly influenced by the rainfall during the previous winter. Therefore, annual change in minimum groundwater level (Y, mm) was plotted against the rainfall for the preceding year (X, mm yr^{-1}). The regression based on the minimum groundwater level is:

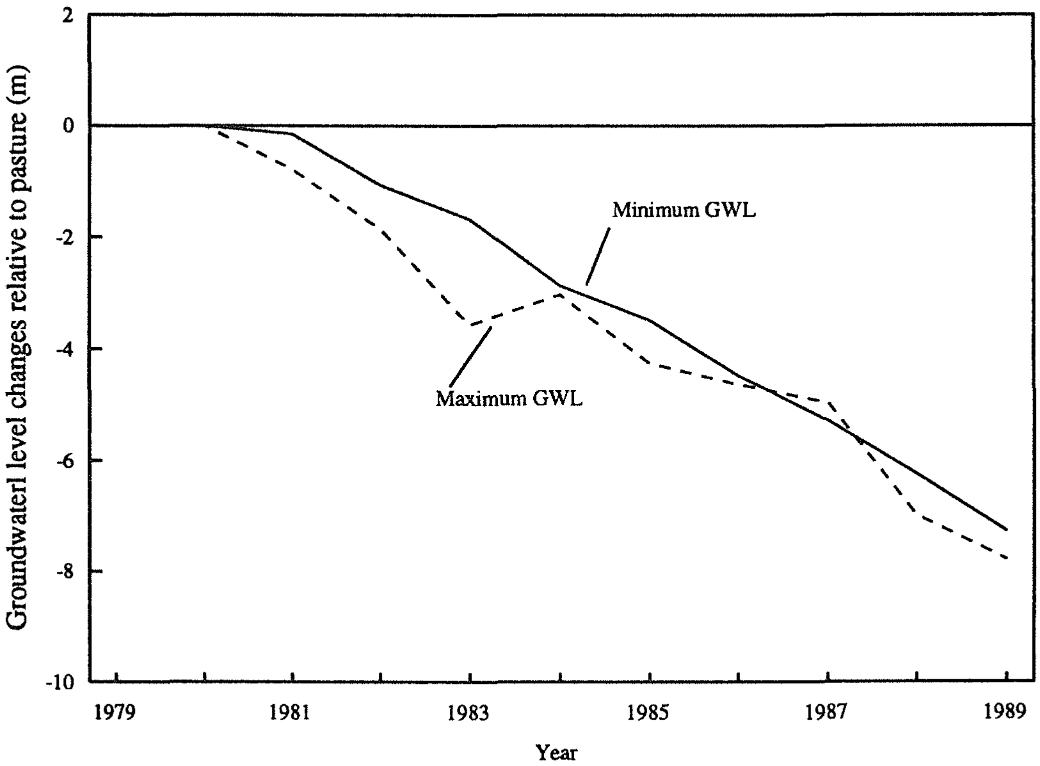


Figure 9 Comparison of the reduction of minimum and maximum groundwater levels

$$Y = -2687 + 3.11X \qquad (1)$$

Equation 1 predicts a fall in the average minimum groundwater level of 470 mm yr^{-1} for the long term average rainfall (713 mm yr^{-1}). The minimum groundwater level would remain steady if the preceding year's rainfall was 865 mm (Fig. 10a).

As the maximum groundwater level occurs soon after the winter rains (in the same year), the annual change in average maximum groundwater level (Y, mm) was plotted against the rainfall which occurred in the same year (X, mm yr^{-1}). The regression based on the maximum groundwater level is:

$$Y = -3200 + 3.76X \qquad (2)$$

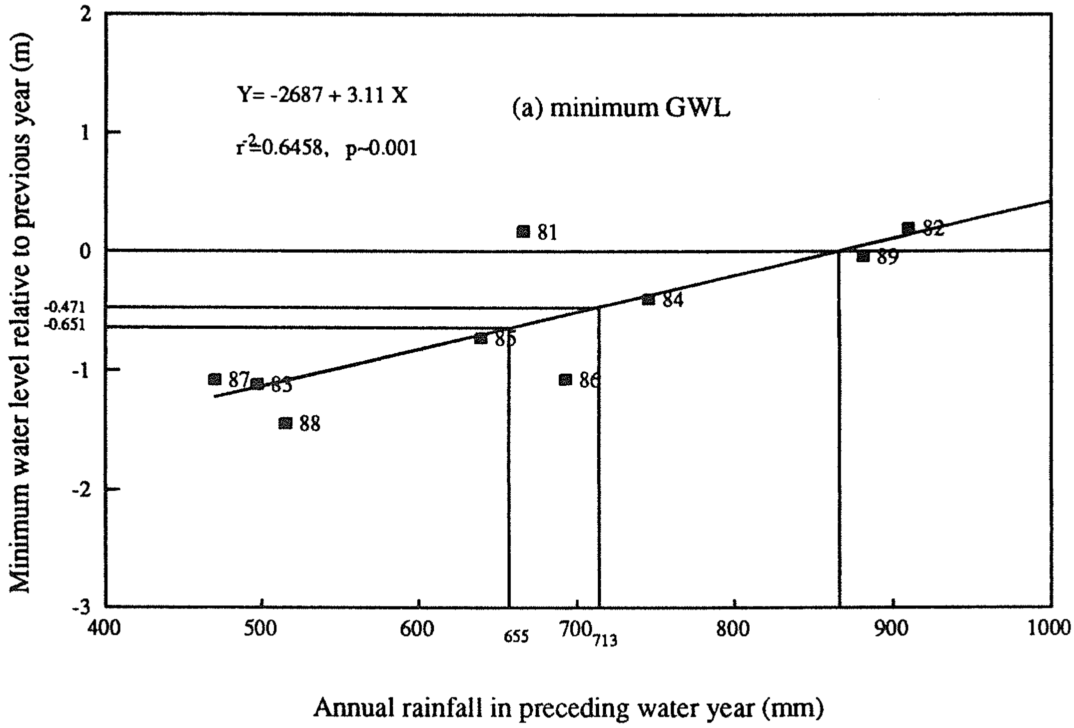
From equation 2 the fall in average maximum groundwater level would be 520 mm yr^{-1} in an average rainfall year. The maximum groundwater level would remain steady if the rainfall was 851 mm (Fig. 10b).

6.4 Potentiometric Surface across the Valley

Fig. 11 shows the temporal variation in potentiometric surfaces across the bore transect 375-91 of the arboretum site. Three years (1980, 1985 and 1989) have been plotted as an example. There has been significant reduction in groundwater level beneath the reforestation. This result indicates such extensive reforestation is an effective strategy for lowering shallow, saline groundwater tables.

6.5 Groundwater Flow

The minimum and maximum groundwater potentiometric contours for each year have been analysed. Contour plans for the beginning (May '80 and September '80) and end of study period (May '89 and September '89) are shown in Fig. 12. The direction of groundwater flow at the beginning of the study was north-west.



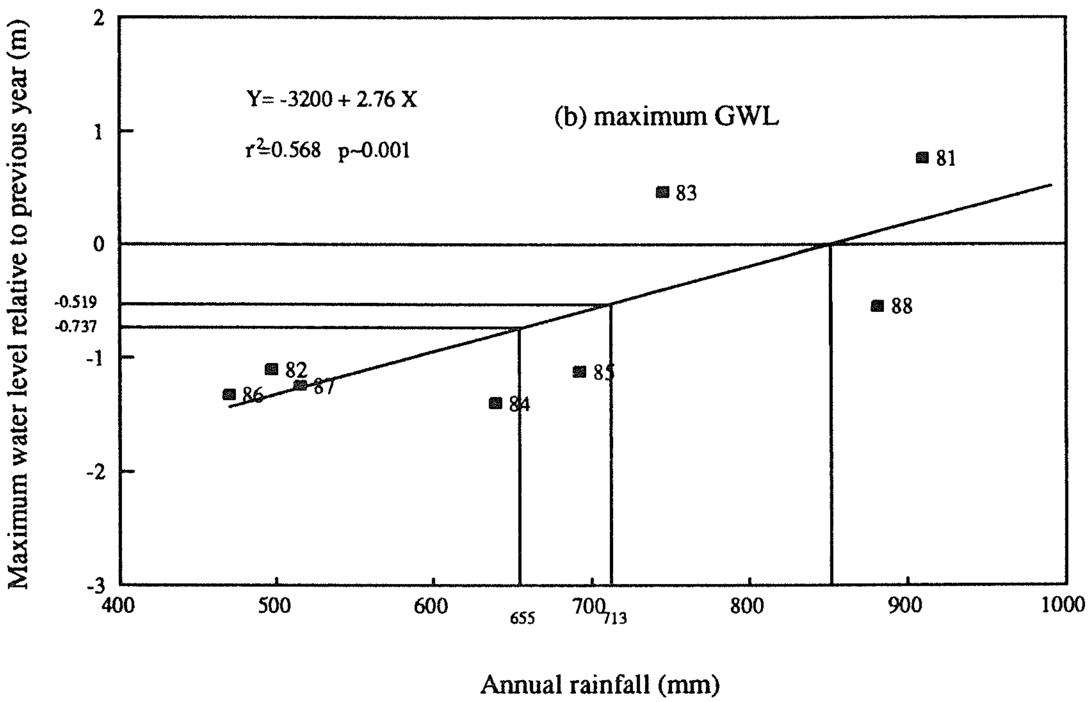


Figure 10 Relationship between change in groundwater level relative to previous year and annual rainfall

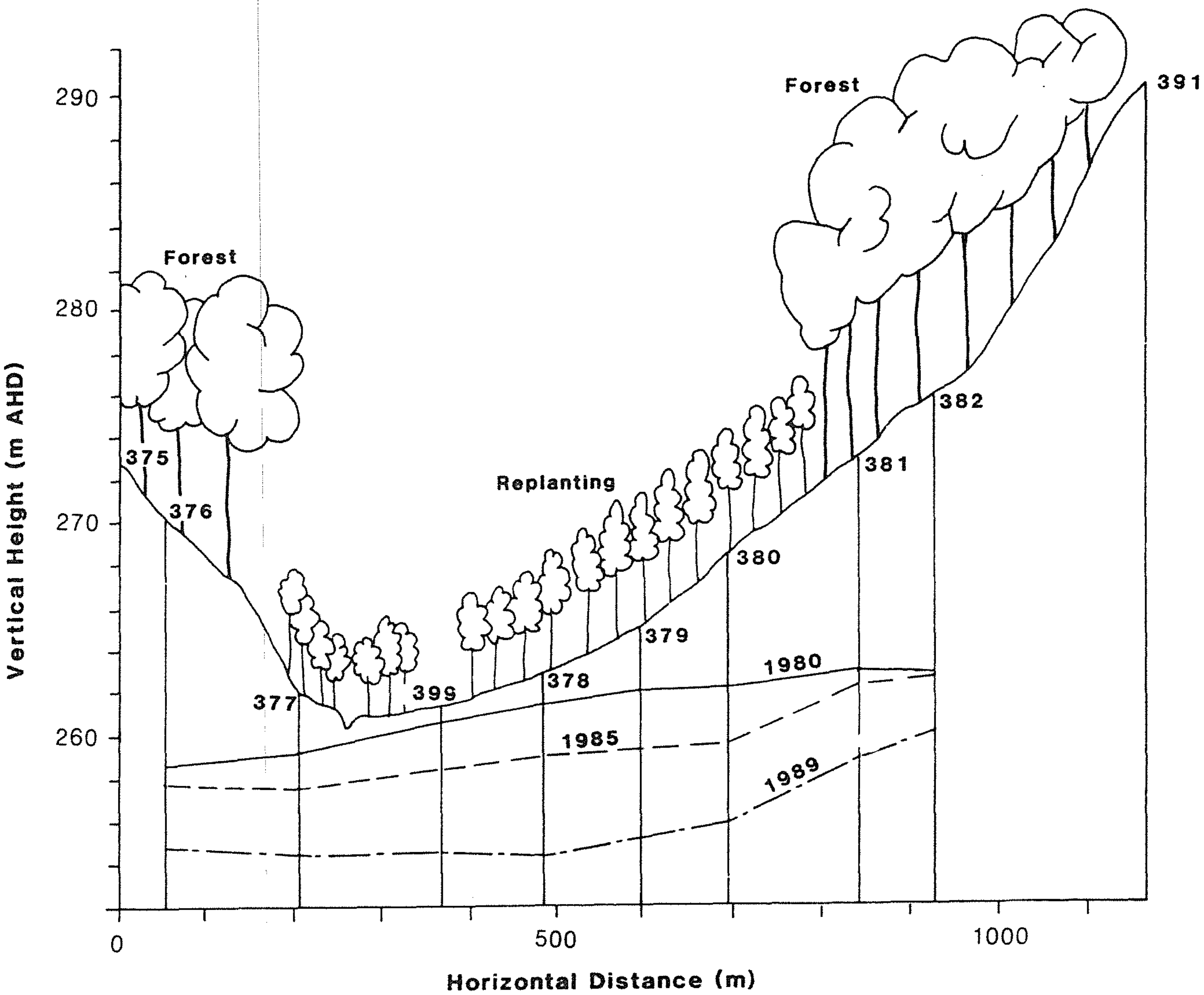


Figure 11 Valley cross-section ---- potentiometric surfaces

Elevated groundwater levels beneath the cleared area resulted in flow beneath the creek to the forest on the northern side of the valley. By the end of the study period, the reduction in groundwater levels beneath the arboretum resulted in a slight change in groundwater flow. The flow system south of the creek continues to flow north-westerly. However, the flow system north of the creek reversed and now flows southerly towards the creek.

6.6 Groundwater Salinity

6.6.1 Groundwater Salinity Trend Beneath Pasture

The response of groundwater salinity under the control site is reported by Bari et al. (1991a) in detail. They classified salinity data into three categories :

(a) All bores
(b) Fresh bores
(c) Saline bores

The results of the pumped samples taken in May 1989 were compared with the results of the samples taken in May 1980. The average reduction in groundwater salinity of all bores was 41%. Salinity reduction in individual bores ranged from 8.3% to 48.9%. The fresh and saline bore groups averaged 34% and 61% declines respectively.

6.6.2 Groundwater Salinity Trends Beneath the Arboretum Site

The groundwater salinities for bores at the arboretum site are shown in Appendices A and B. The temporal variation in salinity was erratic. In some cases variation of more than five-fold occurred from one observation to the next. However, as experienced in other experimental sites (Bari et al., 1990; Bari et al., 1991a, b) this variation is probably not a true representation of groundwater salinity. To obtain a more representative sample, all bores were pumped and developed in May 1989 and then sampled and analysed.

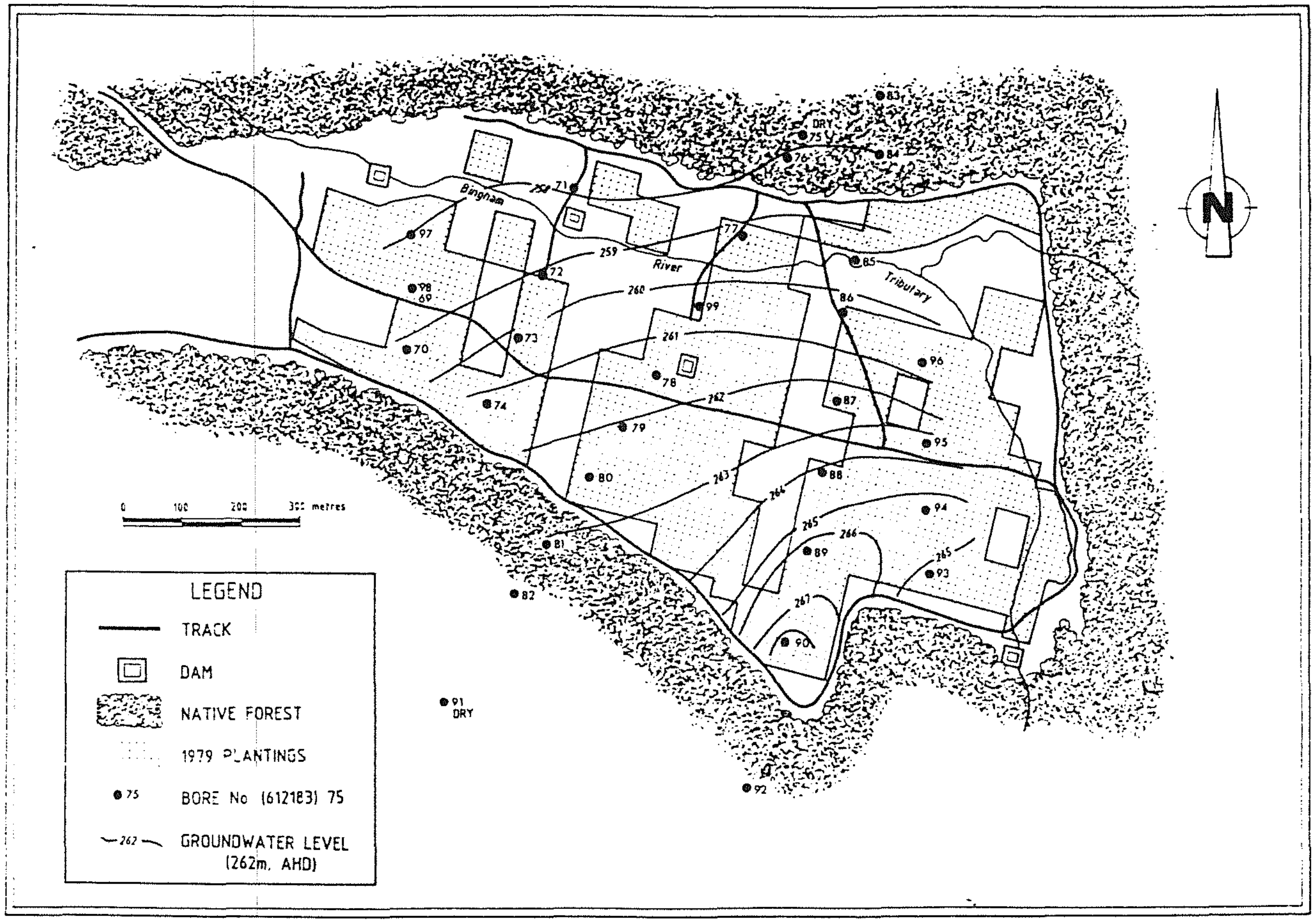


Figure 12a Groundwater flow directions - May 1980

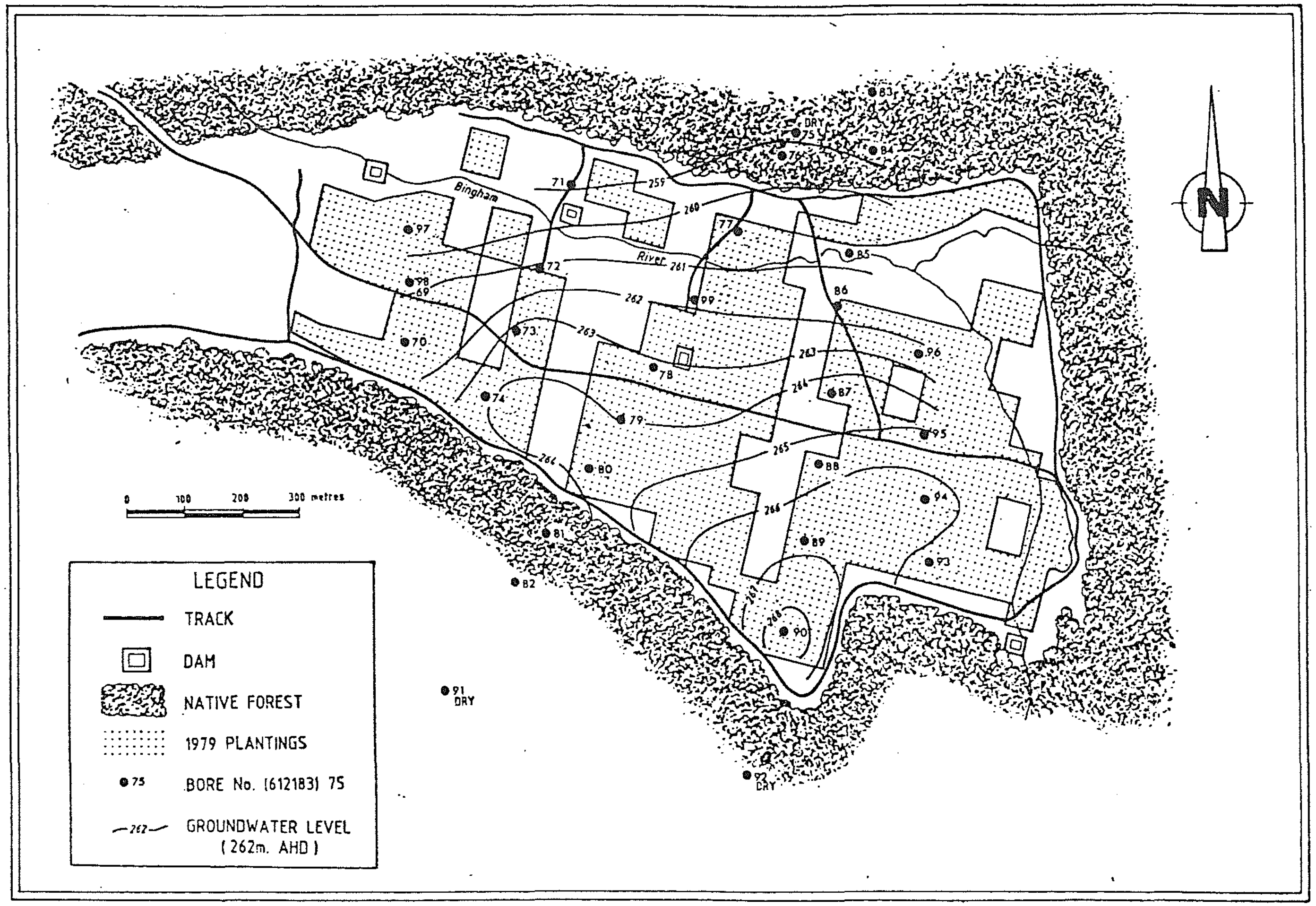


Figure 12b Groundwater flow directions - September 1980

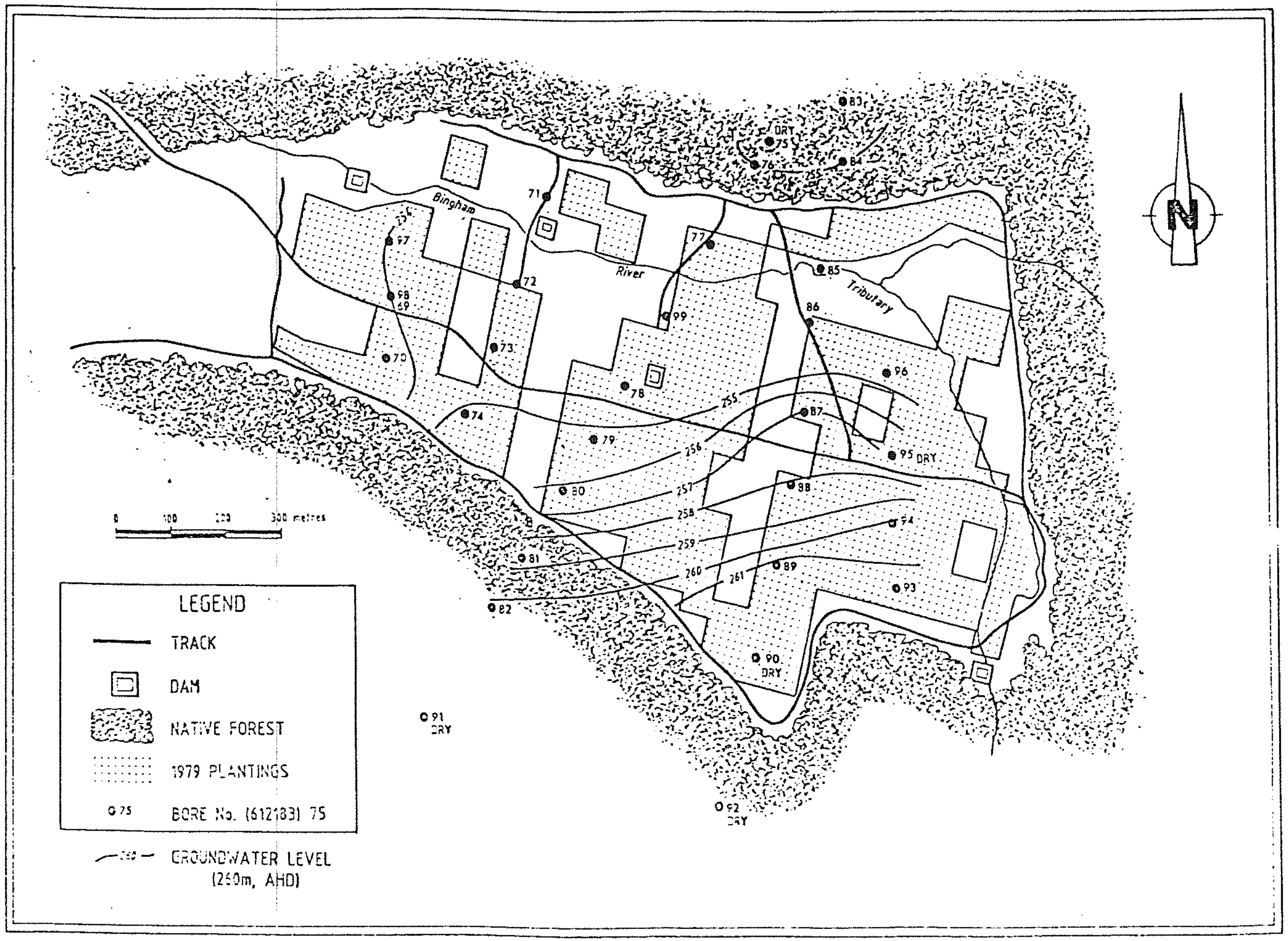


Figure 12c Groundwater flow directions - May 1989

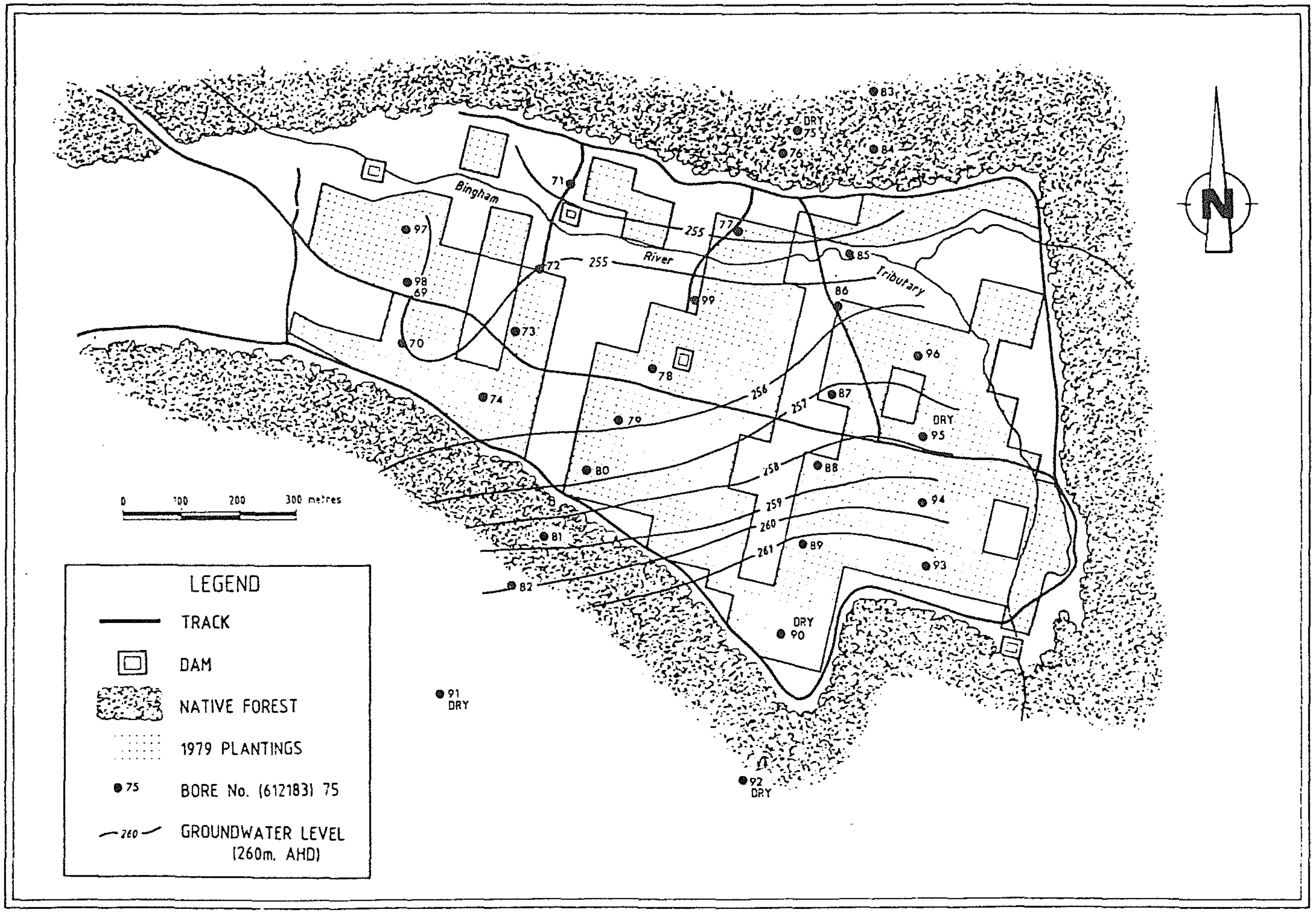


Figure 12d Groundwater flow directions - September 1989

Bore salinity data from the arboretum site were classified into three groups:

(a) All bores
(b) Bores screened at the water table
(c) Bore screened below water table

The results of the pumped samples taken on 31/5/89 were compared with results of those taken on 7/5/80. Table 3 shows the average reduction in salinity for all bores was 11%. However, there was a marked variation in salinity change, from a decrease of 93% to an increase of 1117%. The average salinity of other two groups of bores also declined, varying from 1% to 34%.

Groundwater salinity varies considerably across the site. This spatial variability has changed only slightly during the study period (Fig. 13a). Salinities range from 1000 mgL^{-1} to 12000 mgL^{-1} TSS; but the most recent analysis shows the areas of lower salinity are more extensive (Fig. 13b).

Soil Salinity

Soil salinity profiles measured across the bore transect 375-91 in 1979 and 1989 are shown in Fig. 14. There has been a slight change in salinity profiles in bores 375 and 382. These bores are located within the native forest, upslope of the arboretum. The salt content in bore 380 has reduced overall, but there is a slight accumulation between 4 and 6m below the surface (Fig. 14c). There has also been a slight accumulation of salt between 0.5 and 7m depths in bore 378 (Fig. 14b). Both of these bores are located within the arboretum area.

Table 3 : Groundwater salinity -- Arboretum site

Bore group	Bore no.	Salinity (mgL^{-1}) on 7/5/80		Salinity (mgL^{-1}) on 31/5/89		% change in salinity	
		Indiv.	Average	Indiv.	Average	Indiv.	Average
	G61218373	338.00		4112.00		1116.57	
	G61218374	6834.00		9138.00		33.71	
	G61218379	4309.00		3268.00		-24.16	
Bores	G61218386	1008.00	5729.7	208.00	5653.3	-79.37	-1.3
screened	G61218388	7015.00		5565.00		-20.67	
at water	G61218389	9961.00		10179.00		2.19	
table	G61218393	12227.00		13571.00		10.99	
	G61218394	11929.00		10578.00		-11.33	
	G61218396	3292.00		216.00		-93.44	
	G61218397	4739.00		4495.00		-5.15	
	G61218398	1375.00		856.00		-37.75	
	G61218369	5146.00		893.00		-82.65	
	G61218370	5603.00		4979.00		-11.14	
Bores	G61218372	1669.00		436.00		-73.88	
screened	G61218377	2267.00	3884.9	1359.00	2576.3	-40.05	-33.7
below	G61218378	5030.00		4602.00		-8.51	
water	G61218380	1825.00		505.00		-72.33	
table	G61218399	5654.00		5260.00		-6.97	
All			5012.3		4456.7		-11.1

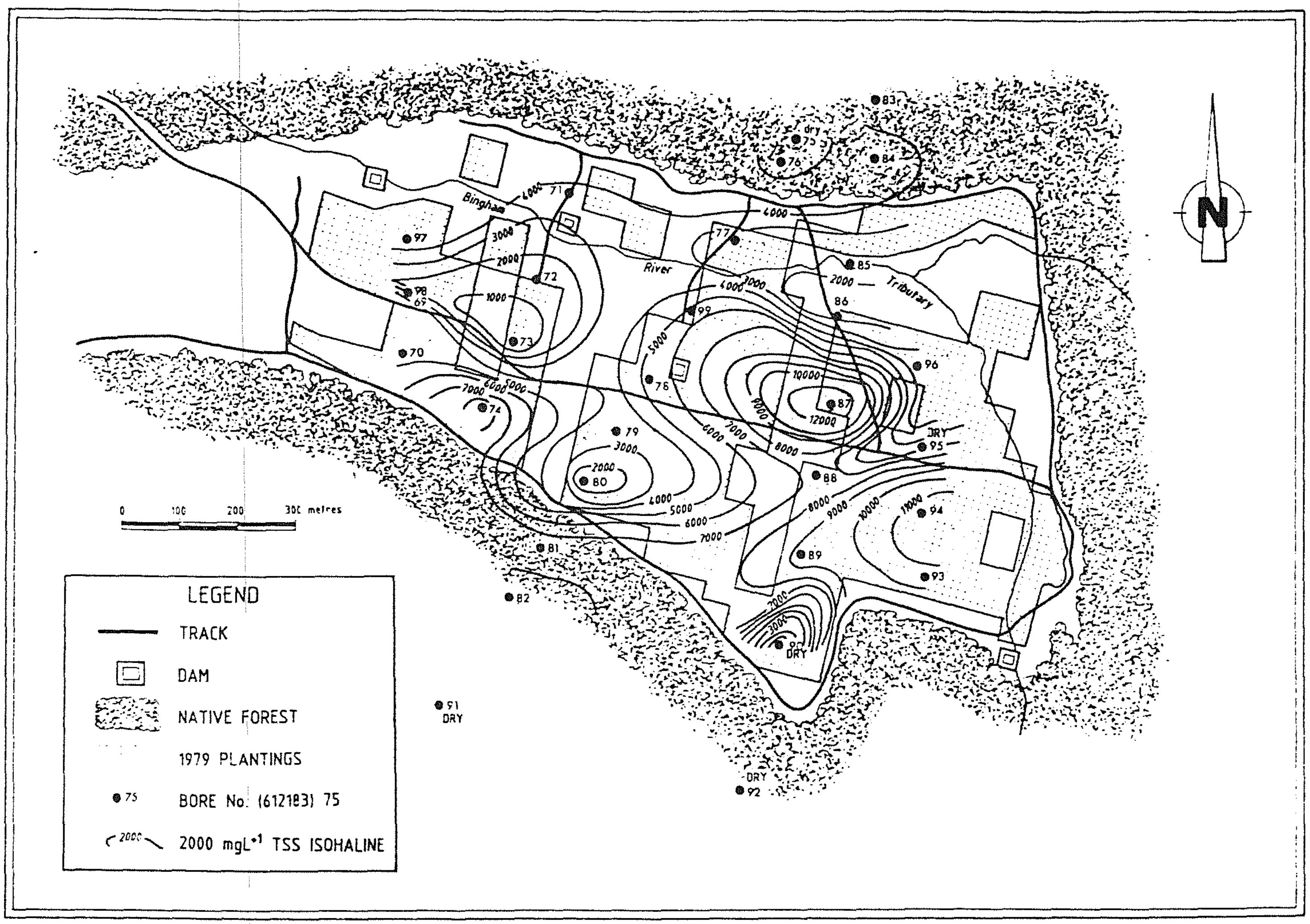


Figure 13a Isohalines based on annual average salinity - 1980

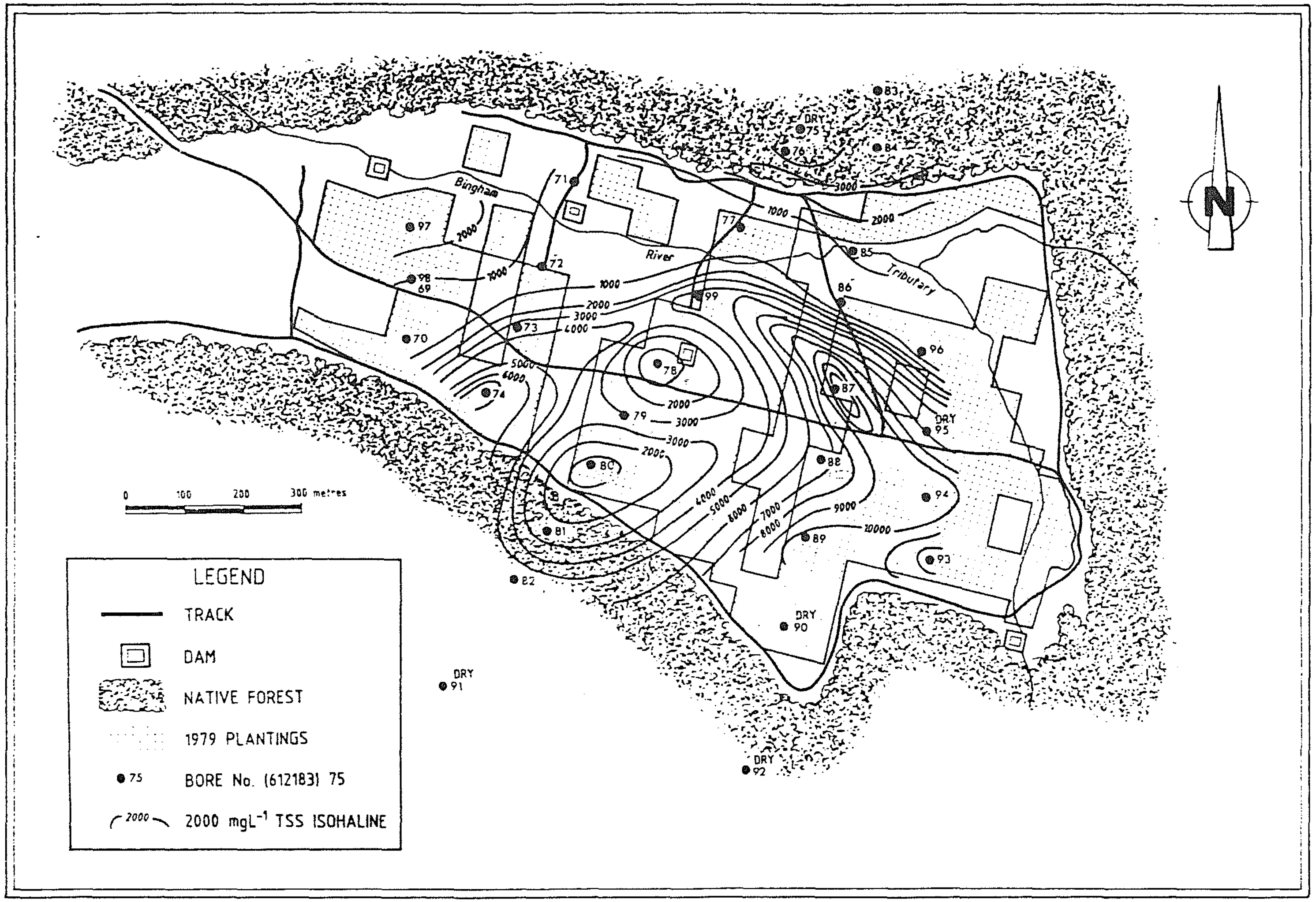


Figure 13b Isohalines based on annual average salinity - 1988

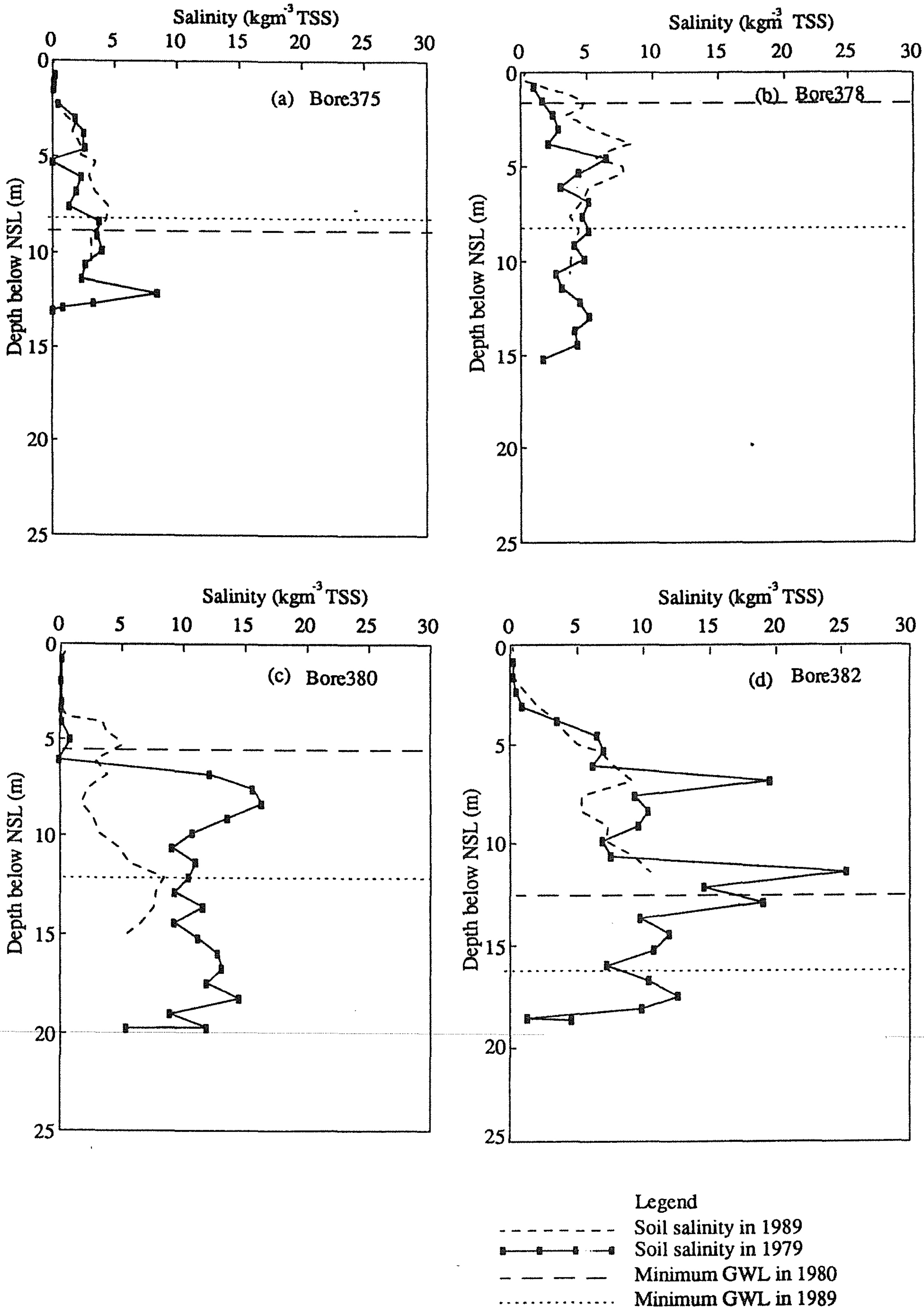


Figure 14 Comparison of soil salinity profiles for 1979 and 1989

7. DISCUSSION

7.1 Rainfall and Groundwater Level Reduction

During the study period (1980-89), the average annual rainfall was 8% lower than the long term (1926-88) average. If long-term average rainfall conditions had prevailed, regression analyses indicate groundwater levels would have fallen under the arboretum site, and would have risen under the control (pasture). If the climate of south-west Western Australia were to become drier as a result of the predicted Greenhouse Effect (Pittock, 1989), then the lower rainfall would assist in lowering groundwater levels.

7.2 Suitability of Pasture Control

At the pasture control site 14% of cleared land was reforested, mainly at the valley floor and lower slopes. This reforestation may have some influence on the groundwater levels in the control bores which are located on the midslopes. However, since groundwater levels have risen beneath pasture during the study period, it is considered the influence has been negligible. The observed rise is fairly representative of groundwater response under agricultural pasture where groundwater has approached equilibrium (Ruprecht and Schofield, 1989).

7.3 Limitations of Linear Regressions

The regression analyses for groundwater levels beneath the arboretum imply that changes in groundwater level are dependant only on annual rainfall, i.e. independent of tree crown cover, rooting depth, depth to groundwater etc. These other variables are time dependent and are not easily quantifiable. Therefore, the regressions should be considered to be indicative only.

7.4 Groundwater Salinity

The temporal variation observed in monthly samples at the control site is discussed by Bari *et al*. (1991a,b) in detail. Similarly there have been variations in groundwater salinity at the arboretum site (Appendix B). This apparent variation is probably caused by fresh water leakage from the unsaturated zone at the time of intensive rainfall and/or by improper sampling. Therefore, the monthly sample results are considered unreliable and have not been included in the salinity analysis. Analysis of pumped samples shows an average decrease of 11% over the study period. The significance of this result is that salinities have not increased as a result of evaporative concentration as was assumed likely by a number of authors (e.g. Conacher, 1982; Morris and Thomson, 1983; Williamson, 1986). The decrease in groundwater salinity may indicate that solute leaching from the aquifer beneath the reforestation stand is occurring at a slightly faster rate than increasing concentration due to transpiration. In the situation of a declining groundwater table other processes will also affect groundwater salinity, such as solution-dissolution rates and solute deposition in the unsaturated zone.

7.5 Comparison Between Arboretum Site and Valley Planting Site

The effects of valley planting on saline groundwater table have been reported by Bari et al. (1991a). The valley planting site is located about 3 km north-east of the arboretum site. The physiography of the two sites are similar. Prior to the establishment of trees, 44% of the valley planting site was cleared for pasture grazing compared to 35% of the arboretum site. At both sites, trees were planted on the valley floor and lower slopes. The initial mean annual salinity was 5400 mg L^{-1} TSS at the valley planting site and 4900 mg L^{-1} TSS at the arboretum site. The principal species planted at the valley planting site were E. rudis (55% of the reforestation), E. camaldulensis (19.4%), E. wandoo (17.8%), E. calophylla (1.2%) and E. globulus (6.6%), whereas at the arboretum site 63 species of eucalypts and two species of pines were planted.

At the valley planting site 35% of the cleared area was planted at an initial stem density of 625 sph and later reduced by thinning to 150 to 550 sph. Trees were planted at the arboretum site with an initial density of 625 sph covering 70% of the cleared farmland. Tree density was reduced through natural attrition. By 1988 densities varied from nil to 600 sph. The average crown cover at the valley planting site was 41% and 39% at the arboretum.

The greater reduction in minimum groundwater level at the arboretum site (5.5 m cf. 1.5 m at the valley planting site) was probably due to higher percentage of cleared area being planted. The groundwater salinity at the valley planting site was reduced by 30% whereas at the arboretum site it was 11%.

7.6 Use of Reforestation as Salinity Control

The results clearly demonstrated that the extensive, dense reforestation strategy used at the arboretum was successful in lowering the saline groundwater table substantially across the valley floor (thus eliminating saline groundwater discharge to the stream) in a short (~10 years) period of time. The rate of decline of minimum groundwater level relative to pasture (810 mm yr^{-1}) was the highest among the number of different reforestation strategies tested in the area (Bell et al., 1990). However, this type of extensive reforestation has limited application in agricultural areas. Its application is considered more appropriate for land which has little agricultural value as a result of salinisation.

8. CONCLUSIONS

8.1 Groundwater Level

(i) Seventy percent reforestation of the cleared area has lowered the yearly minimum groundwater level of a partly salinised agricultural site by 5.5 m relative to the ground surface and 7.3 m relative to a pasture control in 10 years. The groundwater level reduction, relative to the control, was near-linear with time and had a continuous downward trend.

(ii) The maximum groundwater level reduction was 5.8 m relative to ground level and 7.8 m relative to pasture.

(iii) During the study period, rainfall was 8% lower than the long term average. Regression analyses imply that the minimum groundwater level would rise relative to the ground surface under pasture and would fall under reforestation under long term average rainfall conditions.

8.2 Groundwater Flow

(i) There has been a slight alteration to groundwater flow since reforestation.

(ii) Following clearing, elevated groundwater levels resulted in groundwater flowing from the southern side of the valley beneath the stream to the native forest on the northern side.

(iii) After 10 years of reforestation, groundwater now flows from both sides of the valley to the stream.

8.3 Groundwater Salinity

(i) The spatial variation of groundwater salinity at both the arboretum and control sites was high (fresh to highly saline).

(ii) During the study period, groundwater salinity at the arboretum site decreased by 11%.

(iii) Extensive reforestation has been successful in controlling groundwater salinity. Its application will be limited in areas where it is in competition with traditional agricultural practices. It is likely to be benificial in areas where agricultural value has been reduced by salinisation of the land.

9. RECOMMENDATIONS

- Extensive reforestation is a viable land use option for salinity control and its further study is strongly recommended.

- To identify the effects of further crown and tree growth, bore monitoring should be continued to obtain yearly minimum and maximum groundwater levels.

- Sampling should be continued so groundwater salinity trends beneath both pasture and arboretum can be assessed further.

- To support interpretation of the groundwater data, tree basal area and tree covers should be measured about every 5 years.

10. ACKNOWLEDGEMENTS

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11. REFERENCES

Bari, M.A., Schofield, N.J. and Boyd, D.W. (1991a). Groundwater level and salinity response beneath valley reforestation at Stene's farm in the Darling Range of Western Australia. Water Authority of W.A., Surface Water Branch, Rep. No. WS 73, 59 pp.

Bari, M.A., Schofield, N.J. and Boyd, D.W. (1991b). Groundwater level and salinity response under agroforestry at Stene's farm in the Darling Range of Western Australia. Water Authority of W.A., Surface Water Branch, Rep. No. WS 77, 53 pp.

Bari, M.A., Schofield, N.J. and Boyd, D.W. (1990). Groundwater level and salinity response under agroforestry at Flynn's farm in the Darling Range of Western Australia. Water Authority of W.A., Surface Water Branch, Rep. No. WS 72, 58 pp.

Bell, R.W., Anson, B. and Loh, I.C. (1988). Groundwater response to reforestation in the Darling Range of Western Australia. Water Authority of W. Australia, Surface Water Branch, Rep. No. WS 24, 89 pp.

Bell, R.W., Schofield, N.J., Loh, I.C. and Bari, M.A. (1990). Groundwater response to reforestation in the Darling Range of Western Australia. J. Hydrol. 115, 297-317.

Bettenay, E., Russell, W.G.R., Hudson, D.R., Gilkes, R.J. and Edmiston, R. (1980). A description of experimental catchments in the Collie area, Western Australia. CSIRO Div. Land Resour. Manage., Tech. Pap. No. 7, 36 pp.

Conacher, A. (1982). Dryland agriculture and secondary salinity. In : W. Hanby and M. Cooper (Editors), Man and the Australian Environment. McGraw-Hill, Sydney, 113-125.

Eastham, J., Rose, C.W., Cameron, D.M., Rance, S.J. and Talsma, T. (1988). The effect of tree spacing on evaporation from an valley planting experiment. J. Agricul. and Forest Mat. 42, 355-368.

Hayes, R.J. and Garnaut, G. (1981). Annual rainfall characteristics of the Darling Plateau and the Swan Coastal Plain. Public Works Dept. of W. Australia, Water Resources Branch, Rep. No. WRB 3, 28 pp.

Hookey, G.R., Loh, I.C. and Bartle, J.R. (1987). Water use of eucalypts above saline groundwater. Water Authority of W.A., Surface Water Branch, Rep. No. WH 32, 75 pp.

Luke, G.J., Burke, K.L. and O'Brien, T.M. (1988). Evaporation data for Western Asutralia. W. Australian Dept. Agric. Div. Resour. Manag., Tech. Rep. No. 65, 29 pp.

Montana, C. and Ezcurra, E. (1980). A simple instrument for quick measurement of crown projections. J. Fores. 78, 699.

Morris, J.D. and Thomson, L.A.J. (1983). The role of trees in dryland salinity control. Proc. R. Soc. Vic. 95(3), 123-131.

Peck, A.J., Thomas, J.F. and Williamson, D.R. (1983). Salinity issues : Effects of man on salinity in Australia. Water 2000 Consultants Report No. 8, Aust. Gov. Publ. Serv., 78 pp.

Pittock, A.B. (1980). Actual and anticipated changes in Australia's climate. In : GREENHOUSE - planning for Climate Change (Ed. G.I. Pearman), CSIRO Melb. Aust. pp 35-51.

Ruprecht, J.K. and Schofield, N.J. (1989). Infiltration measurement on a jarrah forest hillslope within the Del Park catchment, Western Australia. Surface Water Branch, Water Authority of W.A., Rep. No. WS 53, 62 pp.

Schofield, N.J. (1990). Determining reforestation area and distribution for salinity control. J. Hydrol. Sci. 35 :1-19.

Schofield, N.J., Loh, I.C., Scott, P.R., Bartle, J.R., Ritson, P., Bell, R.W., Borg, H., Anson, B. and Moore, R. (1989). Vegetation strategies to reduce stream salinities of water resource catchments in south-west Western Australia. Water Authority of W.A., Surface Water Branch, Rep. No. WS 33, 98 pp.

Schofield, N.J. and Ruprecht, J.K. (1989). Regional analysis of stream salinisation in south-west Western Australia. J. Hydrol. 112, 19-39.

Schofield, N.J., Ruprecht, J.K. and Loh, I.C. (1988). The impact of agricultural development on the salinity of surface water resources of south-west Western Australia, Water Authority of Western Australia, Surface Water Branch, Rep. No. WS 27, 69 pp.

Schofield, N.J., Stoneman, G.L. and Loh, I.C. (1989). Hydrology of the jarrah forest. In : B. Dell (Editor), The Jarrah Forest. Kluwer Academic Publishers, Dordrecht, 179-201.

Sharma, M.L., Barron, R.J.W. and Fernie, M.S. (1987). Areal distribution of infiltration parameters and some soil physical properties in lateritic catchments. J. Hydrol., 94, 109-127.

Williamson, D.R. (1986). The Hydrology of salt affected soils in Australia. Reclam. Reveg. Res. 5, 181-196.

APPENDIX A

Hydrogeological and Plantation Details of the Arboretum Site

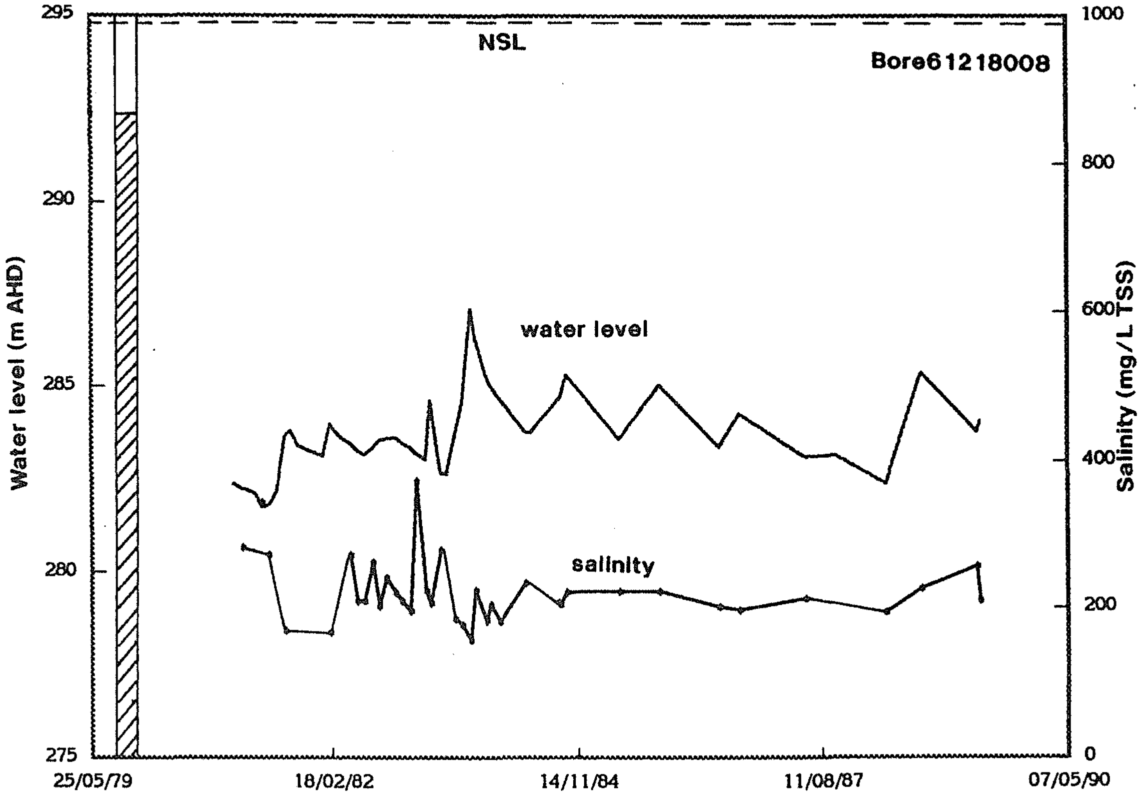
Plot	SWRIS bore no.	Initial depth to water table (m)	Initial mean salinity (mg L^{-1})	Species	(stem ha^{-1}) 1985	Crown cover (%)
1	-	-	-	E. longicornis	212	-
2	-	-	-	E. oleosa	238	-
3	-	-	-	E. salubris	139	-
4	61218371	3.39	3953	E. salmonophloia	139	-
5	-	-	-	E. saligna	600	-
				Botryoides cross		
6	-	-	-	E. globulus	519	-
7	-	-	-	E. accedens	519	-
8	61218377	2.87	2479	E. polyanthemos	350	49
9	-	-	-	E. largiflorens	612	-
10	61218385	3.59	2440	E. largiflorens	538	35
11	-	-	-	pasture	356	-
12	-	-	-	E. rubida	406	-
13	-	-	-	E. robusta	619	-
14	-	-	-	E. viminalis	438	-
15	-	-	-	P. raidata	306	-
16	-	-	-	P. pinaster	256	-
17	-	-	-	E. melanophloia	362	-
18	-	-	-	E. melanophloia	425	-
19	-	-	-	E. sideroxylon		
			-	(Tricarpa)	350	-
20	61218397	3.16	4677	E. odorata	362	31
21	-	-	-	E. leucoxylon	475	-
				ssp. pruinosa		
22	-	-	-	E. gardeneri	262	-
23	-	-	-	E. loxophleba	0	-
24	-	-	-	E. spathulata	106	-
25	-	-	-	E. sargentii	44	-
26	-	-	-	E. rudis	494	-
27	-	-	-	E. camaldulensis	525	-
28	-	-	-	E. camaldulensis	594	-
29	61218386	2.19	1019	E. camaldulensis	594	39
30	-	-	-	E. camaldulensis	550	-
31	-	-	-	E. robusta	525	-
32	61218396	6.25	3437	E. botryoides	531	37
33	-	-	-	E. botryoides	525	-
34	-	-	-	E. botryoides	475	-
35	-	-	-	E. intertexta	125	-
36	-	-	-	E. ocrophloia	94	-
37	-	-	-	E. crebra	262	-
38	-	-	-	E. crebra	344	-
39	-	-	-	E. crebra	394	-
40	61218398	7.54	1254	E. radiata	406	47
				spp radiata		
41	-	-	-	E. falcata	356	-
42	-	-	-	E. microtheca	412	-
43	61218372	1.95	1483	E. mannifera	519	35
				ssp. maculosa		
44	-	-	-	E. platypus	81	-
45	61218399	1.02	5692	E. conferruminata	38	39
46	-	-	-	E. occidentalis	450	-

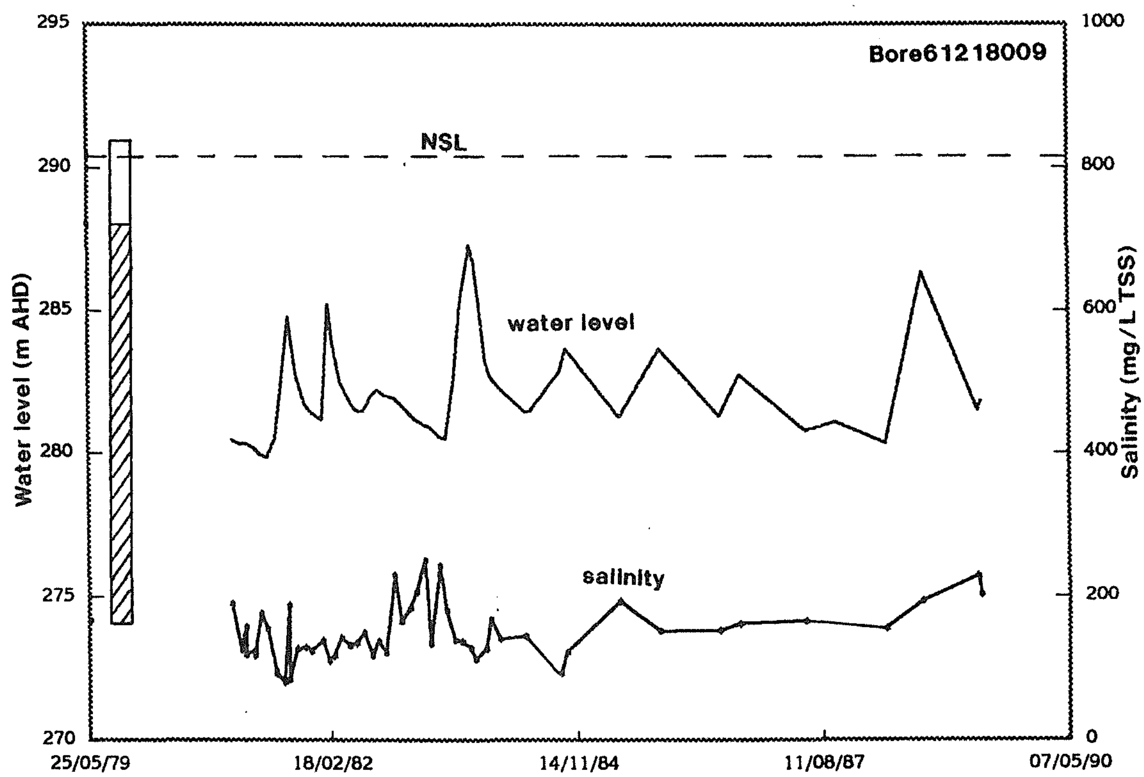
Plot	SWRIS bore no.	Initial depth to water table (m)	Initial mean salinity ($mg\ L^{-1}$)	Species	($stem\ ha^{-1}$) 1985	Crown cover (%)
47	-	-	-	E. kondininensis	131	-
48	-	-	-	E. patens	181	-
49	-	-	-	E. wandoo	175	-
50	-	-	-	E. wandoo	81	-
51	61218387	7.07	11492	E. laeliae	88	14
52	-	-	-	E. goniocalyx	556	-
53	-	-	-	E. dives	244	-
54	-	-	-	E. paniculata	419	-
55	-	-	-	E. paniculata	531	-
56	-	-	-	E. resinfera	556	-
57	-	-	-	E. ocrophloia	62	-
58	-	-	-	E. crebra	0	-
59	-	-	-	E. microtheca	100	-
60	-	-	-	E. microtheca	206	-
61	61218369	7.59	4613	E. radiata	481	47
62	-	-	-	E. astringens	394	-
63	-	-	-	E. drepanophylla	31	-
64	61218373	5.97	333	E. sideroxylon spp sid.	475	66
65	-	-	-	E. griffithsii	200	-
66	-	-	-	E. woolsiana	425	-
67	691218378	1.66	5130	E. woolsiana	431	35
68	-	-	-	E. largiflorens	312	-
69	-	-	-	E. microcarpa	544	-
70	-	-	-	E. caculata	231	-
71	-	-	-	E. wandoo	25	-
72	-	-	-	E. megacarpa	188	-
73	-	-	-	E. goniocalyx	531	-
74	-	-	-	E. dives	306	-
75	61218395	7.11	4076	E. viminsali	575	35
76	-	-	-	E. cladocalyx	475	-
77	-	-	-	E. paniculata	256	-
78	-	-	-	E. resinifera	467	-
79	61218370	11.19	4449	E. radiata	212	22
80	-	-	-	E. sideroxylon spp. sid.	356	-
81	61218374	10.49	8613	E. decorticans	325	29
82	-	-	-	E. huberana	412	-
83	-	-	-	E. flocktoniae	156	-
84	-	-	-	E. melliodora	494	-
85	61218379	3.12	3663	E. microcarpa	588	35
86	-	-	-	E. microcarpa	606	-
87	-	-	-	E. maculata	325	-
88	-	-	-	E. maculata	212	-
89	-	-	-	E. citriodora	125	-
90	-	-	-	E. marginata	0	-
91	61218388	10.46	7078	E. aromophloia	506	33
92	-	-	-	E. goniocalyx	531	-
93	-	-	-	E. viminalis	394	-
94	61218394	10.45	11762	E. viminalis	431	47

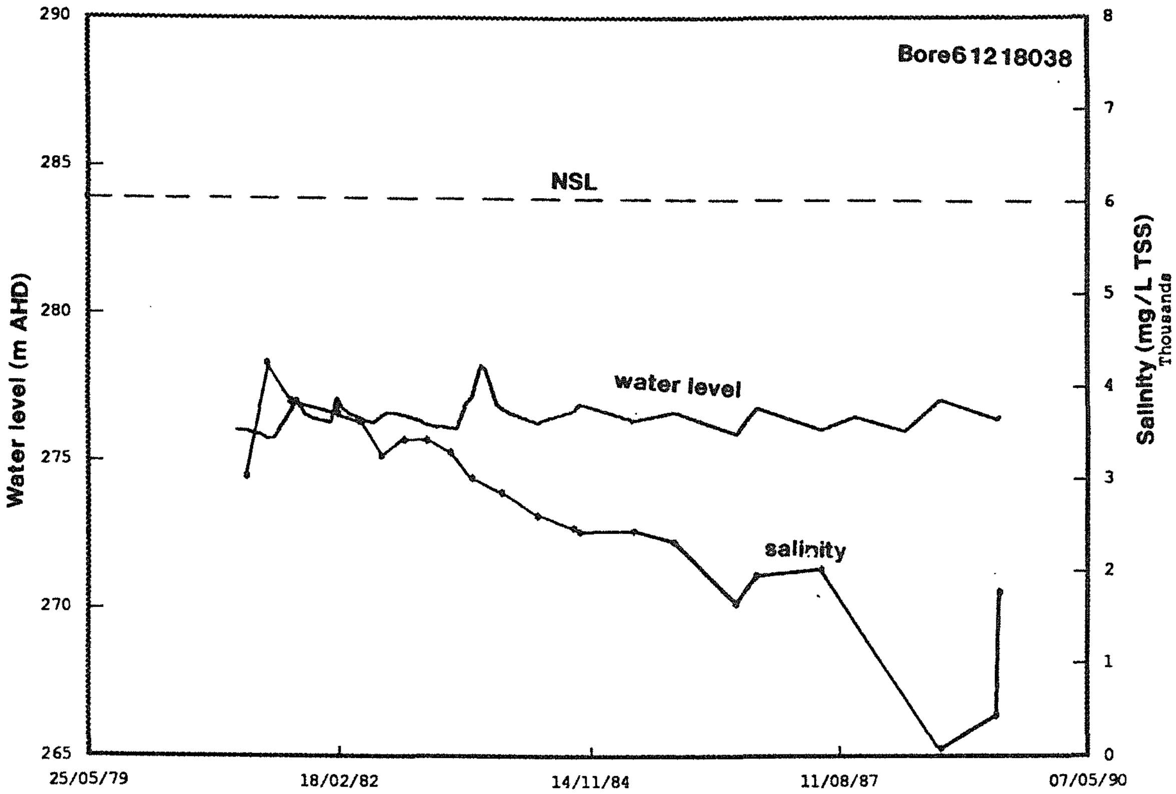
Plot	SWRIS bore no.	Initial depth to water table (m)	Initial mean salinity (mg L^{-1})	Species	(stem ha^{-1}) 1985	Crown cover (%)
95	-	-	-	E. gomphocephala	544	-
96	-	-	-	E. rubida	438	-
97	-	-	-	E. intertexta	200	-
98	-	-	-	E. albens	500	-
99	-	-	-	E. albens	438	-
100	-	-	-	E. albens	506	-
101	-	-	-	E. transcontinentalis	0	45
102	61218380	6.15	1937	E. melliodora (rosea)	594	-
103	-	-	-	E. melliodora (melliodora)	525	-
104	-	-	-	E. maculata	475	-
105	-	-	-	E. maculata	344	-
106	-	-	-	E. citriodora	106	-
107	-	-	-	E. citriodora	169	-
108	-	-	-	E. marginata	0	-
109	61218389	14.93	9101	E. aromophloia	494	47
110	-	-	-	E. goniocalyx	543	-
111	-	-	-	E. baxteri	300	-
112	-	-	-	E. baxteri	281	-
113	61218393	14.93	10906	E. baxteri	431	37
114	-	-	-	E. intertexta	250	-
115	-	-	-	E. gomphocephala	231	-
116	-	-	-	E. citriodora	256	-
117	-	-	-	E. calophylla	100?	-
118	-	-	-	E. marginata	294?	-
119	-	-	-	E. calophylla	212	-
120	-	-	-	E. macrorrhyncha	300	-
121	-	-	-	E. cladocalyx	462	-
122	61218390	19.5	307	E. cladocalyx	344	45
123	-	-	-	E. macrorrhyncha	225	-

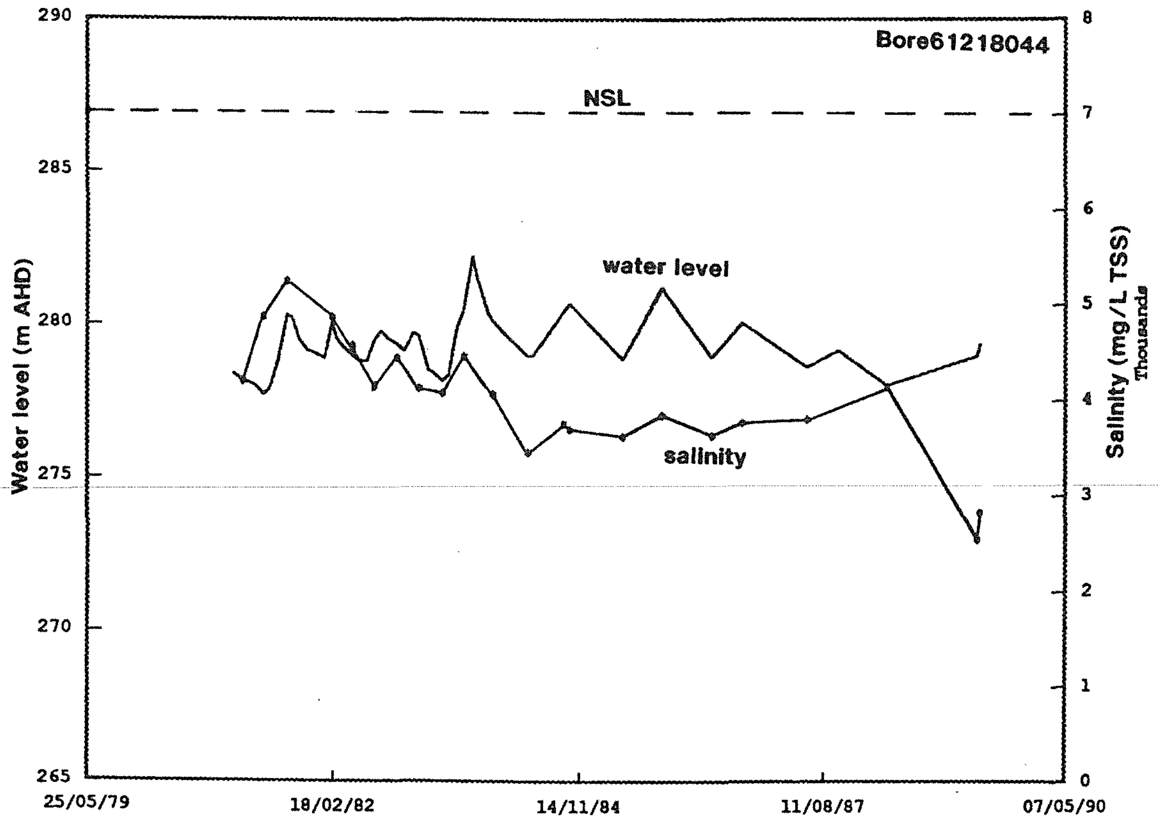
APPENDIX B

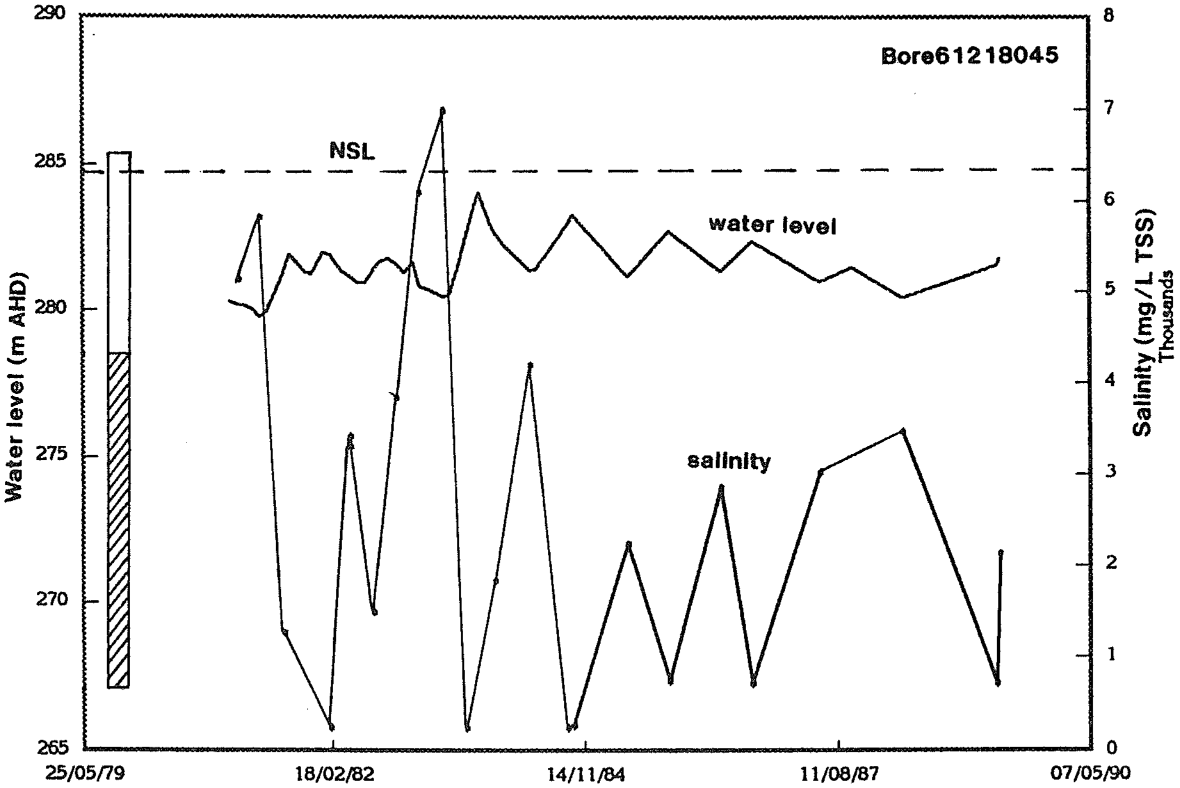
Groundwater Level and Salinity Graphs for each Control and Reforested Bore


295
290
285
280
275
Water level (m AHD)
NSL
Bore61218008
water level
salinity
1000
800
600
400
200
0
Salinity (mg/L TSS)
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90

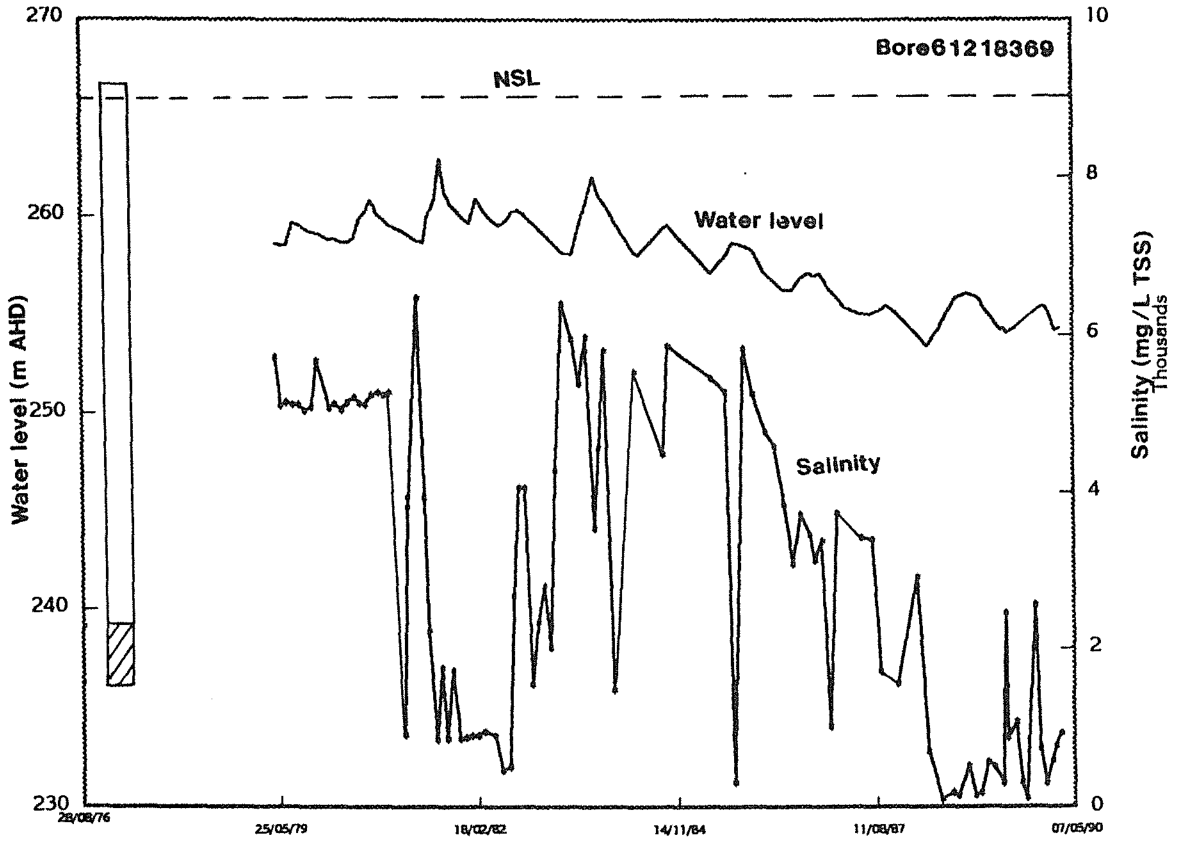

295
290
285
280
275
270
Water level (m AHD)
Bore61218009
NSL
water level
salinity
1000
800
600
400
200
0
Salinity (mg/L TSS)
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90

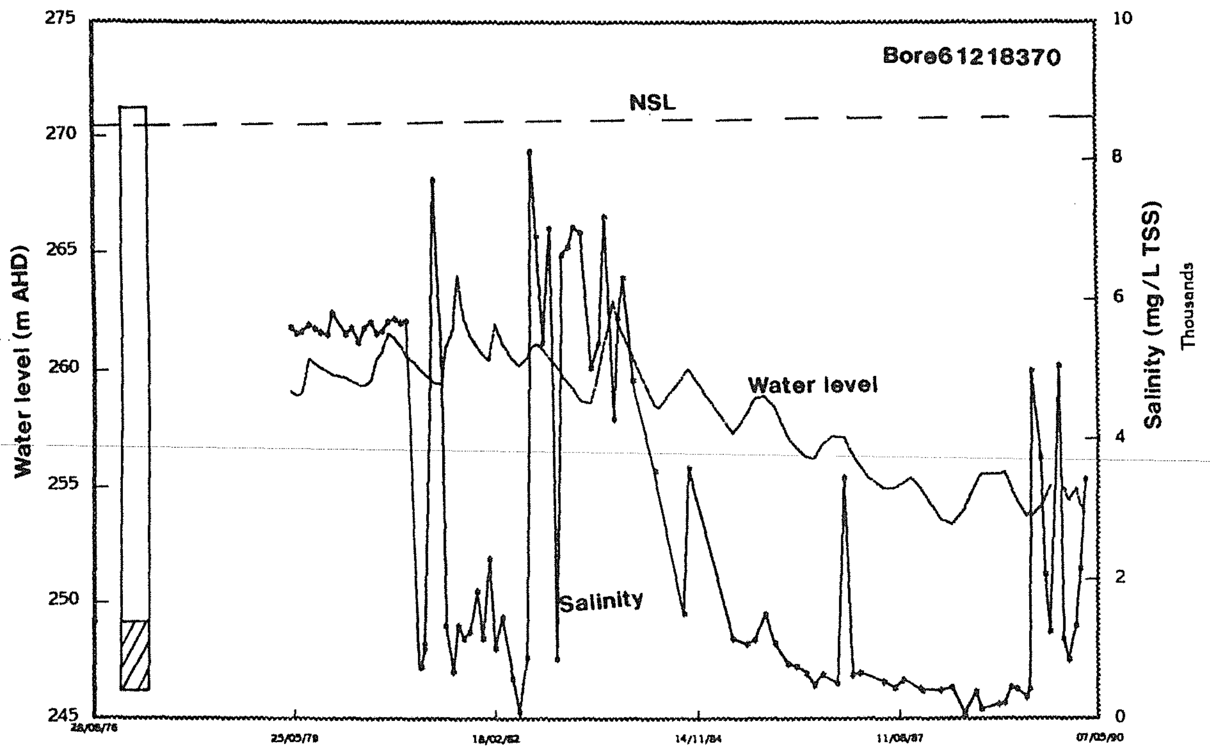

Bore61218038
NSL
water level
salinity
Water level (m AHD)
Salinity (mg/L TSS) Thousands
290
285
280
275
270
265
8
7
6
5
4
3
2
1
0
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90

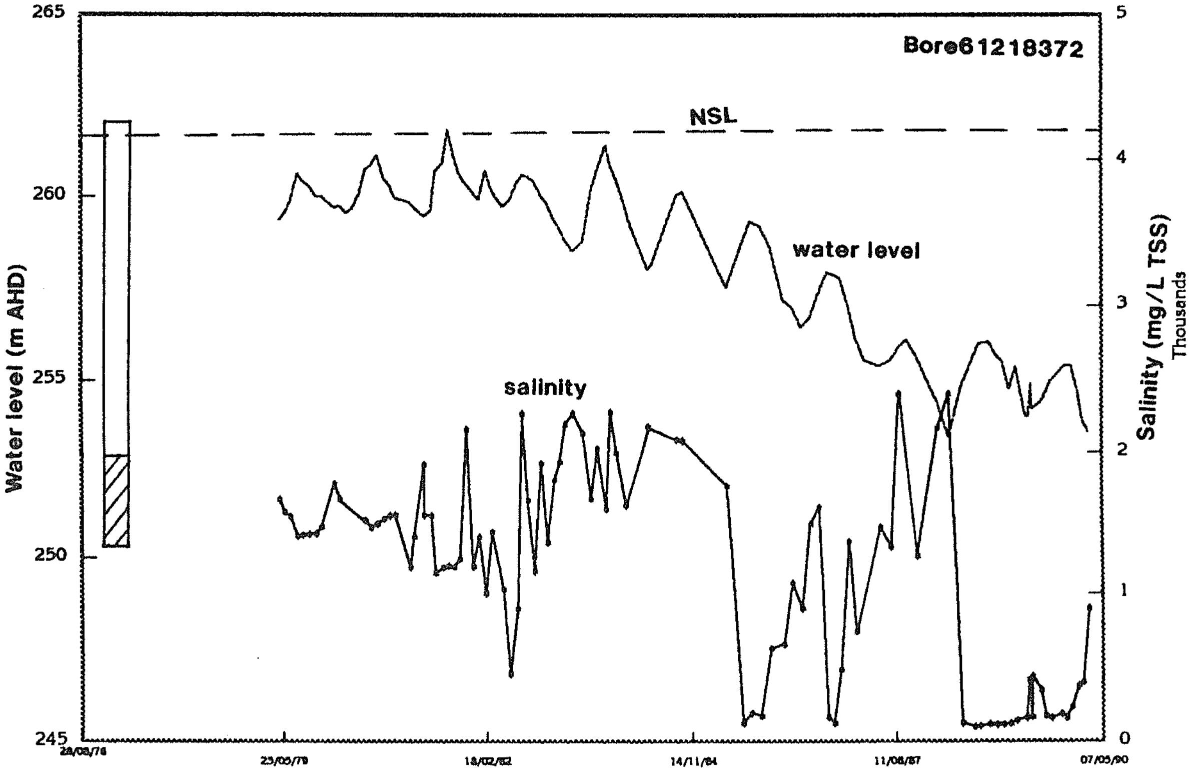

Bore61218044
NSL
water level
salinity
Water level (m AHD)
Salinity (mg/L TSS) Thousands
290
285
280
275
270
265
8
7
6
5
4
3
2
1
0
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90

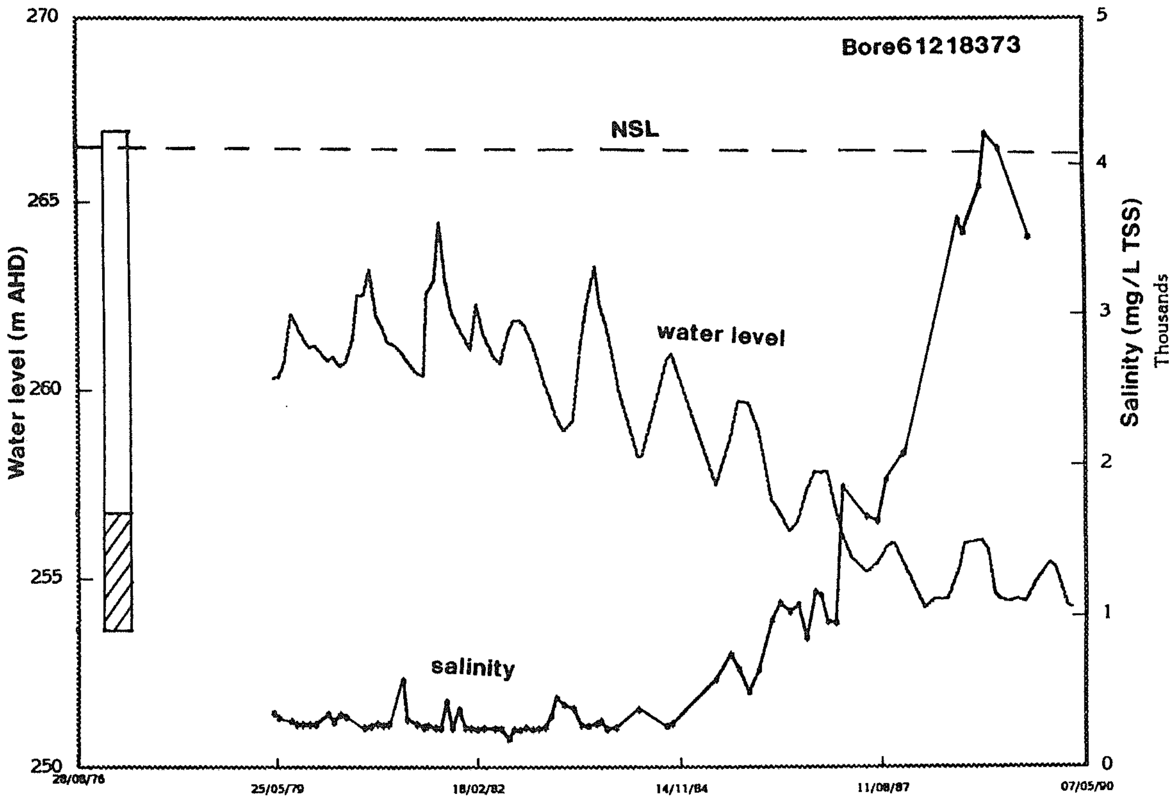


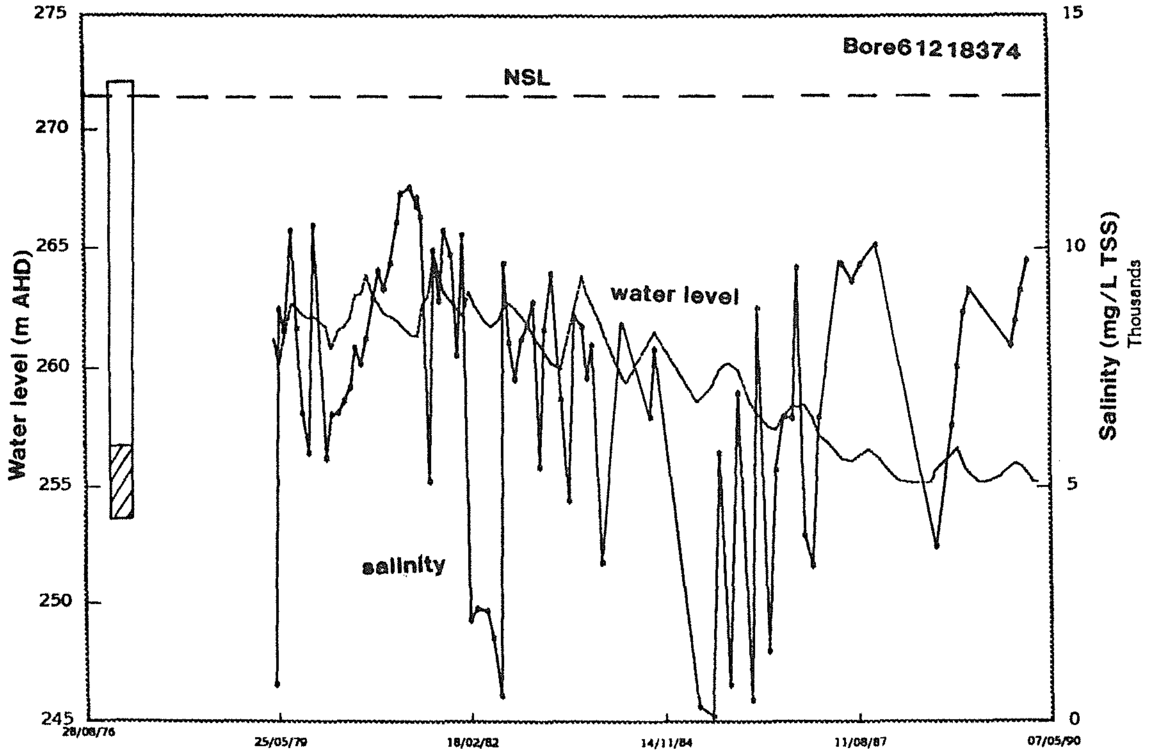
Bore61218045
NSL
water level
salinity
Water level (m AHD)
Salinity (mg/L TSS) Thousands
290
285
280
275
270
265
8
7
6
5
4
3
2
1
0
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90

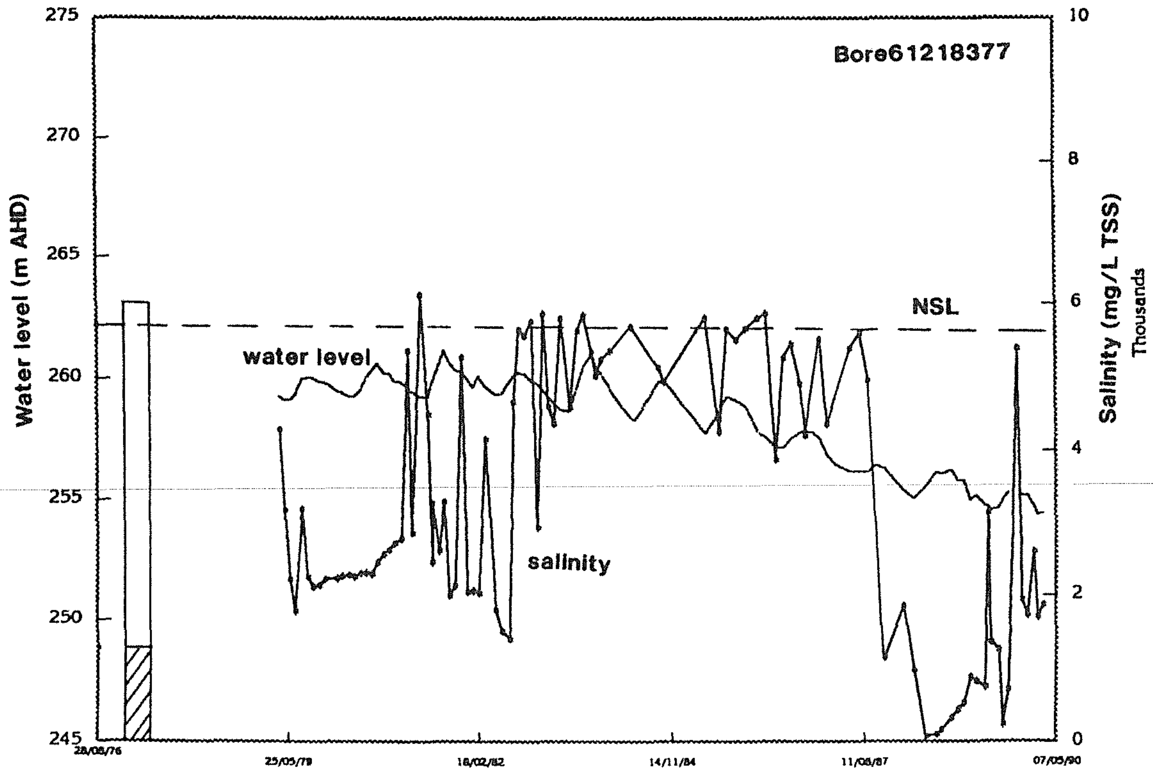

Bore61218369
NSL
Water level
Salinity
Water level (m AHD)
Salinity (mg/L TSS)
Thousands
270
260
250
240
230
10
8
6
4
2
0
28/08/76
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90

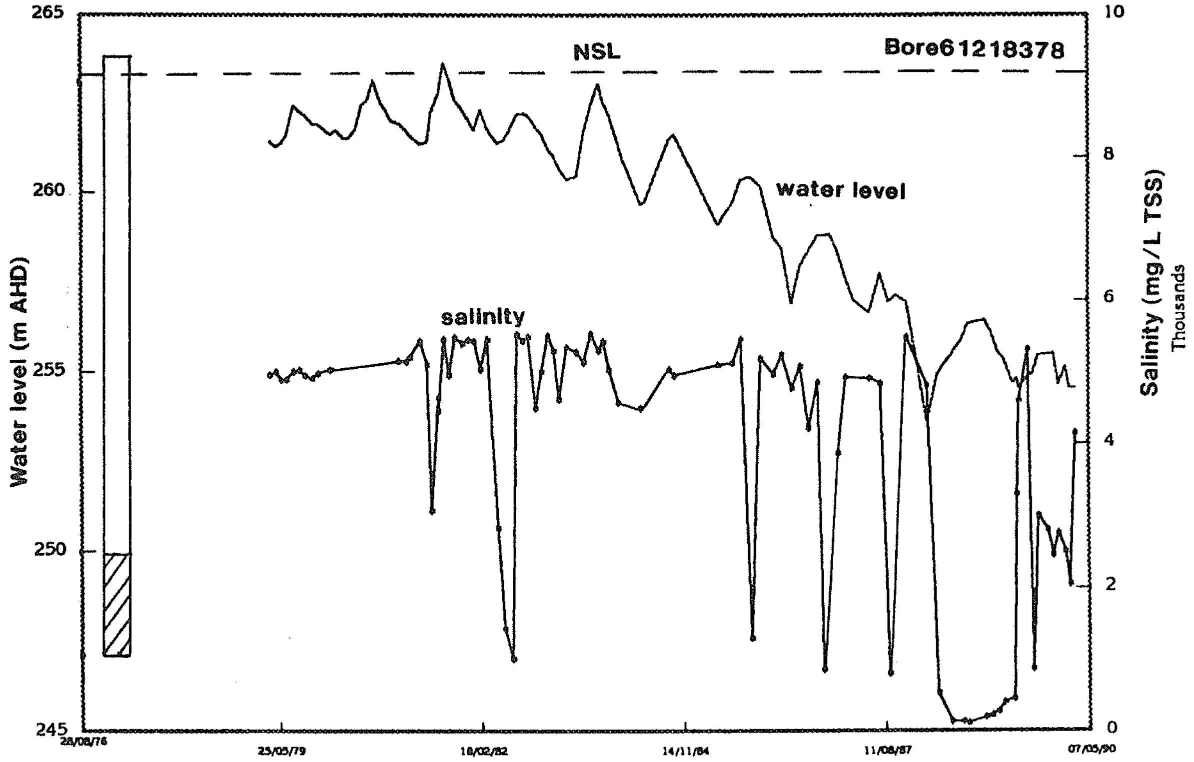

Bore61218370
NSL
Water level
Salinity
Water level (m AHD)
Salinity (mg/L TSS)
Thousands
275
270
265
260
255
250
245
10
8
6
4
2
0
28/08/76
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90

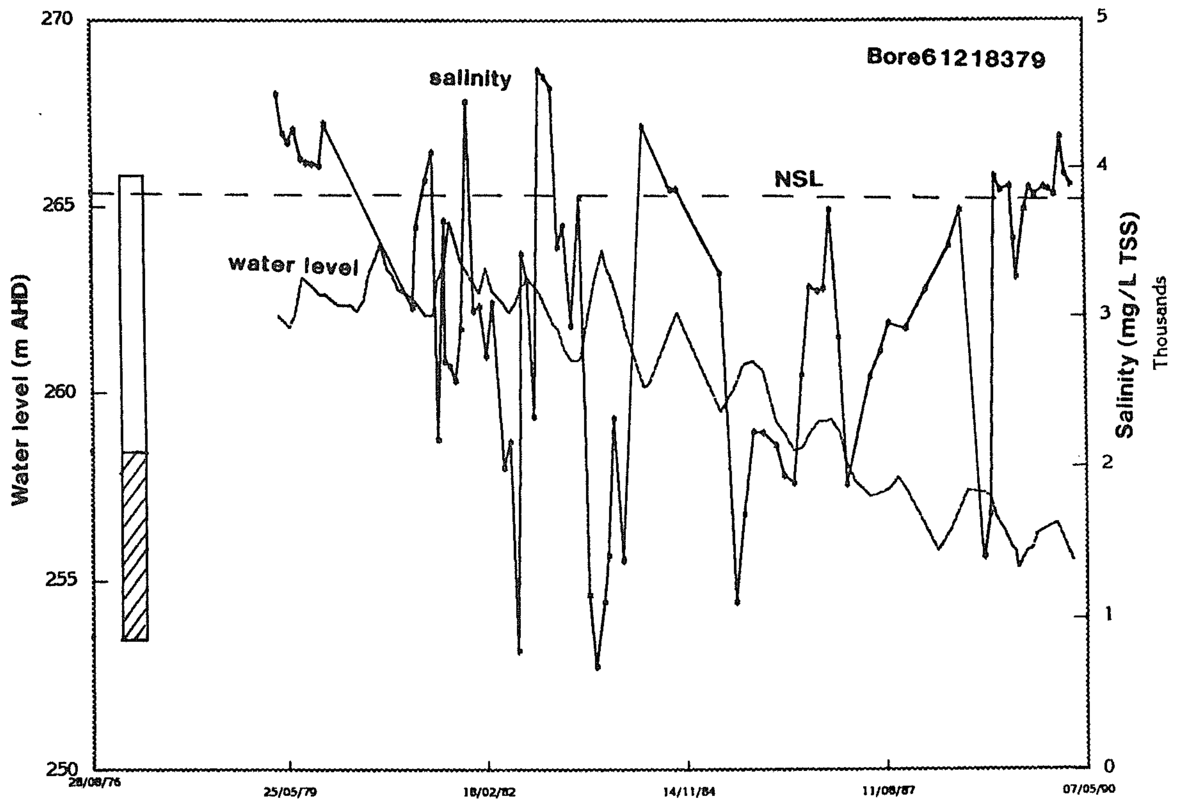

Bore61218372
NSL
water level
salinity
Water level (m AHD)
Salinity (mg/L TSS)
Thousands
265
260
255
250
245
5
4
3
2
1
0
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90

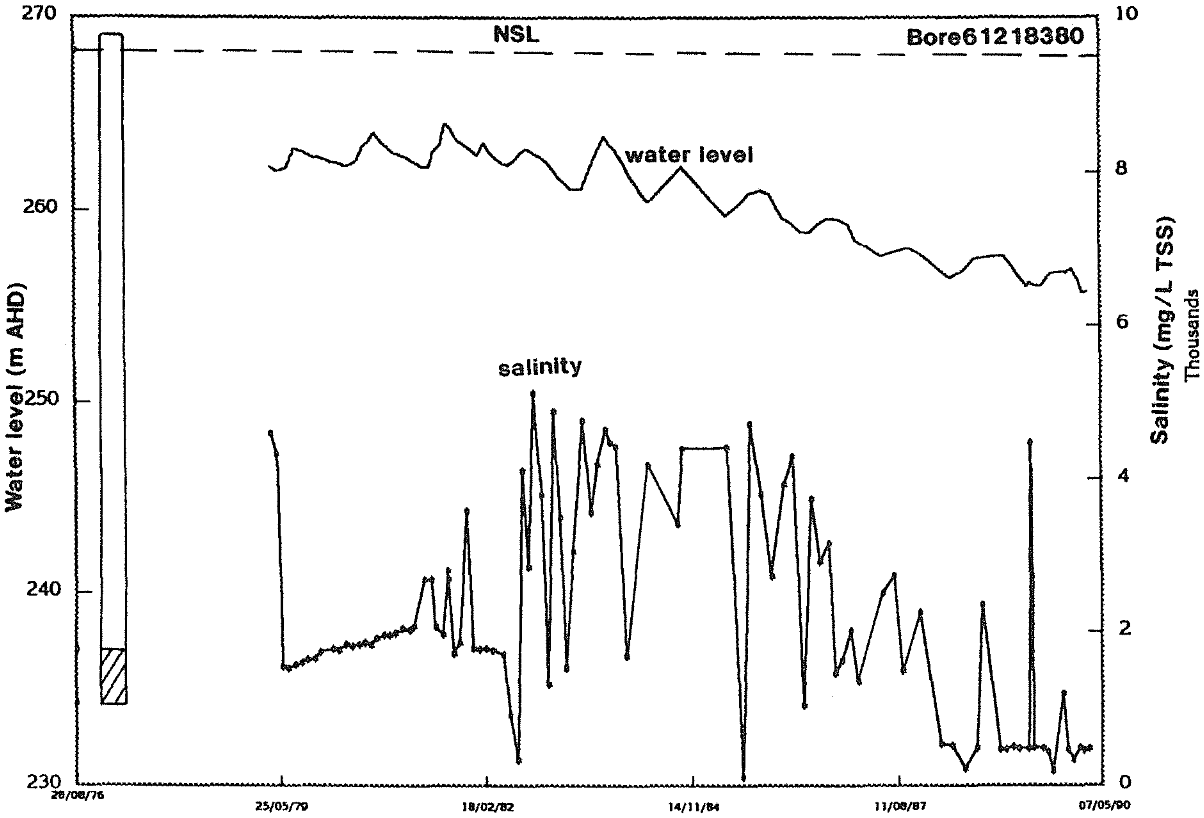

Bore61218373
NSL
water level
salinity
Water level (m AHD)
Salinity (mg/L TSS)
Thousands
270
265
260
255
250
5
4
3
2
1
0
28/08/76
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90

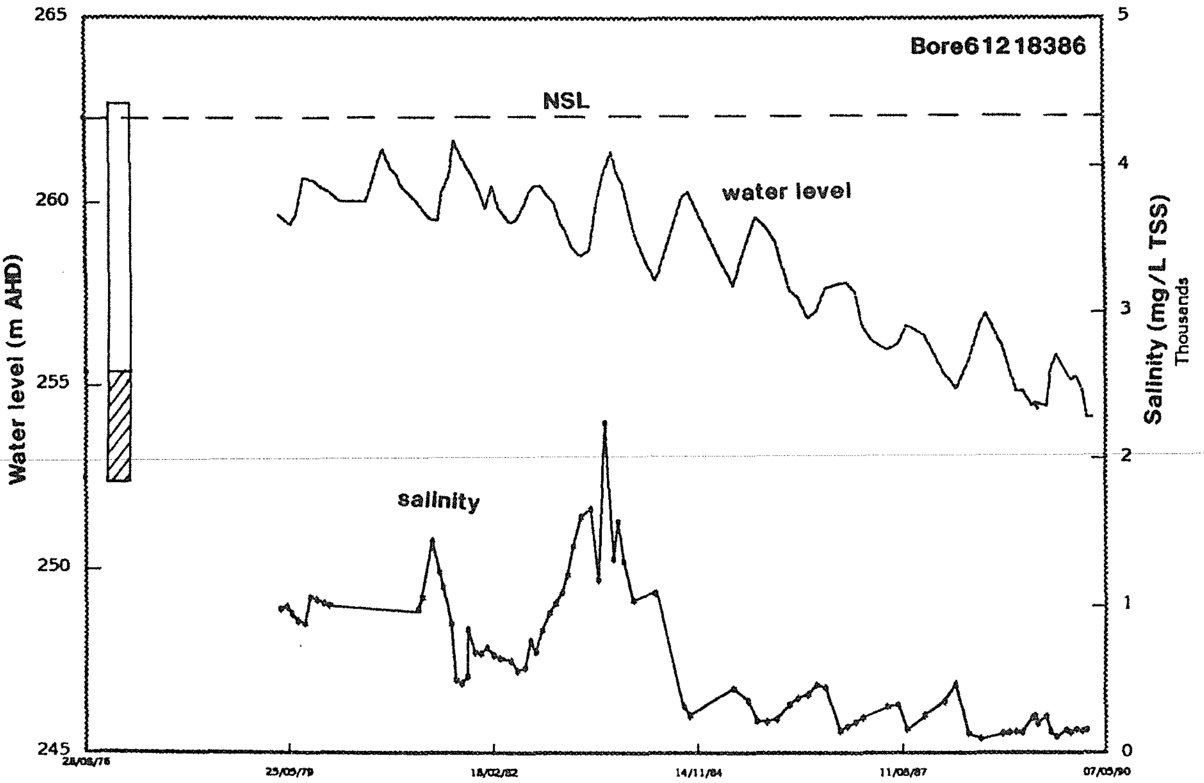

Bore61218374
NSL
water level
salinity
Water level (m AHD)
Salinity (mg/L TSS) Thousands
275
270
265
260
255
250
245
15
10
5
0
28/08/76
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90

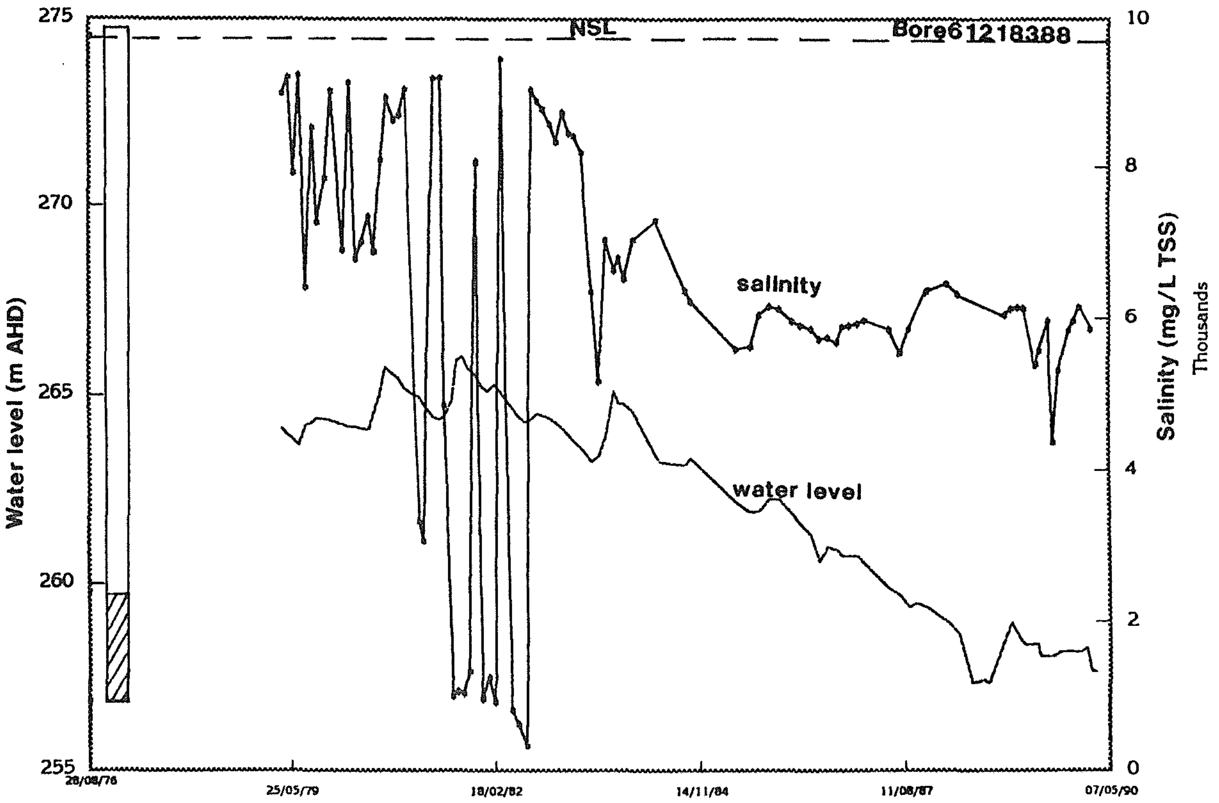

Bore61218377
NSL
water level
salinity
Water level (m AHD)
Salinity (mg/L TSS) Thousands
275
270
265
260
255
250
245
10
8
6
4
2
0
28/08/76
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90

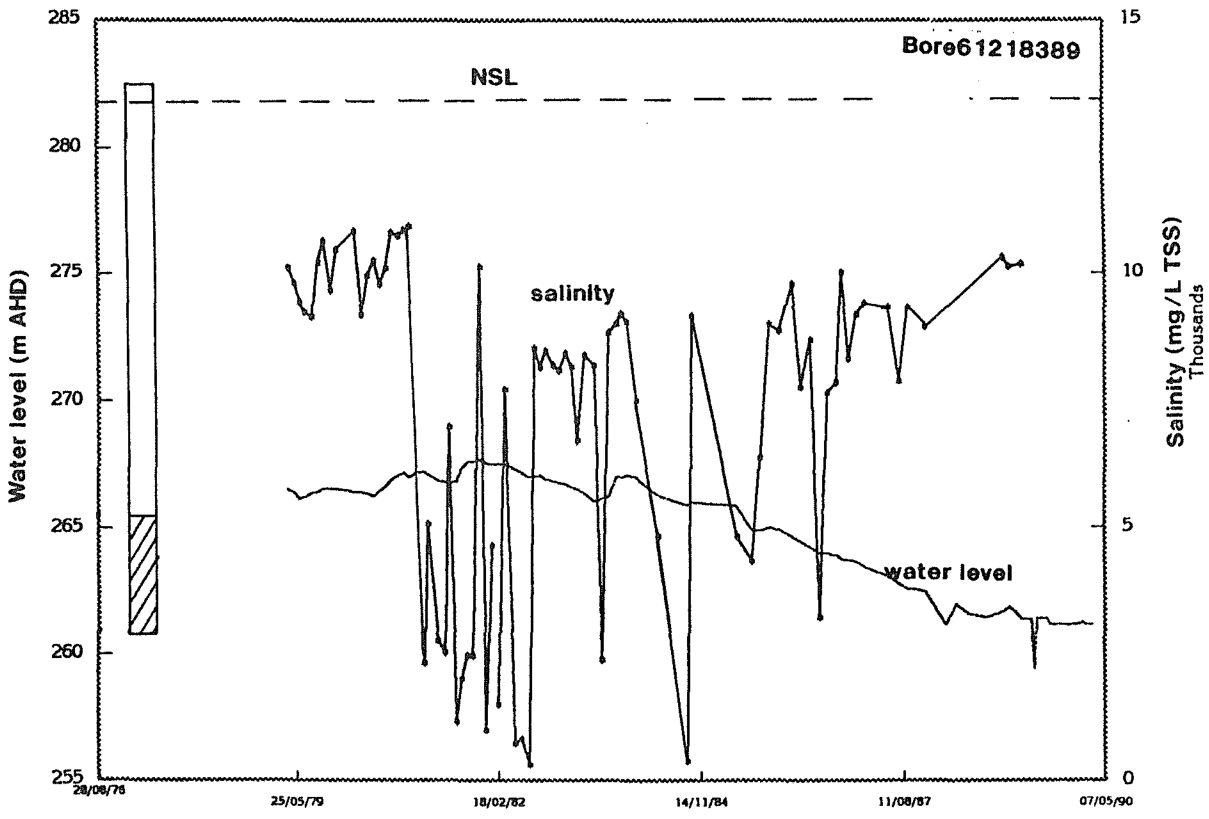

Bore61218378
NSL
water level
salinity
Water level (m AHD)
Salinity (mg/L TSS)
Thousands
265
260
255
250
245
10
8
6
4
2
0
28/08/76
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90

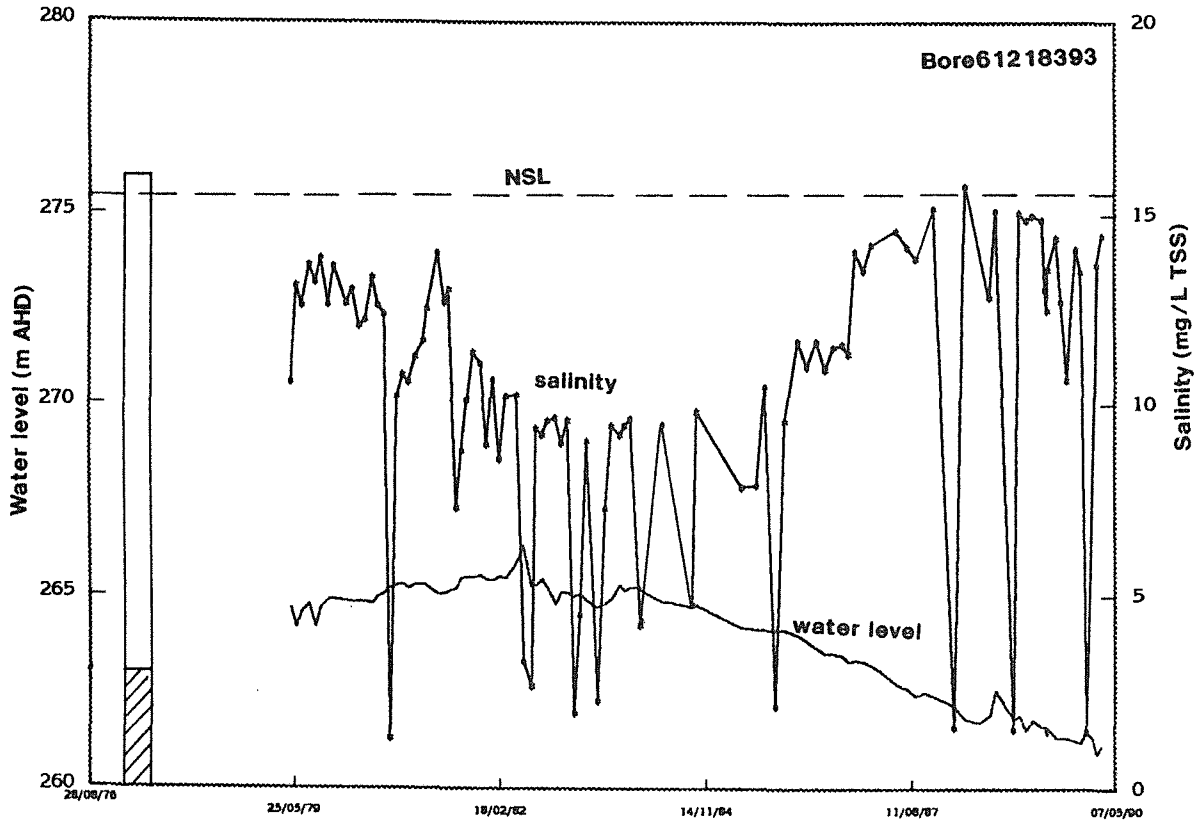

Bore61218379
salinity
NSL
water level
Water level (m AHD)
Salinity (mg/L TSS)
Thousands
270
265
260
255
250
5
4
3
2
1
0
28/08/76
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90


270
260
250
240
230
10
8
6
4
2
0
NSL
Bore61218380
water level
salinity
Water level (m AHD)
Salinity (mg/L TSS)
Thousands
28/08/76
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90

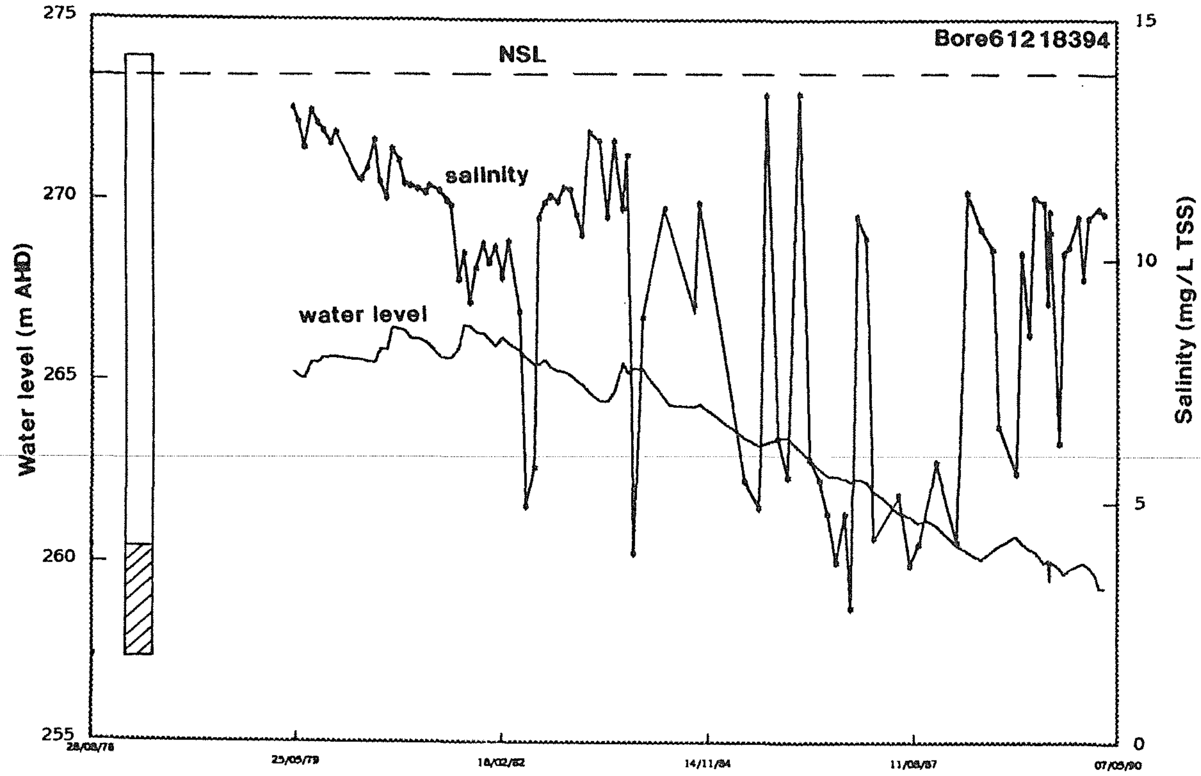

265
260
255
250
245
5
4
3
2
1
0
Bore61218386
NSL
water level
salinity
Water level (m AHD)
Salinity (mg/L TSS)
Thousands
28/08/76
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90


NSL
Bore61218388
salinity
water level
Water level (m AHD)
Salinity (mg/L TSS)
Thousands
275
270
265
260
255
10
8
6
4
2
0
28/08/76
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90

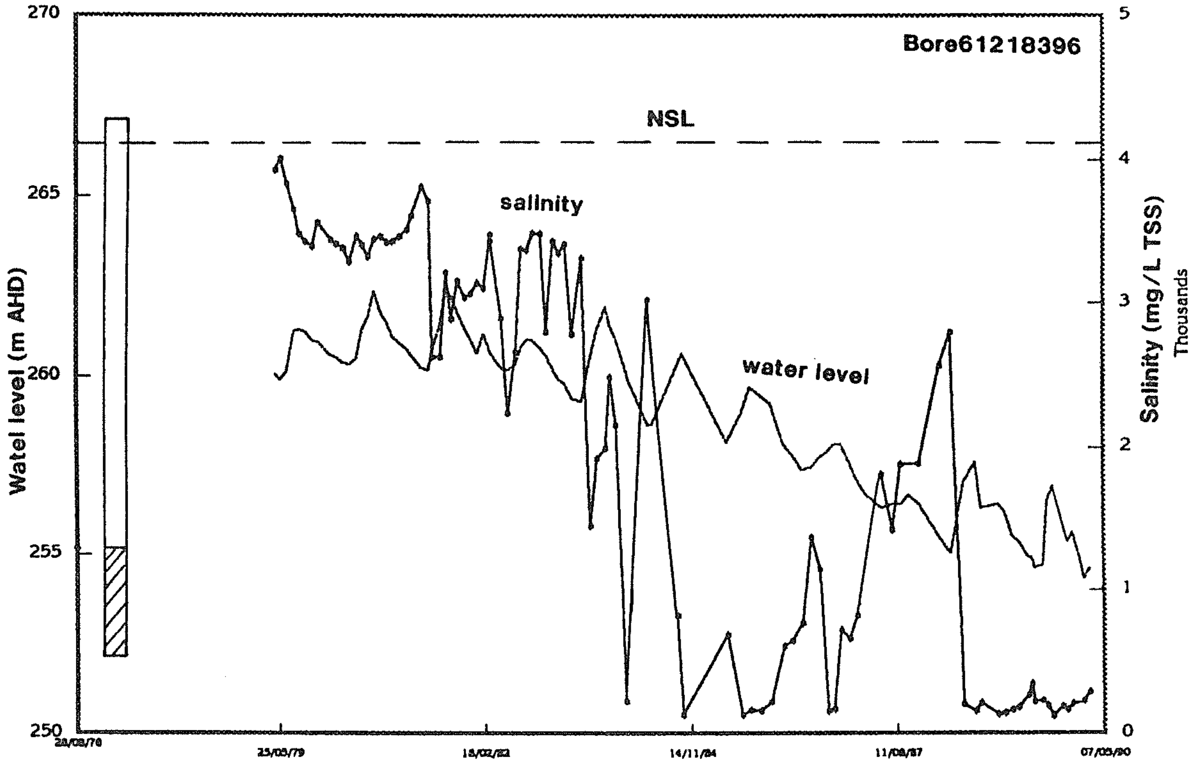

Bore61218389
NSL
salinity
water level
Water level (m AHD)
Salinity (mg/L TSS)
Thousands
285
280
275
270
265
260
255
15
10
5
0
28/08/76
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90

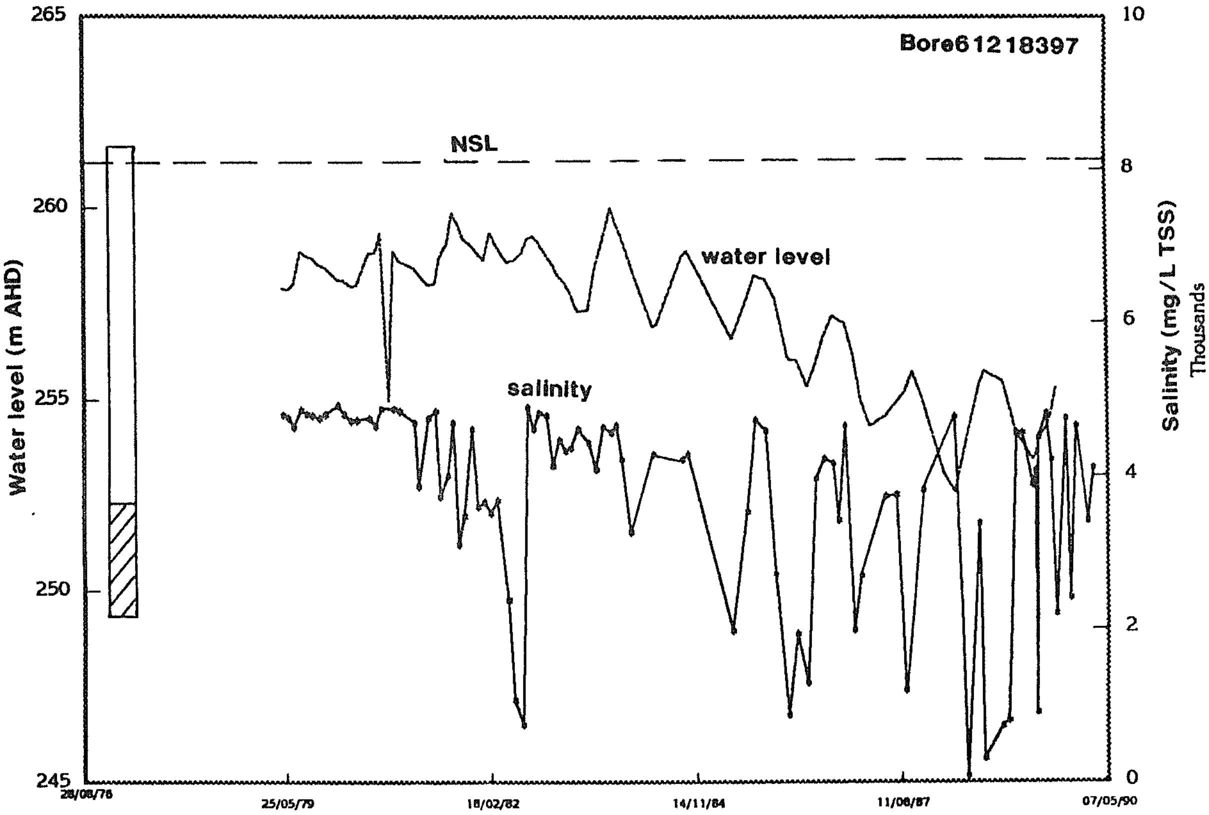


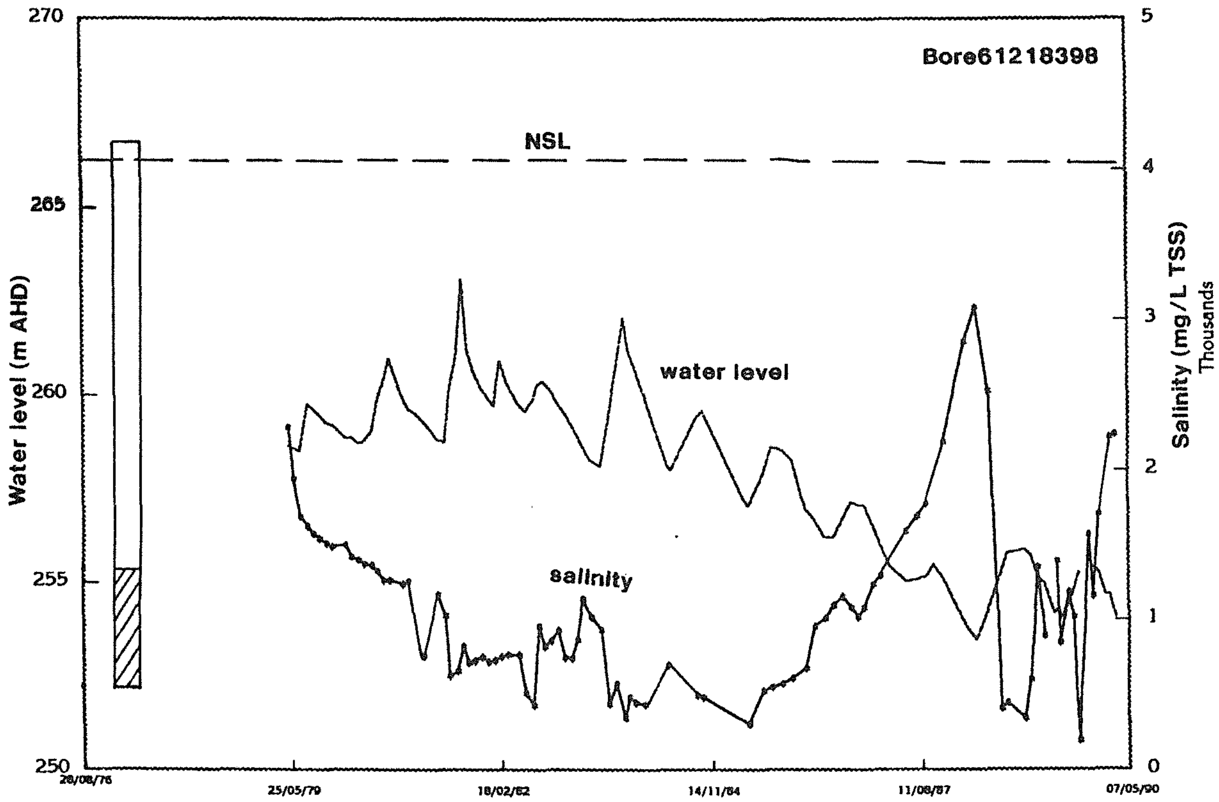
Bore61218393
NSL
salinity
water level
Water level (m AHD)
Salinity (mg/L TSS)
Thousands
280
275
270
265
260
20
15
10
5
0
28/08/76
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90

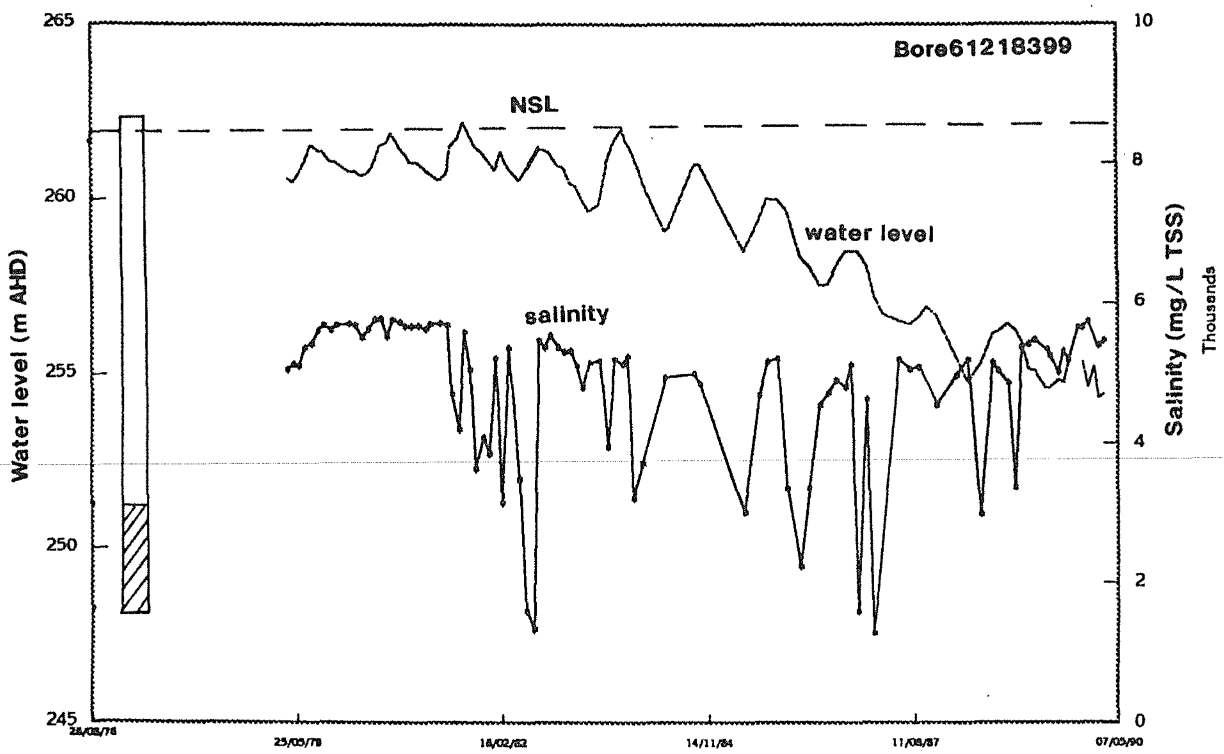


Bore61218394
NSL
salinity
water level
Water level (m AHD)
Salinity (mg/L TSS)
Thousands
275
270
265
260
255
15
10
5
0
28/08/76
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90


Bore61218396
NSL
salinity
water level
Watel level (m AHD)
Salinity (mg/L TSS)
Thousands
270
265
260
255
250
5
4
3
2
1
0
28/08/76
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90


Bore61218397
NSL
water level
salinity
Water level (m AHD)
Salinity (mg/L TSS)
Thousands
265
260
255
250
245
10
8
6
4
2
0
28/08/76
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90


Bore61218398
NSL
water level
salinity
Water level (m AHD)
Salinity (mg/L TSS)
Thousands
270
265
260
255
250
5
4
3
2
1
0
28/08/76
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90


Bore61218399
NSL
water level
salinity
Water level (m AHD)
Salinity (mg/L TSS)
Thousands
265
260
255
250
245
10
8
6
4
2
0
28/08/76
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90