Water Authority
of Western Australia

Water and Salt Balance of a Partially Reforested Catchment in the South-West of Western Australia

Report No. WS 98
April 1992

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WATER RESOURCES DIRECTORATE
Surface Water Branch

Water and Salt Balance of a Partially Reforested Catchment in the South-West of Western Australia

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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 t 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 partial reforestation of th cleared land.

One important reforestation strategy is to plant trees on the lower slopes and discharge zones of the valley. Typically this covers about 20% of the cleared land. To date more than 6500 ha of farmland has been reforested in the eastern Wellington Dam catchment. This report assesses groundwater level, groundwater salinity, streamflow and stream salinity at Maringee Farm. This farm is located nea the eastern boundary of the Wellington Dam catchment where rainfall is about 650 mm yr^{-1}. Groundwater and streamflow data has been analysed for the period 1983 to 1990.

During this study period, the minimum groundwater level beneath reforestation declined 3.6 m compared to the pastur control and 0.4 m compared to the ground surface. The reduction was fairly uniform which may be attributable to the continuous crown growth of the plantations. The maximu groundwater level dropped 2.2 m relative to pasture and 1.0 m relative to the ground surface. Groundwater salinity beneath reforestation reduced by 3% during the study period The reduction beneath pasture was 15%.

Streamflow consisted of three separate sources: surface runoff, shallow subsurface flow and deep groundwater flow. Surface runoff made up 30% of the streamflow over the study period. This relatively high contribution was due to a large area of permanent saturation. Surface runoff supplied only 3.5% of total salt to the stream. The shallow subsurface flow system contributed 57% of streamflow and 8% of total salt. The deeper, more saline groundwater yielded 13% of streamflow and 88% of stream salt. While reforestation has slightly lowered groundwater level and groundwater salinity, there is no evidence that it has lowered streamflow and salt load. It appears reforestation has resulted in slightly lower stream salinity at the onset of streamflow (April/May) but the effect in terms of total stream salt load was negligible.

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1. INTRODUCTION

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

During the late 1970s and early 1980s, a number of experimental sites were established to investigate the effectiveness of various reforestation strategies in reducing stream salinity. Maringee Farm, in the Wellington Dam catchment, is one of these sites. At Maringee, the lower slopes and floor of the valley were reforested with eucalypts. About 20% of the cleared land was reforested at an initial tree density of 625 stems per hectare (sph). Trees were planted with the aim of lowering groundwater levels in the vicinity of the streamline, thereby reducing or eliminating groundwater solute discharge to the stream.

Hydrological data from Maringee Farm has previously been analysed by Bell et al.(1988); Schofield et al.(1989); and Hookey and Loh (1985). This report updates the earlier reports and provides the most comprehensive analysis of the groundwater and streamflow data from this site.

2. EXPERIMENTAL OBJECTIVES

The primary aim of the study was to reduce groundwater levels and hence salt discharge from the catchment in a relatively short period of time (~ 10 years). The specific objectives of the study were:

2.1 Groundwater Level and Salinity

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

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

(iii) quantify the effect of reforestation on groundwater levels;

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

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

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

2.2 Streamflow and Stream Salinity

(i) determine the magnitude and dynamics of the sources of streamflow and stream salinity;

(ii) assess the spatial and temporal variations in the sources of streamflow and stream salinity;

(iii) determine the effects of reforestation on various sources of streamflow and stream salinity.

3. SITE DESCRIPTION

3.1 Location

The experimental site is located in the Darling Range, approximately 40 km east of Collie (Fig. 1). It lies close to the eastern boundary of the Wellington Dam catchment.

3.2 Site History

Progressive clearing of Maringee farm for pasture development commenced in 1925 (Table 1). By 1976, 55% of the site had been cleared. Most of clearing had been on the lower slopes. The State Government purchased the farm in 1976. It was purchased as part of a programme to reforest farmland within Wellington Dam catchment. The aim of the programme was to reduce salinity of flow into Wellington Reservoir (Loh, 1988).

3.3 Climate

The Wellington Dam catchment has a Mediterranean climate, i.e. cool, humid, wet winters and hot, dry summers. About 80% of the annual rainfall occurs in winter (June to August). The long term average rainfall of the experimental site is estimated to be 650 mm yr^{-1} (Hayes and Garnaut, 1981; Bell et al., 1990). 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 during summer, to a minimum of less than 0°C during winter.

3.4 Hydrology

Maringee Farm has a catchment area of 12.75 km^2 (Fig. 1). Mairdebing Creek flows through the catchment. The hydrometric network was established in 1982. In 1983, the depth to minimum groundwater level across the cleared area varied from 0.0 m (i.e.

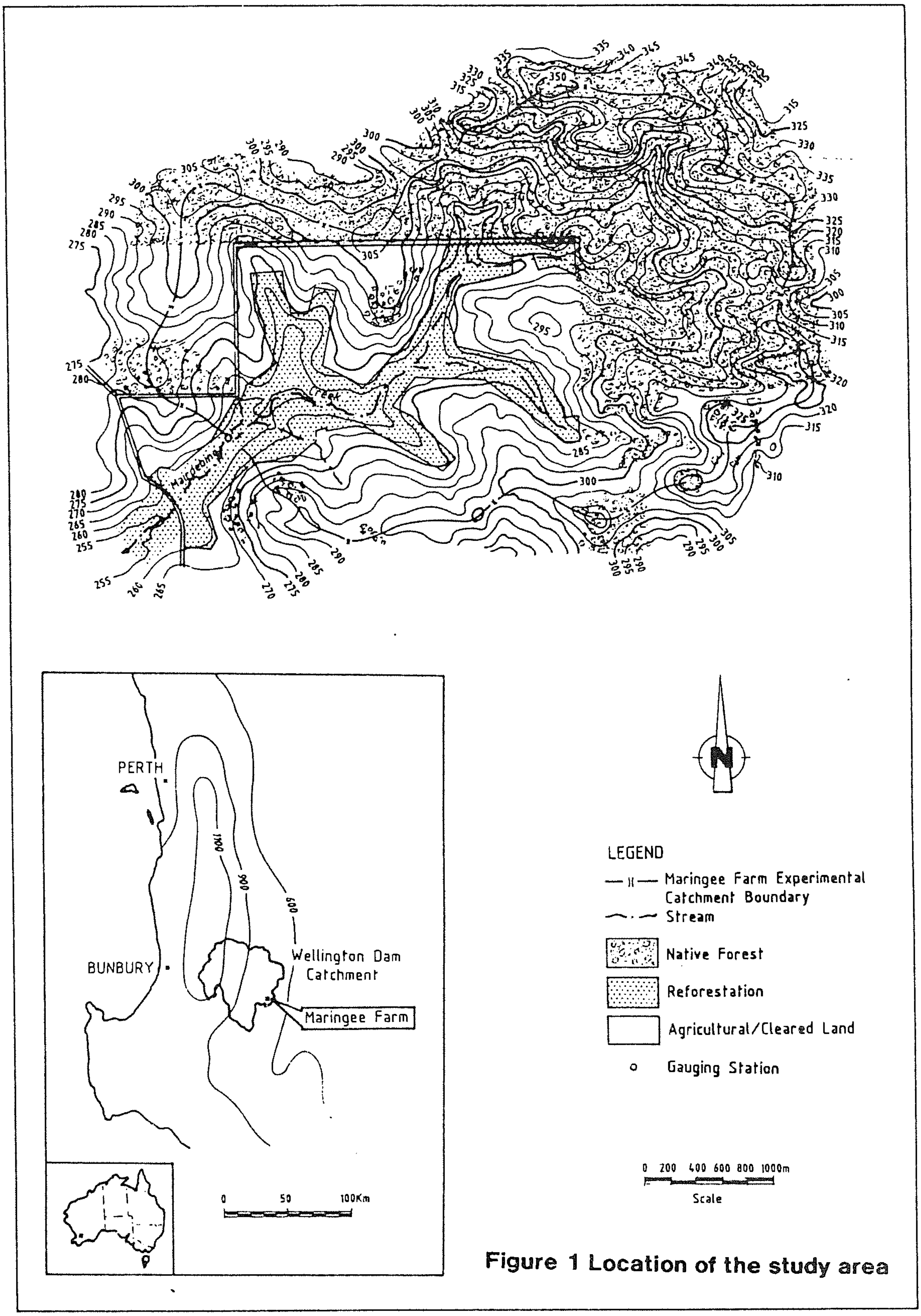

Figure 1 Location of the study area

Table 1: Clearing history at Maringee Farm

Year	cleared area (ha)	% of total area	reforested area (ha)	% of total area
1925	16.5	1.3	-	-
1960	72.3	5.7	-	-
1966	181.8	14.3	-	-
1971	582.0	46.7	-	-
1976	696.3	54.6	-	-
1982	-	-	180.8	14.3
1986	-	-	153.2	12.0
1990	-	-	125.0	9.8

catchment area = 1275 ha

at ground surface) to 5.0 m. The average groundwater salinity was 18000 mg L^{-1} Total Soluble Salts (TSS). The average stream salinity was 1600 mg L^{-1} TSS. Saline seeps were evident along the stream line.

3.5 Topography

Maringee Farm's elevation ranges from 260 to 350 m AHD. The upslope forested portion of the catchment is slightly steeper than the reforested zone. Most of the monitoring bores are located in the reforested portion which has an average slope of 4% (Fig. 2).

3.6 Soil and Geology

The soil at Maringee Farm consists of multicoloured clayey silty sand and silty sandy clay. The soil profile varies between a few metres to about 40 m thick. Laterite occurs on the ridges and flanks of hills, and grades to colluvial and alluvial deposits in the valleys. The lower portions of the drainage lines are filled by alluvial deposits. Details of the geology at Maringee Farm were reported by Martin (1984).

3.7 Vegetation

Between 1981 and 1982, 46 plots were established in the cleared area along the stream line. Each plot was planted with two eucalypt species at an initial stem density of 625 stems per hectare (sph). In 1986 two additional plots were planted at a density of 830 sph (Fig. 2). Tree survival was poor on the salt affected and waterlogged plots. In 1988 stem density varied from nil to 500 sph. The average was 270 sph (Appendix A). Trees were not thinned or pruned at the study site.

Prior to reforestation the cleared area of the Maringee Farm supported a vigorous germination of annual rye grasses (*Lolium*

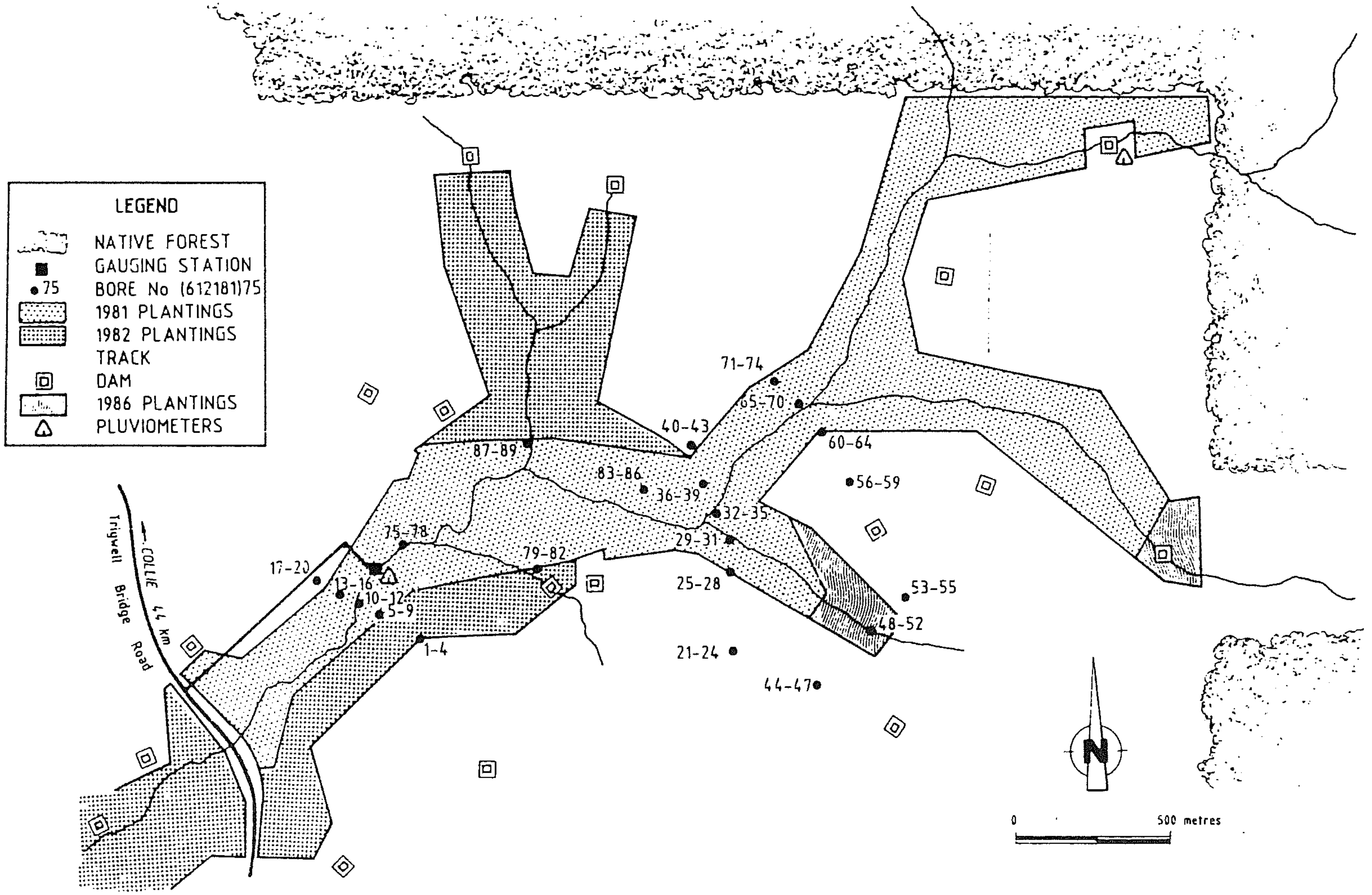

Figure 2 Reforestation layout and hydrometric network

spp), barley (Hordium marinum) and other grasses. These grasses were used for intensive sheep grazing. The upslope native vegetation is dominated by jarrah (E. marginata) with the principal sub-dominants being marri (E. calophylla) and wandoo (E. wandoo).

4. HYDROLOGICAL DATA COLLECTION

4.1 Rainfall

The long term average rainfall for Maringee Farm is about 650 mm yr^{-1} (Hayes and Garnaut, 1981; Bell et, al., 1990). Rainfall over the study period (1983-90) was 13% less than the long term average. During that period annual rainfall varied between 438 mm and 698 mm, with an average of 438 mm. The rainfall was higher than the long term average in only two years (1983 and 1988).

4.2 Groundwater

A network of 89 monitoring bores were installed at Maringee farm in 1982 (Fig. 2). This included a transect across the valley of the catchment, extending from an upslope area retained as pasture to a reforested area downslope. The bores within the pasture area provided control data for the study. A 'nest' of 3 to 5 bores were drilled at each monitoring point, to provide 'shallow' (<2 m depth), 'intermediate' (<10 m) and 'deep' (>10 m) groundwater information. The shallow and intermediate bores were completed with 1 m long screens. The screen length for the deep bores was 2 m (Appendix B).

Most of the bores were monitored for water level and salinity once a month during the study period (1983-90). Salinity was measured from the samples collected within the screen area of the bores. Pumped samples were taken from all bores in 1989. The groundwater salinity (Total Soluble Salts, TSS) was determined using the derived relationship between TSS (mg L^{-1}) and electrical conductivity (m Sm^{-1}) shown in Appendix C.

4.3 Streamflow

A calibrated, sharp-crested V notch weir was installed at the outlet of the catchment in May 1982. The water level over the weir (stage) was continuously recorded by a float operated graphical recorder and converted to discharge using a rating curve. Water samples were obtained using an automatic pumping sampler, and were also manually collected during visits to the site. Samples were routinely analysed for electrical conductivity, chloride concentration and temperature. A few selected samples were analysed for major ions from which a relationship between stream salinity (TSS) and electrical conductivity was derived (Appendix C). Electrical conductivity of stream water has been recorded continuously since the installation of the weir. A method used to calculate streamflow and salt load is given in Appendix D.

5. GROUNDWATER AND REFORESTATION

5.1 Groundwater Level

5.1.1 Groundwater levels beneath pasture

Between 1983 and 1990 the bores beneath pasture indicated an average rise in minimum groundwater level of 3.25 m (Fig. 3). The average rise in maximum groundwater level was 1.2 m (Fig. 4). Significant rises in groundwater levels observed in 1984 and 1987 have been attributed to high rainfall in the preceding year. The groundwater level hydrographs are shown in Appendix E and minimum and maximum groundwater levels are given in Appendix F.

5.1.2 Groundwater levels beneath reforestation

Trees planted on farm land decrease the vertical recharge to the groundwater table by increasing transpiration and interception loss (Eastham *et al.*, 1988; Schofield, 1990a; Schofield, *et al.*, 1991; Schofield and Bari, 1991; Bari, *et al.*, 1990; Bari and Schofield, 1991). To determine the effects of reforestation on groundwater levels annual minima and maxima were analysed and compared with the groundwater levels of the control bores.

Minimum Groundwater Level

Minimum groundwater levels beneath the reforestation areas declined by an average of 0.4 m over the study period. The decline relative to pasture control bores was 3.6 m. The annual changes in minimum groundwater levels are plotted in Fig. 3. Rises in minimum groundwater levels, against the overall trend, were observed in 1984 and 1989 following years of above-average rainfall. Between 1985 and 1988 minimum groundwater levels under areas of reforestation were in steady decline in response to a period of below average rainfall (1984-87). In contrast, minimum groundwater levels beneath pasture during this period rose at a constant rate.

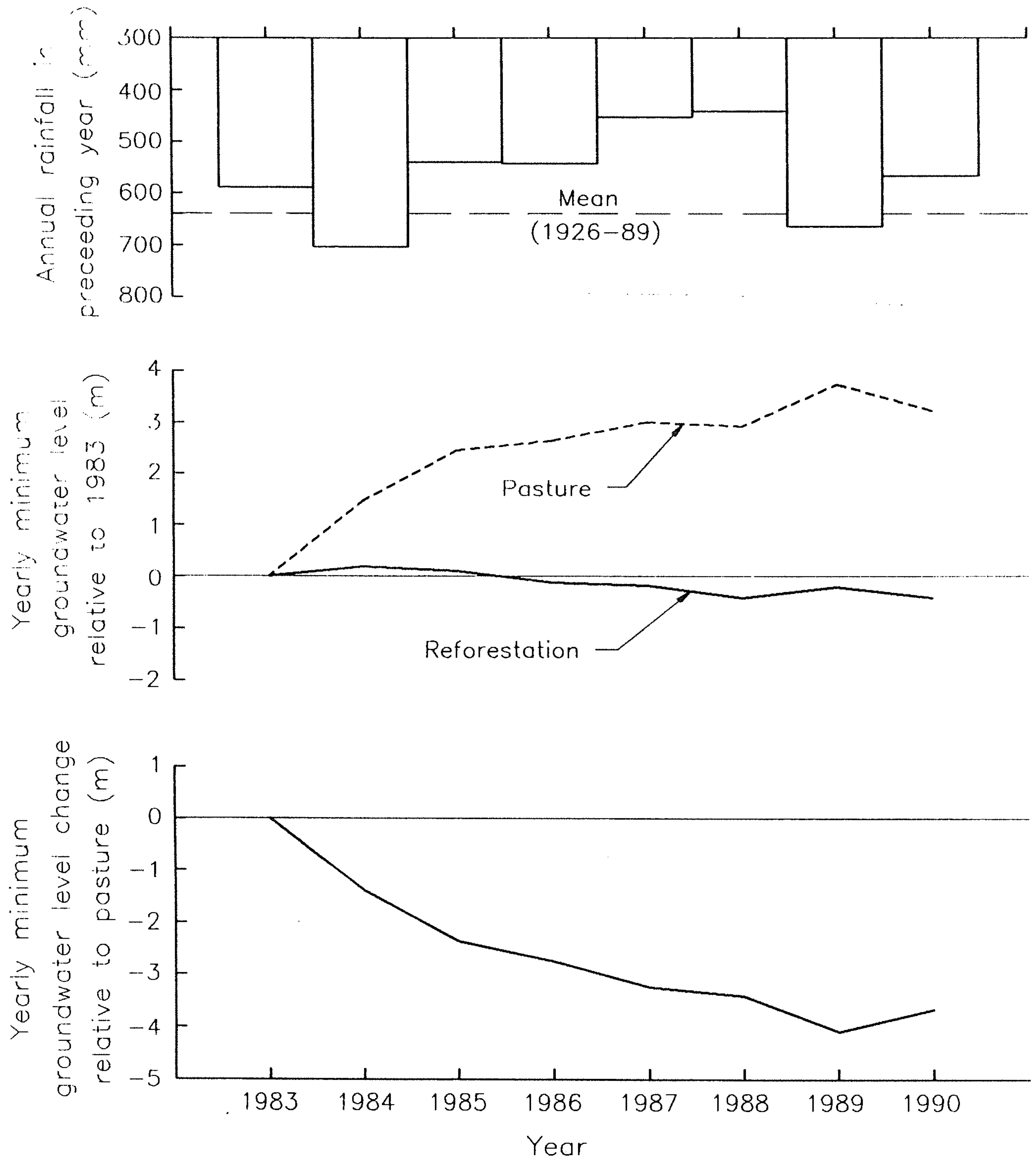

Figure 3 Annual rainfall and minimum groundwater level

Maximum Groundwater Level

Maximum groundwater level under reforestation declined 1.0 m (relative to ground surface) and 2.2 m (relative to the control) in the period 1983 to 1990 (Fig. 4). Between 1985 to 1987, in response to a series of years of below average rainfall, maximum groundwater levels declined slightly while levels beneath control were unchanged. Slight increases in maximum groundwater levels were observed under both reforestation and pasture in 1988 following a year of rainfall above the long term average.

Comparison of minimum and maximum groundwater level changes

The annual changes in minimum and maximum water levels relative to the pasture are shown in Fig. 5. In 1984 minimum and maximum groundwater levels reductions were similar. Since then, reduction in the minimum groundwater level has been greater than the maximum. Also minimum groundwater level trend was more consistent than the maximum.

5.1.3 Groundwater table across the valley transect

Fig. 6 shows the temporal variation in the groundwater table across the valley along bore transect 21-42. Three years (1983, 1986 and 1990) have been plotted as an example. There has been a slight reduction in groundwater levels beneath reforestation and a significant increase in groundwater levels under pasture. This result indicates that reforestation has been successful to some degree in lowering the groundwater levels in the vicinity of the stream.

5.1.4 Groundwater flow

The annual minimum groundwater level contours for each year have been analysed. Contour plans for the beginning (May 1983) and end (May 1990) of the study period are shown in Fig. 7. The

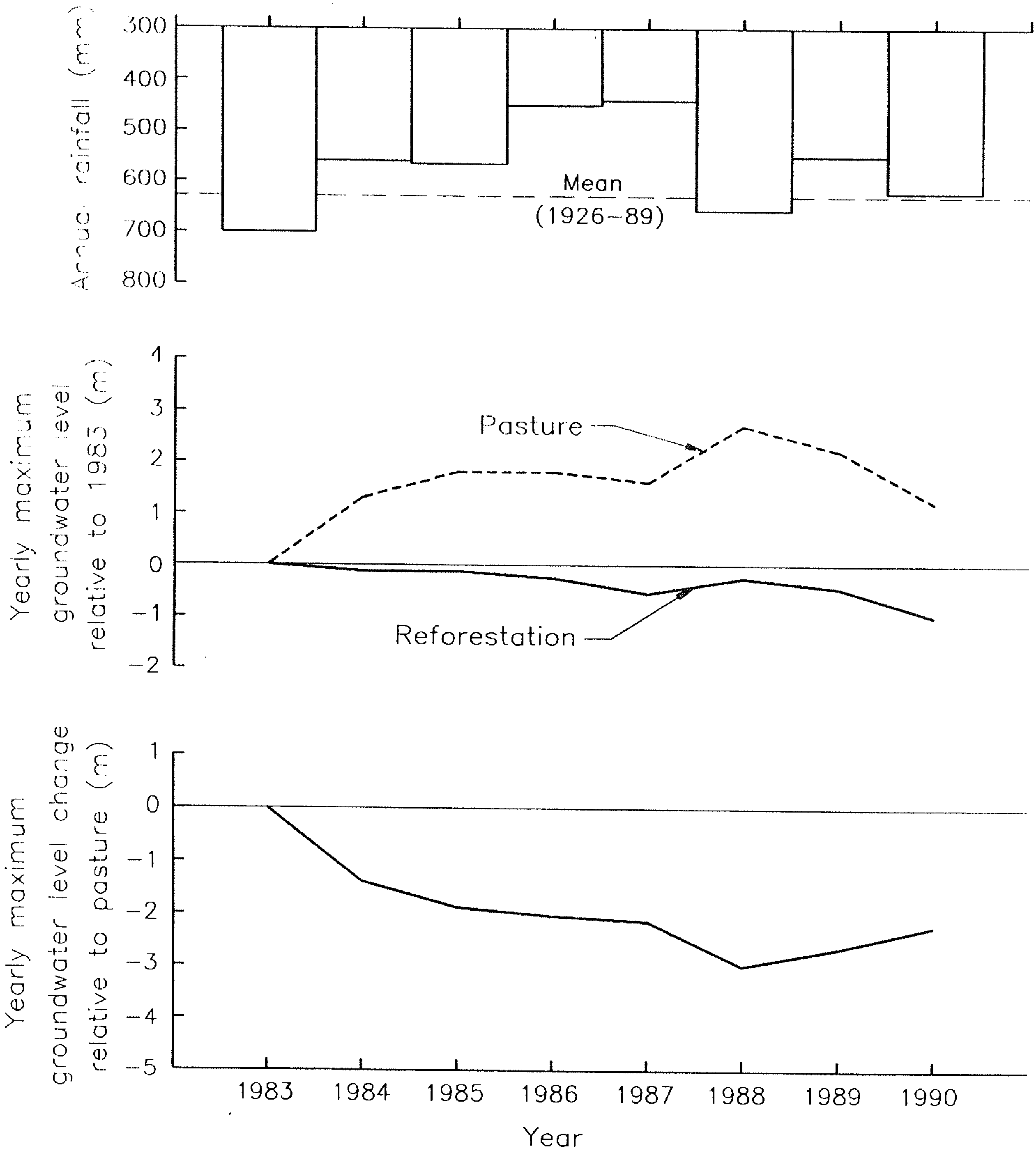

Figure 4 Annual rainfall and maximum groundwater level

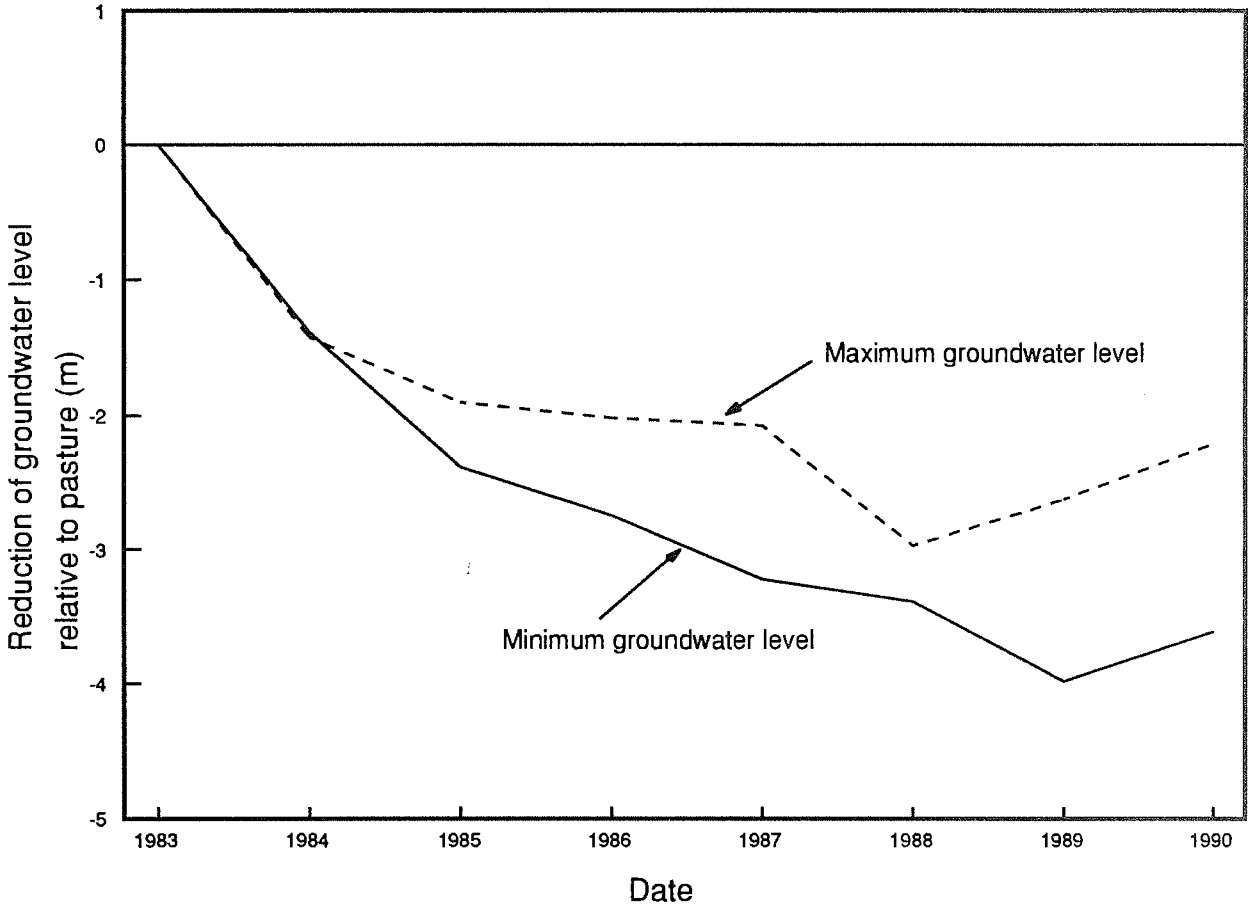

Figure 5 Comparison between reduction of minimum and maximum groundwater levels

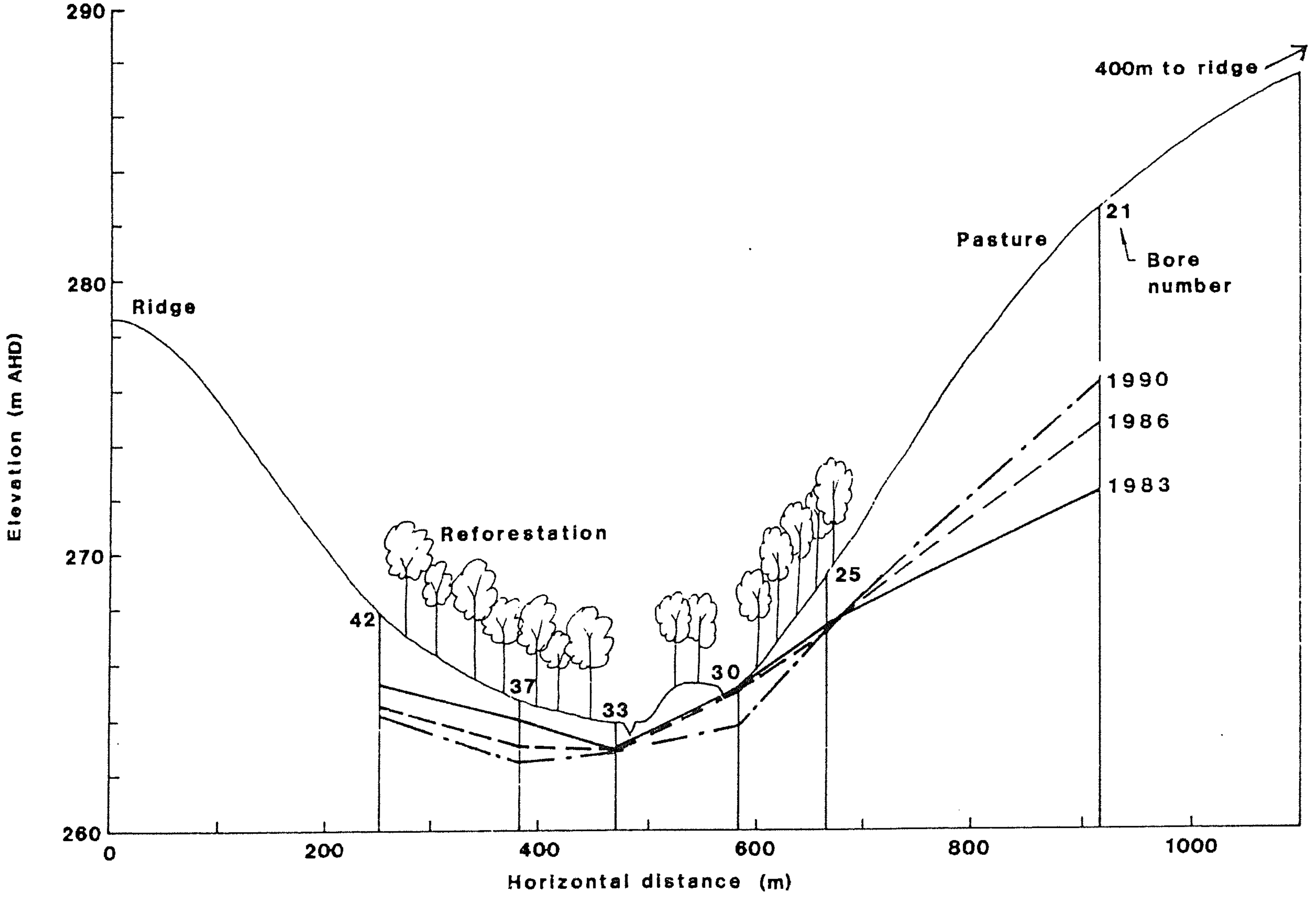

Figure 6 Groundwater levels across bore transect

following features of the groundwater system beneath the study site were identified:

(i) The direction of groundwater flow is generally towards the stream line.

(iii) Although reforestation lowered the minimum groundwater table the overall flow direction did not alter.

5.2 Groundwater Salinity

5.2.1 Groundwater salinity beneath pasture

The groundwater salinities of all pasture bores are shown in Appendix E. Spatial variation in salinity is considerable (Table 2). For example, in 1983 salinity ranged from 9031 mg L^{-1} TSS (bore 53) to 16926 mg L^{-1} TSS (bore 21) and in 1990, from 6885 mg L^{-1} TSS (bore 53) to 13267 mg L^{-1} TSS (bore 44). Salinity decreased in all bores during the study period. The decrease ranged from 6% (bore 44) to 30% (bore 51). The average decrease in groundwater salinity was 15%.

Table 3 compares the groundwater salinity of pumped samples collected in May 1983 and 1989. The analysis shows an average reduction in groundwater salinity of 15%. The reduction in salinity in individual bores ranged from 2% to 24%.

5.2.2 Groundwater salinity beneath reforestation

The groundwater salinities beneath reforestation are shown in Appendix E. Salinity data from the reforestation bores were analysed in three categories:

(a) all bores;
(b) bores screened at water table;
(c) bores screened below water table.

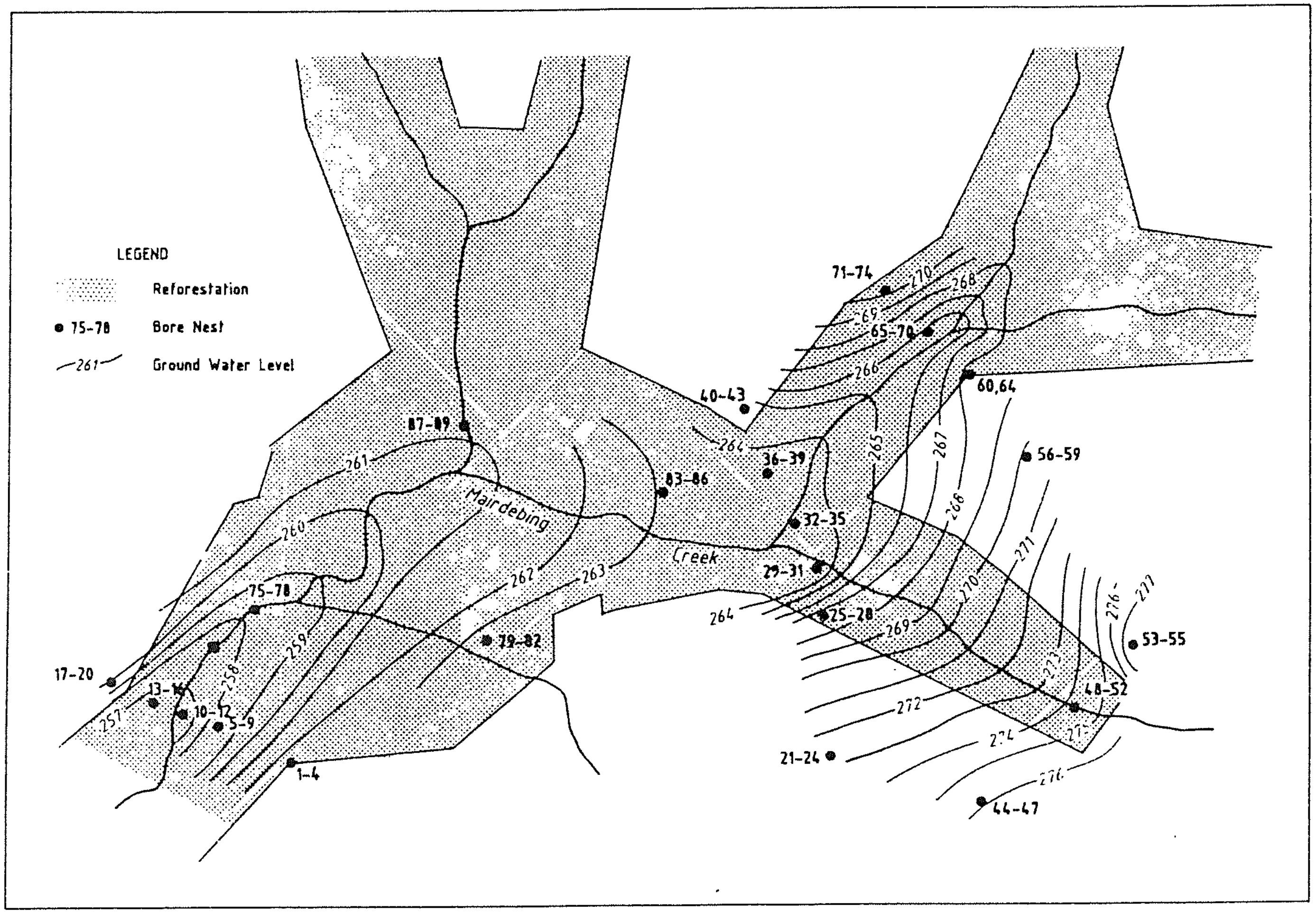

Figure 7 Regional groundwater flow directions – (a) May 1983

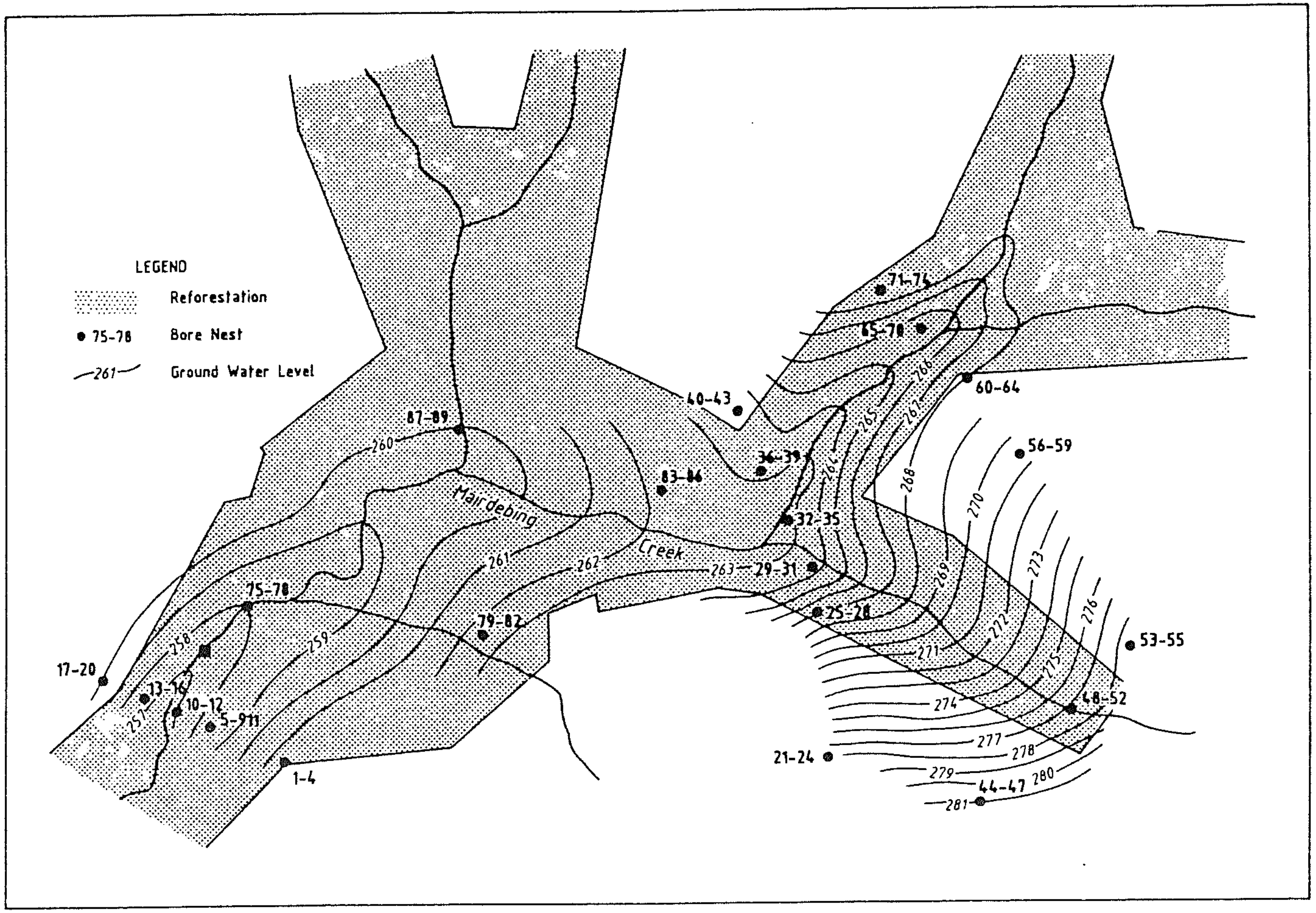

Figure 7 Reegional groundwater flow directions – (b) May 1990

Table 2: Average annual salinity (mgL^{-1}) --- pasture bores

Bore No.	1983	1984	1985	1986	1987	1988	1989	1990	% Change	Mean
G61218121	16926.0	14969.5	13304.0	14461.8	15380.5	13237.0	12736.5	13267.0	-24.8	14285.3
G61218144	14224.2	12963.5	14111.0	13974.0	15332.7	12808.0	13389.0	13871.0	-5.9	13834.2
G61218153	9031.4	13791.0	8123.5	7808.5	7162.0	5772.0	6371.0	6885.0	-29.5	8118.1
Mean	11810.2	13908.0	11846.2	12081.4	12625.1	10605.7	10832.2	11341.0	-15.5	12079.2

Table 3: Salinity comparisons ------ pasture bores

Bore No.	Salinity (mg L^{-1}) on 19/5/83	Salinity (mg L^{-1}) on 10/5/89	% change
G61218121	16539	12665	-23.7
G61218144	13880	13612	-1.9
G61218153	9064	7135	-21.3
Mean	13161	11137	-15.4

Plots of average annual salinity for each of these groups show similar downward trends (Fig. 8). Table 4 indicates the spatial variation in salinity beneath reforestation is low (coeff. of variation ranges from 0.1 to 0.2). In 1983, groundwater salinity ranged from 13433 mg L^{-1} (bore 33) to 21311 mg L^{-1} TSS (bore 7). In 1990 groundwater salinities ranged from 13952 mg L^{-1} TSS (bore 33) to 21168 mg L^{-1} TSS (bore 7). Over the period 1983 to 1990 groundwater salinity increased in 5 bores and declined in 6 (Table 4). The average reduction in groundwater salinity in all reforestation bores was 3%.

Comparing groundwater salinities from pumped samples taken in May 1983 and 1989, the average decrease was also 3% (Table 5). Salinity increased in two bores (0.5% in bore 85 and 23% in bore 33) and declined in the others by between 0.5% to 19%. The bore group screened at the water table had a 5% decline and the group screened below the water table had a 2% reduction.

5.3 Soil Salinity

Soil salinity profiles were measured in 1982 and 1989 (Appendix G). Soil salinity has changed in most bores during that time. Profiles measured across the bore transect 21-42 are shown in Fig. 9. Bore 21, located in upslope pasture, has shown a slight decline in salinity. Whereas, there has been a slight accumulation of salts between 0 to 5 m depth in bores 29 and 36. These two bores are located beneath reforestation, in the valley floor. Soil salinity in bore 40 remained the same during the study period.

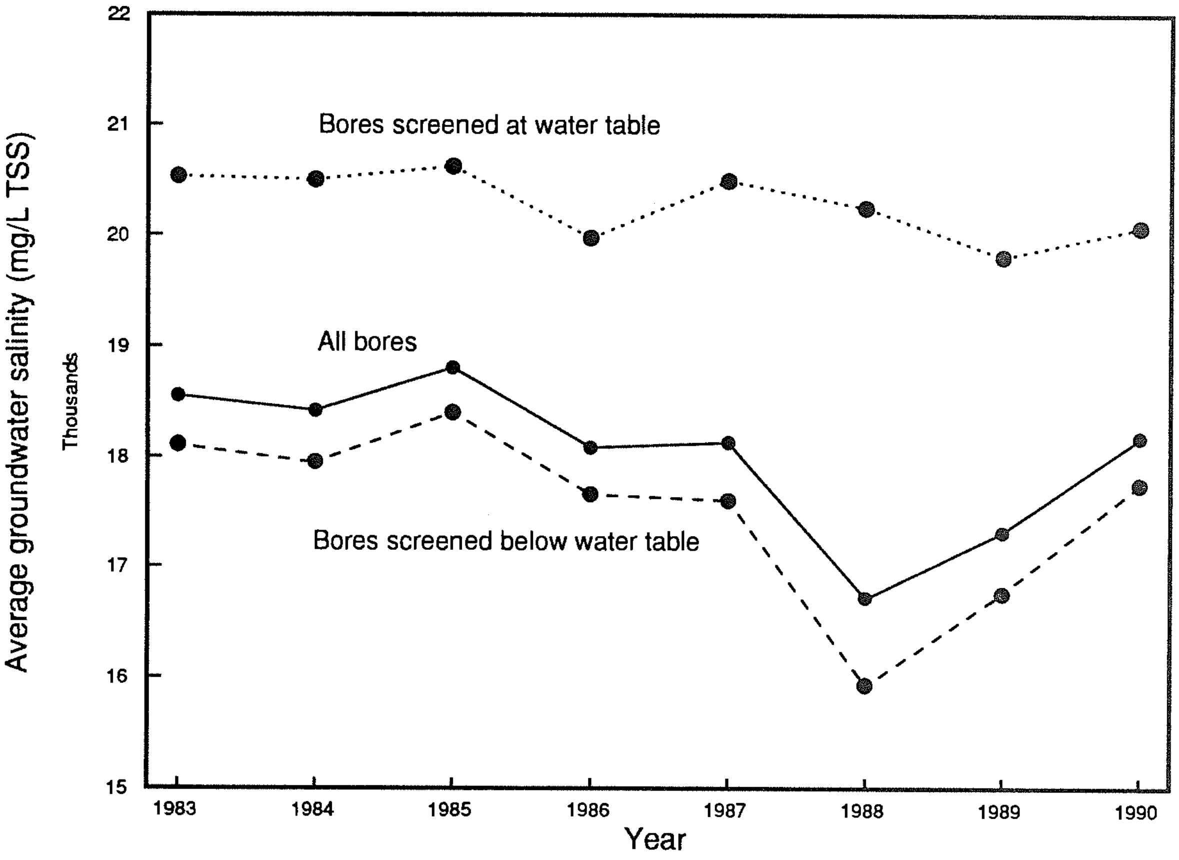

Figure 8 Groundwater salinity of bore groups beneath reforestation

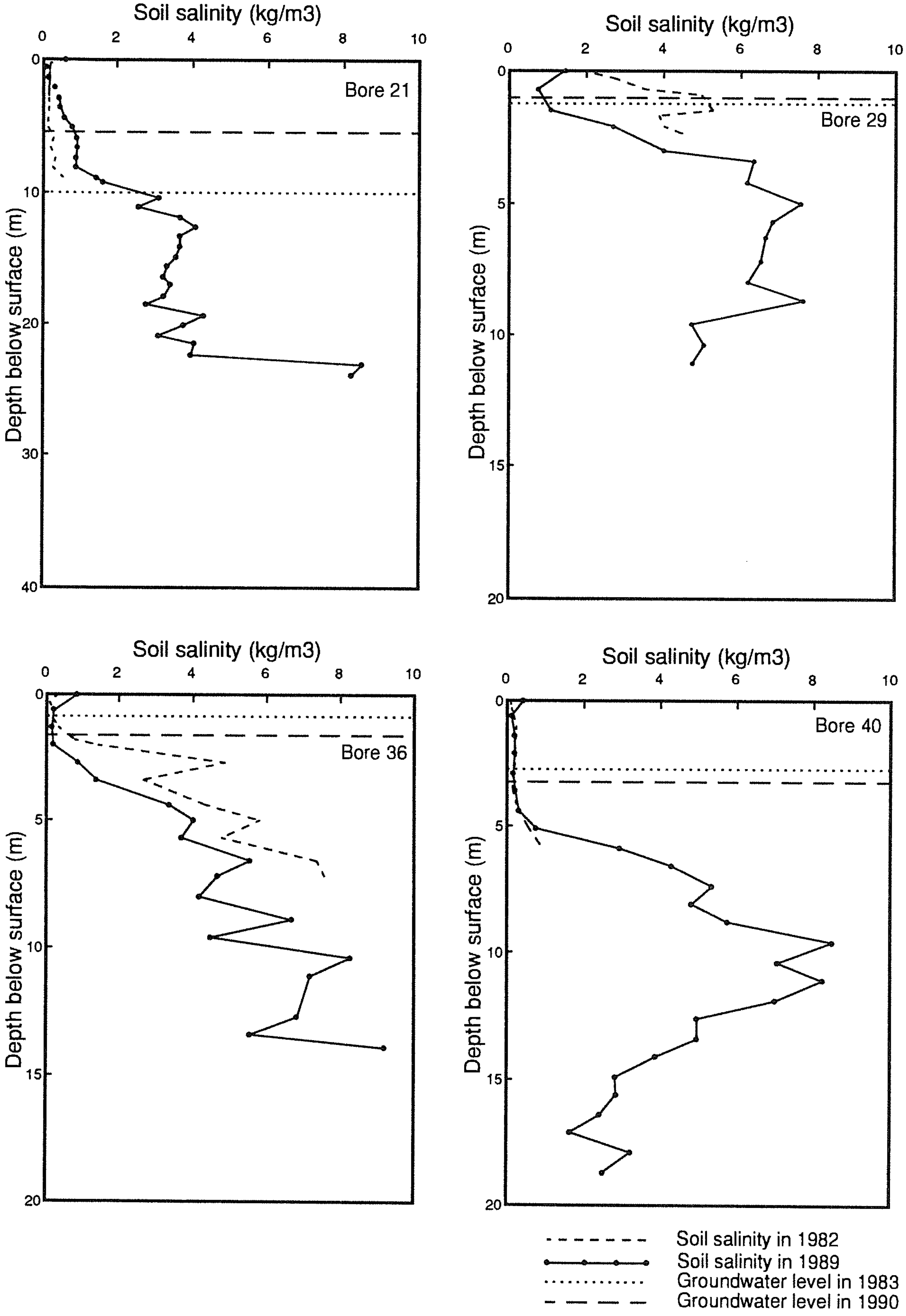

Figure 9 soil salinity profiles across bore transect

Table 4: Average annual salinity (mgL^{-1}) ----- reforestation bores

Bore No.	1983	1984	1985	1986	1987	1988	1989	1990	% change	Mean
G61218107	21311.3	21224.3	21454.0	20704.0	21025.0	21240.0	20972.0	21168.0	0.7	21137.3
G61218112	19513.0	19514.0	19846.5	19310.5	19346.5	19453.0	19039.0	19668.0	0.8	19461.3
G61218115	15633.0	16746.5	17881.5	17274.0	17988.5	16309.0	17238.5	18739.0	2.0	17226.3
G61218125	19061.3	18703.3	18596.0	15719.0	11289.3	9150.0	12922.8	16174.0	-15.2	15202.0
G61218130	19834.5	19775.0	19775.0	19239.0	19939.3	19239.0	18631.8	18953.0	-4.4	19423.2
G61218133	13433.3	13201.3	14059.0	14648.0	15845.7	16095.0	15612.8	13952.0	3.9	14605.9
G61218136	18580.6	18417.5	18917.5	18467.6	19082.7	18739.0	18363.8	18925.0	1.9	18686.8
G61218175	19131.1	18810.3	19167.5	18540.0	18796.3	12815.0	17631.5	18310.0	-4.3	17900.2
G61218181	18988.1	18346.0	18703.5	18059.3	18654.0	19596.0	18131.5	18167.0	-4.3	18580.7
G61218185	19465.3	19042.5	19367.5	18846.0	19644.0	14094.0	16091.5	17596.0	-9.6	18018.4
G61218187	19037.1	18738.8	19010.0	18035.7	17762.3	17095.0	15734.3	18145.0	-4.7	17944.8
Mean	18544.4	18410.9	18798.0	18076.6	18124.9	16711.4	17306.3	18163.4	-2.9	18017.0
CV	0.12	0.11	0.10	0.09	0.15	0.21	0.12	0.10		0.10

CV = Coefficient of variation

Table 5: Salinity comparisons --- reforestation bores

Bore group	Bore No.	Salinity ($mg L^{-1}$) on 19/5/83	Mean	Salinity ($mg L^{-1}$) on 10/5/89	Mean	Change (%) individual	Change (%) Mean
Screening at water table	G61218107	21097		20740		-1.69	
	G61218130	19811	20454	18096	19418	-8.66	-5.1
Screening below water table	G61218112	19596		19543		-0.27	
	G61218115	16381		16309		-0.44	
	G61218125	18167		16667		-8.26	
	G61218133	12308	17651	15166	17288	23.22	-2.1
	G61218136	18024		17881		-0.79	
	G61218175	18739		15238		-18.68	
	G61218181	18453		18024		-2.32	
	G61218185	18882		18953		0.37	
	G61218187	18310		17810		-2.73	
All			18161		17675		-2.7

6. STREAMFLOW AND STREAM SALINITY

6.1 Catchment Water and Salt Input

6.1.1 Rainfall

Daily rainfalls for the catchment were obtained by averaging record from the two pluviometers located in the catchment (Fig. 2). Rainfall details are provided in Table 6.

6.1.2 Saltfall

Catchment saltfall (Total Soluble Salts, mgL^{-1}) was calculated using a regional value of chloride in rainfall as derived by Hingston and Gailitis (1977). The salt concentration of rainfall was estimated to be 8.5 mgL^{-1} TSS. Table 6 shows the derived annual saltfall during the study period.

6.2 Seasonal Variation in Streamflow and Salt Loads

6.2.1 Streamflow

The daily streamflow hydrographs (mm) for eight years between 1983 and 1990 are shown in Appendix H. Streamflow was highest in 1983 and lowest in 1987.

Streamflow occurred an average of 204 days each year. The minimum being 193 days in 1987 and maximum, 218 days in 1985. In most cases streamflow commenced in April/May, following a significant rainfall event, and ceased in November or early December.

6.2.2 Stream salinity and salt loads

Stream salinity (Total Soluble Salts, TSS) shown in Appendix H varies considerably throughout the year. Flows which occur after the dry summer months can have salinities as high as 35000 mgL^{-1} TSS. Mid-winter flows are much lower in salinity at around 700 mg L^{-1} TSS. Salinity is relatively stable for winter streamflow events (Appendix I). Flows in spring have higher salinity but not as high as autumn. Stream salinities were lower in high rainfall years (1983, 88, 90) and highest in low rainfall years (1986, 87).

Stream salt discharge was highest during the mid-winter high flows and lowest during low flows in autumn and summer (Appendix J).

6.3 Annual Streamflow and Salt Loads

The annual salt load and streamflow data give a non-linear relationship from year to year (Fig. 10). A relationship between annual salt load (L_t, $kgha^{-1}$ TSS) and annual stream flow (Q_t, mm) established for the period 1983-90 was:

$$L_t = 360.1Q_t^{0.381} \qquad (1)$$
$$r^2=0.88,\ n=8,\ p^{\sim}0.001$$

A relationship between streamflow and annual flow-weighted salinity (TSS, mgL^{-1}) was also determined (Fig. 11):

$$TSS = 36.8x10^3Q_t^{-0.618} \qquad (2)$$
$$r^2=0.95,\ n=8,\ p^{\sim}0.001$$

6.4 Sources of Streamflow and Salt Discharge

The subsurface hydrology of the catchment is characterised by the presence of a shallow, seasonal, relatively fresh groundwater system and a deep, permanent more saline groundwater system. Both systems discharge salt and water into the stream. Surface runoff occurs principally during storm periods from the areas of saturation. This process of streamflow generation for a partially cleared catchments is typical in the south-west of Western Australia. The relative proportions of these stream flow components can be quantified by applying the model of source proportions (Stokes and Loh, 1982; Stokes, 1985; Sharma, *et al.*, 1980).

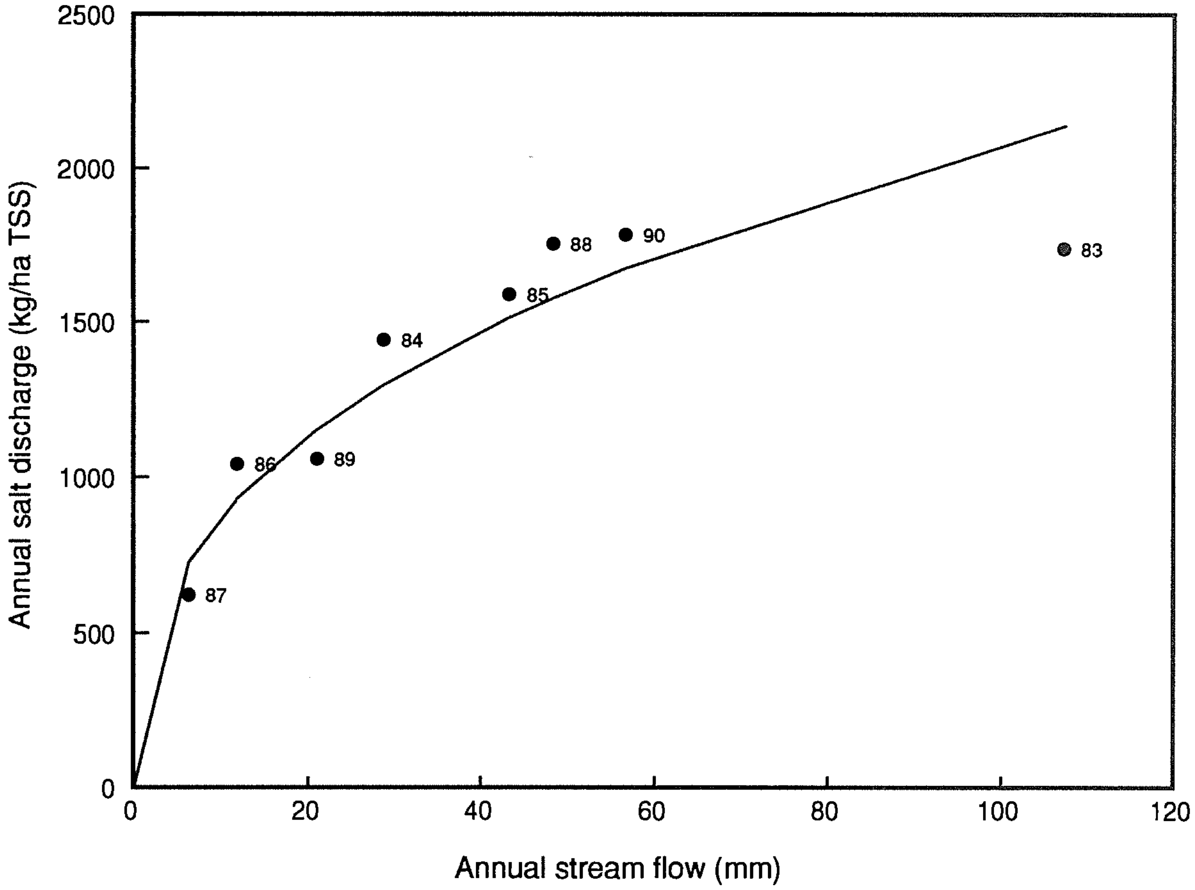

Figure 10 Relationship between annual streamflow and salt load

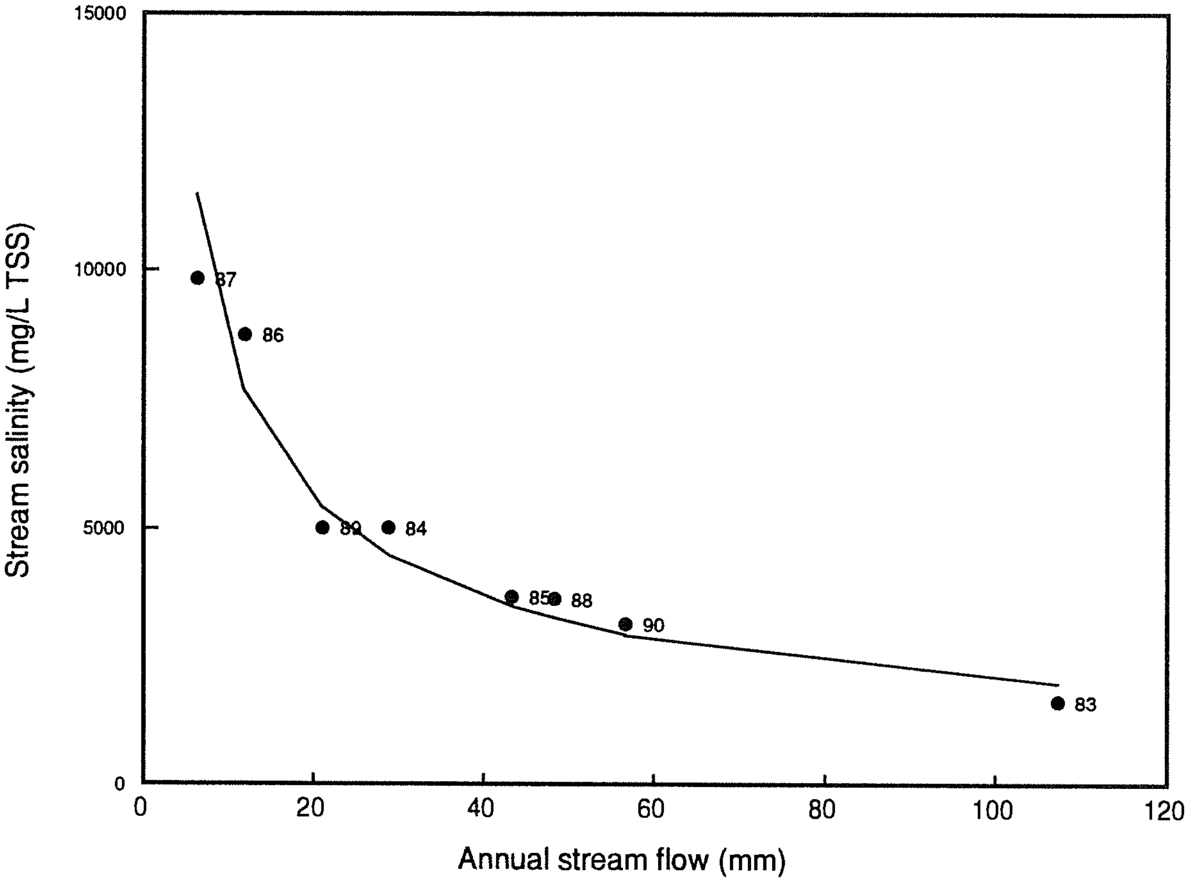

Figure 11 Relationship between annual streamflow and stream salinity

6.4.1 The model of source proportions

This model assumes streamflow and salt are generated from three sources:

(i) surface runoff (Q_r),
(ii) discharge from a shallow, seasonal groundwater system (Q_u),
(iii) discharge from a deeper, permanent groundwater system (Q_g).

Therefore stream discharge (Q_t) is composed of three separate sources:

$$Q_t = Q_r + Q_u + Q_g \qquad (3)$$

And the corresponding salt load:

$$L_t = L_r + L_u + L_g \qquad (4)$$
$$C_tQ_t = C_rQ_r + C_uQ_u + C_gQ_g \qquad (5)$$

where C denotes the salinity of three different sources.

During storm events both surface runoff (Q_r) and base flow (Q_b) contribute to streamflow. Therefore the above equations become:

$$Q_r=Q_t - Q_b \qquad (6)$$
$$Q_u=Q_b(C_g-C_b)/(C_g-C_b) \qquad (7)$$
$$Q_g= Q_b-Q_u \qquad (8)$$

And if there is no surface runoff then:

$$Q_r=0.0 \qquad (9)$$
$$Q_u=Q_t(C_g-C_t)/(C_g-C_u) \qquad (10)$$
$$Q_g=Q_t - Q_u \qquad (11)$$

The salinity of the permanent groundwater system (C_g) was taken as being the average salinity of the 'deep' bores (18000 mgL^{-1}

Table 6: Annual rainfall and salt input

Year	Rainfall M509407 (mm)	Rainfall M509409 (mm)	Average rainfall (mm)	Rainfall as % of long term average	Derived Saltfall (kg/ha)[a]
1983	690.5	700.9	696.4	1.08	57.1
1984	564.3	551.9	558.1	0.99	45.8
1985	570.4	551.5	561.0	0.87	46.0
1986	452.5	440.5	446.5	0.69	36.6
1987	444.2	431.3	437.8	0.68	35.9
1988	651.1	650.0	650.5	1.01	53.9
1989	557.5	545.5	551.5	0.86	45.2
1990	602.4	622.7	612.6	0.95	50.2
Mean	566.6	561.8	564.2	0.87	46.3
CV	0.15	0.17	0.16		0.16

CV = Coefficient of variation

a Chloride ion concentration in rainfall (4.5 mg L^{-1}) was assumed to be 55% of Total Soluble Salts.

Table 7: Average groundwater salinity of shallow bores

Bore	Depth (m)	Screen length (m)	Salinity (mg/L TSS)
126	1.2	1	438
141	1.2	1	445
161	2.0	1	708
172	1.5	1	445
Mean	1.5	1	509

TSS). The shallow subsurface groundwater salinity (C_u) was taken as being the average salinity of the four shallow bores (Table 7).

6.4.2 Travel time of surface runoff

The time for the surface runoff to pass the gauging station, from the furtherest point in the catchment,is dependent upon catchment characteristics. According to the Institution of Engineers Australia (1987) the travel time (t, hour) of a partially cleared catchment (A, km^2) in the south-west of Western Australia is:

$$t = 2.31A^{0.54} \qquad (11)$$

The above equation suggests the travel time for Maringee Farm catchment is 9 hrs.

6.4.3 Components of streamflow

All storm events during the study period were analysed and the surface runoff component was separated from the streamflow. Fig. 12 presents an example of the streamflow hydrograph and the surface runoff.

Surface runoff

The annual contribution of surface runoff (Q_r) as a percentage of streamflow (Q_t) and rainfall (R) are listed in Table 8. Surface runoff ranged from 0.7% of rainfall (1987) to 4.2% (1983) and averaged 2.0% (12.0 mm). As a proportion of total flow, surface runoff ranged from a minimum of 27% (1983) to a maximum of 50% (1987), with an average of 30%. The temporal variation in surface runoff is considerable (CV=0.74).

Shallow subsurface and deep groundwater flow

The annual shallow subsurface (Q_u) and deep groundwater flows (Q_g) are presented in Table 9. The quantity of Qu ranged from a

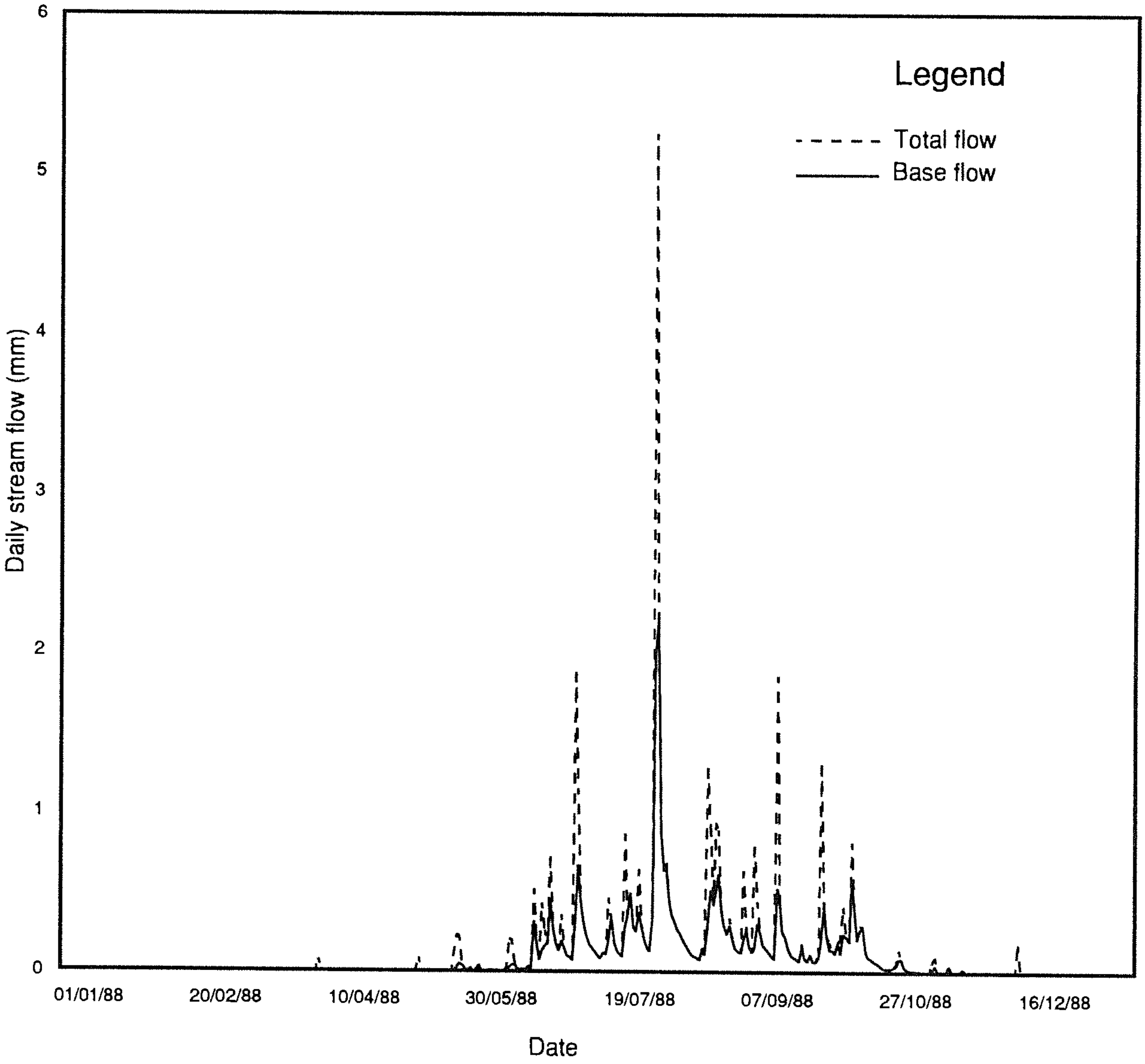

Figure 12 Daily surface runoff and the base flow for 1988

Table 8: Annual surface runoff and streamflow

Year	Rainfall (mm)	Q_t (mm)	Q_r (mm)	Q_t/R (%)	Q_r/Q_t (%)	Q_r/R (%)
1983	696.4	107.3	29.13	15.41	27.16	4.18
1984	558.1	28.8	7.41	5.16	25.72	1.33
1985	561.0	43.3	11.88	7.71	27.47	2.12
1986	446.5	11.9	3.53	2.67	29.60	0.79
1987	437.8	6.3	3.17	14.45	50.07	0.72
1988	650.5	48.3	15.26	7.43	31.58	2.34
1989	551.5	21.1	6.81	3.83	32.21	1.23
1990	612.6	56.7	18.90	9.25	33.33	3.08
Mean	564.2	40.5	12.01	7.17	29.68	2.13
CV	0.16	0.80	0.74			

CV = Coefficient of variation

Table 9: Annual shallow subsurface and deep groundwater flow components

Year	Q_t (mm)	Q_r (mm)	Q_u (mm)	Q_g (mm)	Q_u/Q_t (%)	Q_g/Q_t (%)
1983	107.3	29.13	72.57	5.56	67.66	4.18
1984	28.8	7.41	15.55	5.86	54.00	20.30
1985	43.3	11.88	25.00	6.37	57.81	14.72
1986	11.9	3.53	4.19	4.21	35.13	35.28
1987	6.3	3.17	1.10	2.06	17.35	32.58
1988	48.3	15.26	26.34	6.72	54.51	13.91
1989	21.1	6.81	10.34	4.00	48.91	18.88
1990	56.7	18.90	30.51	7.29	53.81	12.86
Mean	40.5	12.01	23.20	5.26	57.34	13.00
CV	0.80	0.74	0.97	0.32		

CV = Coefficient of variation

minimum of 1.1 mm (1987) to a maximum of 72.7 mm (1983). The temporal variation in Q_u was the highest of the three components (CV=0.97). As a proportion of total flow, Q_u ranged from 17.5% to 68.0% with an average of 57.5% (23.5 mm) over the study period. The deep groundwater flow component, Q_g, was relatively stable compared to the other two components (CV=0.32). During 1983-90, Q_g ranged from 2.1 mm to 7.3 mm with an average of 5.3 mm. As a percentage of total flow, Q_g ranged from 4.2% to 35.3% and averaged 13.0% (Table 9).

Surface runoff, shallow subsurface flow and deep groundwater flow for 1988 are plotted in Fig. 13.

6.4.4 Components of stream salt

Annual stream salt load (Lt, kgha^{-1} TSS) and the three components ---- surface runoff (L_r), shallow seasonal (L_u) and deep groundwater (L_g), are presented in Table 10. The annual stream salt load ranged from a minimum of 621.4 kgha^{-1} TSS to a maximum of 1782.7 kgha^{-1} TSS. Salt discharge from the shallow subsurface system was highly variable, ranging from 5.5 kgha^{-1} TSS in 1987 to 358.4 kgha^{-1} TSS in 1983. The average salt load (L_u) for the period 1983-90 was 115.2 kgha^{-1} TSS, which was 8.4% of the total salt load. There was more salt discharge form the deep groundwater system (L_g) than from the other streamflow components (Table 10). During the study period, it ranged from 580 kgha^{-1} TSS to 1580 kgha^{-1} TSS and averaged 1216.4 kgha^{-1} TSS. Over time the salt discharge from deep groundwater system was less variable than the other two components (CV=0.28). As a proportion of total salt load, L_g ranged from 76.1% to 93.3% and averaged 88.3%.

6.4.5 Relationship between streamflow components

Streamflow and surface runoff

The annual streamflow (Q_t, mm) and surface runoff (Q_r, mm) are shown in Fig. 14. The linear relationship between the two components is:

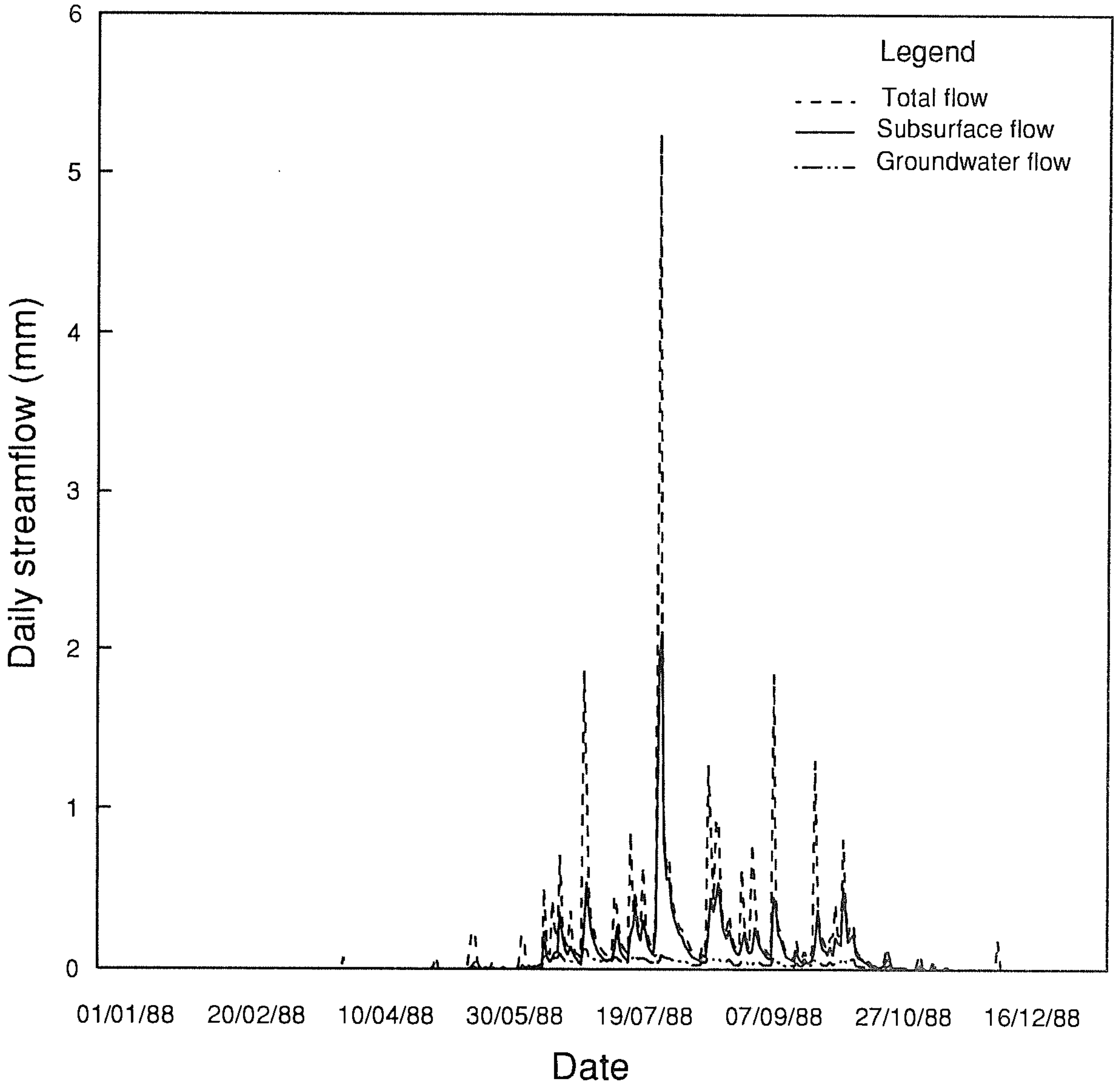

Figure 13 Stremaflow conponents for 1988

Table 10: Annual salt discharge for the three streamflow components

Year	L_t (kg/ha)	L_r (kg/ha)	L_u (kg/ha)	L_g (kg/ha)	L_r/L_t (%)	L_u/L_t (%)	L_g/L_t (%)
1983	1737.0	57.10	358.40	1321.43	3.29	20.63	76.08
1984	1441.9	45.80	77.73	1318.40	3.18	5.39	91.44
1985	1587.5	46.00	125.04	1416.28	2.90	7.88	89.21
1986	1042.9	36.60	20.94	985.35	3.51	2.01	94.48
1987	621.4	35.90	5.49	580.02	5.78	0.88	93.34
1988	1752.7	53.30	131.69	1567.76	3.04	7.51	89.45
1989	1058.8	45.20	51.69	961.22	4.27	4.88	90.85
1990	1782.7	50.20	152.53	1579.94	2.82	8.56	88.63
Mean	1378.1	46.30	115.14	1216.39	3.34	8.38	88.27
CV	0.31	0.16	0.97	0.28			

CV = Coefficient of variation

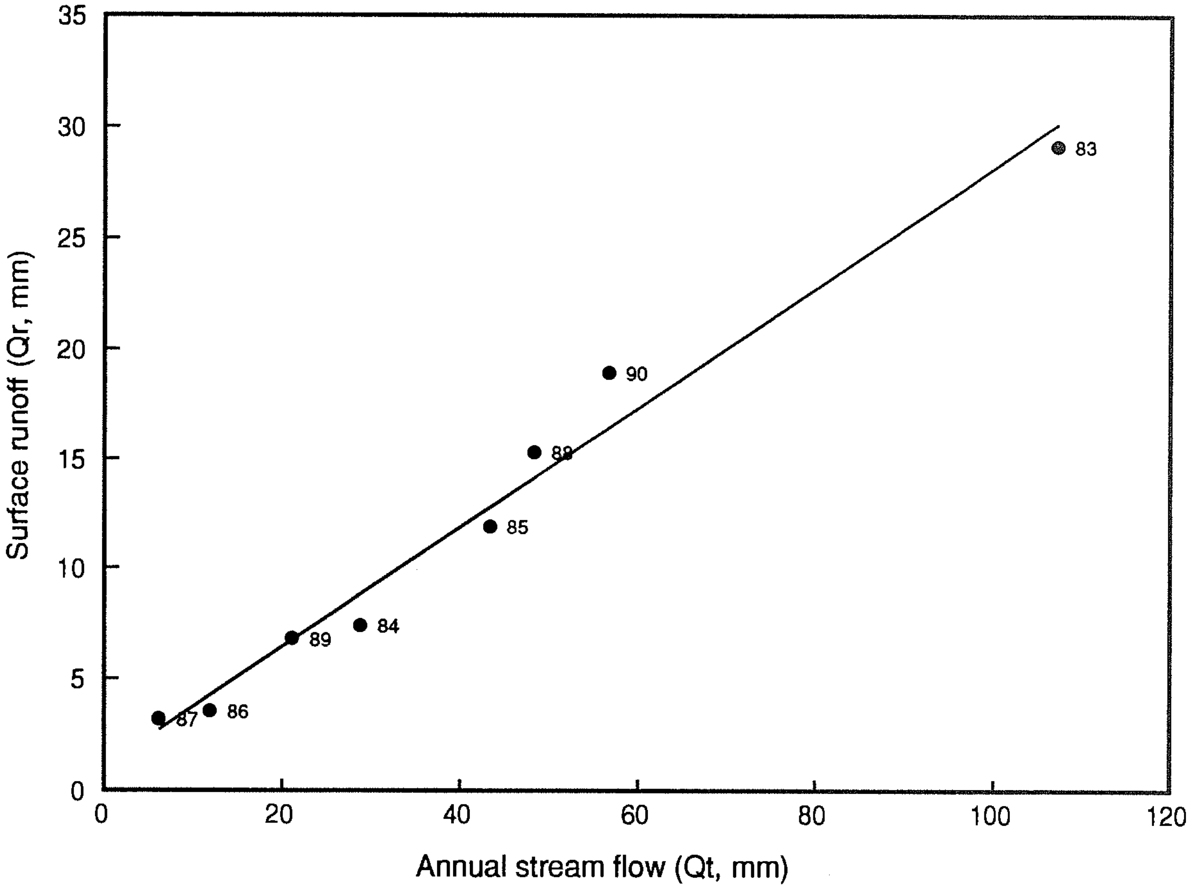

Figure 14 Relationship between annual streamflow and surface runoff

$$Q_r = 1.03 + 0.271Q_t \qquad (13)$$
r^2=0.98, n=8, p~0.001

This equation suggests surface runoff will contribute to streamflow even at very low flows

Streamflow and shallow subsurface flow

Fig. 15 shows the relationship between annual streamflow and shallow subsurface flow components. The linear regression equation is:

$$Q_u = -5.0 + 0.70Q_t \qquad (14)$$
r^2 =0.99, n=8, p~0.001

Equation 14 implies very little subsurface flow occurs when the annual streamflow is less than 7.0 mm.

Surface runoff and shallow subsurface flow

The relationship between Q_r and Q_u is shown in Fig. 16. The linear regression is:

$$Q_u = -6.62 + 2.48Q_r \qquad (15)$$
r^2=0.95, n=8, p~0.001

The above equation suggests the shallow subsurface groundwater system will contribute to streamflow when the annual surface runoff exceeds 2.7 mm.

6.4.6 Annual streamflow components and rainfall

Fig. 17 compares the three components of streamflow with rainfall. Shallow subsurface flow (Q_u) is most sensitive to annual rainfall. Surface runoff (Q_r) is less variable and less sensitive to rainfall than shallow subsurface flow (Q_u). Flow from the deep groundwater system (Q_g) is practically

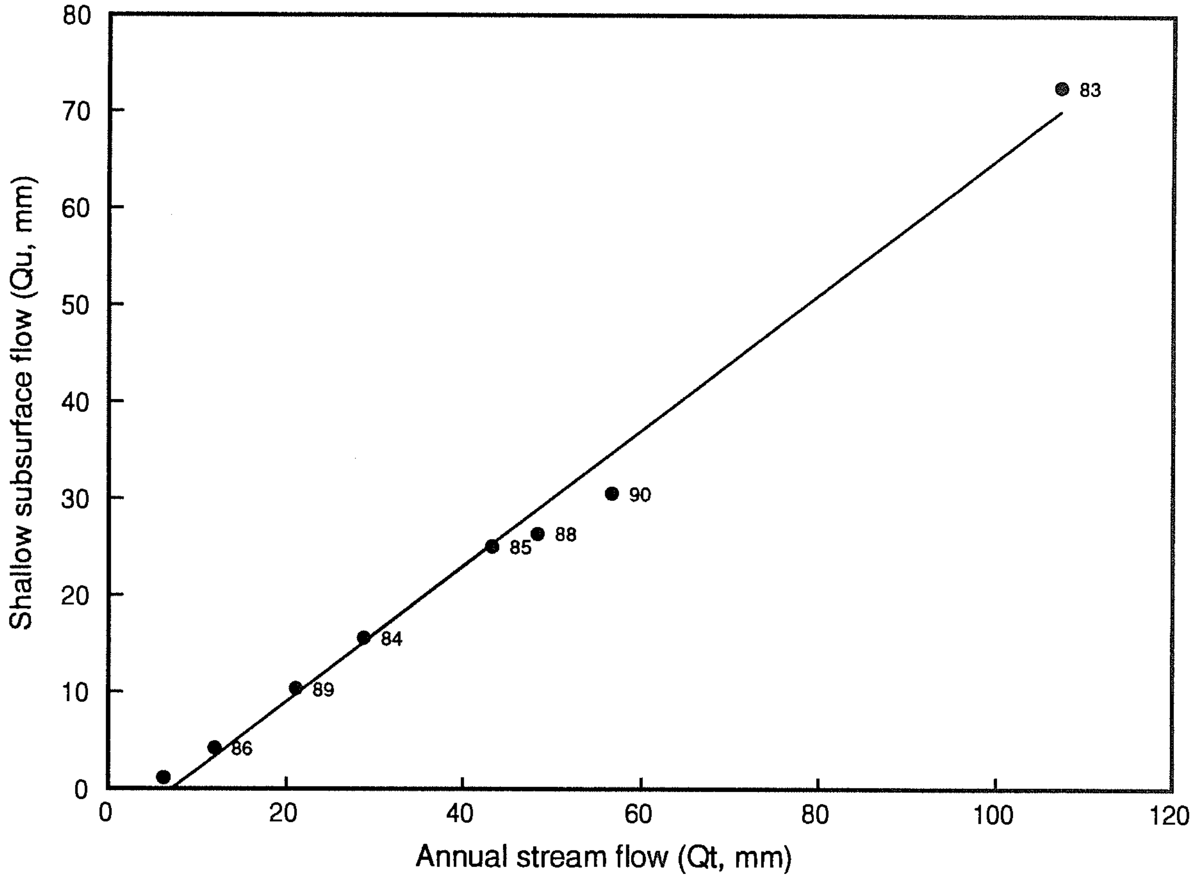

Figure 15 Relationship between annual streamflow and shallow subsurface flow

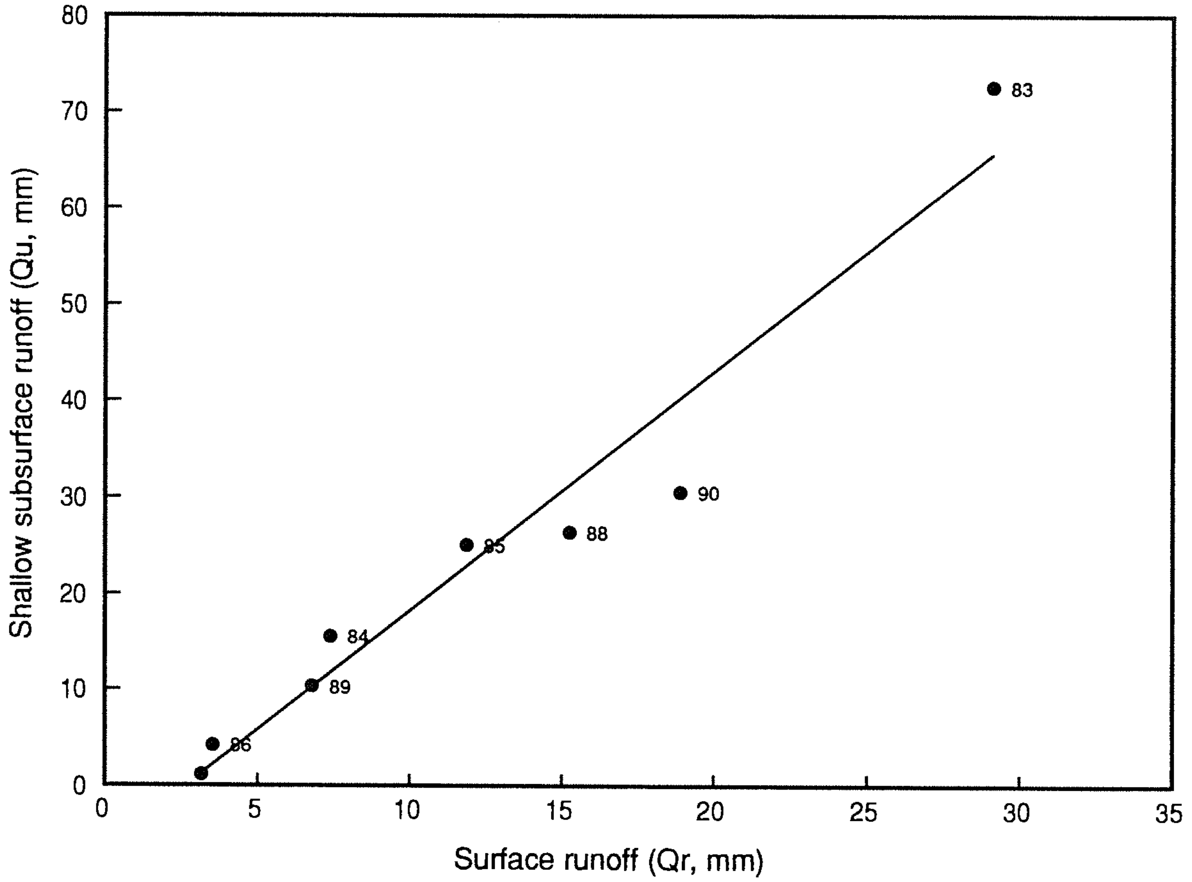

Figure 16 Relationship between surface runoff and shallow subsurface flow

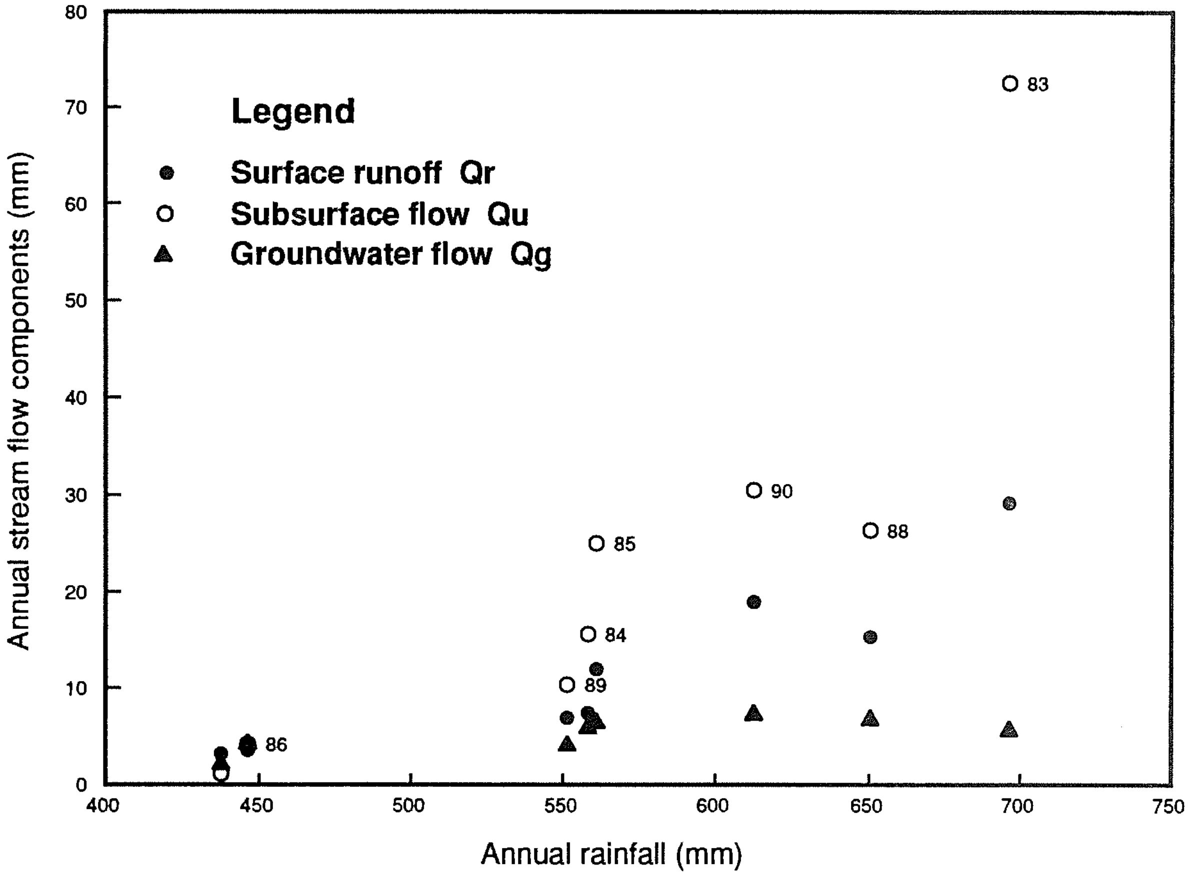

Figure 17 Annual rainfall and streamflow components

independent of rainfall and discharges at an almost steady rate to the stream.

6.5 Catchment Salt Balance

The salt balance equation for a catchment is:

$$L_s = L_r - L_t \tag{16}$$

where L_s=change in the salt storage in the catchment. Using values for average Lr and Lt for the period 1983-90 (Table 10), Ls becomes -1331.8 $\mathrm{kgha^{-1}}$ TSS. That means, Maringee Farm catchment is exporting salt (TSS) at a rate of 1332 $\mathrm{kgha^{-1}yr^{-1}}$. The quantity and distribution of salt across the catchment is presented in Appendix G. The average salt storage in the regolith was 80 kg $\mathrm{m^{-2}}$ (n=22, CV=0.54) (Water Authority of W.A., unpublished data, 1982). Assuming a piston type salt discharge at this rate, total salt leaching from the catchment would require 600 years.

6.6 Streamflow and Reforestation

The groundwater table beneath reforestation declined slightly during the study period (Fig. 3). However there is no evidence that reforestation (in this instance covering 18% of the cleared land) has reduced streamflow.

6.7 Salt Discharge and Reforestation

Fig. 18 presents the weekly flow-weighted stream salinity for the study period. During the first few years after the reforestation, the stream salinity at the commencement of flow (April/May) was more than 30000 $\mathrm{mgL^{-1}}$ TSS. In later years, however, stream salinity at the beginning of flow was stable at about 15000 $\mathrm{mgL^{-1}}$ TSS. It appears reforestation has resulted in a slightly lower stream salinity at the onset of streamflow (April/May) but its effects in terms of total salt discharge was negligible.

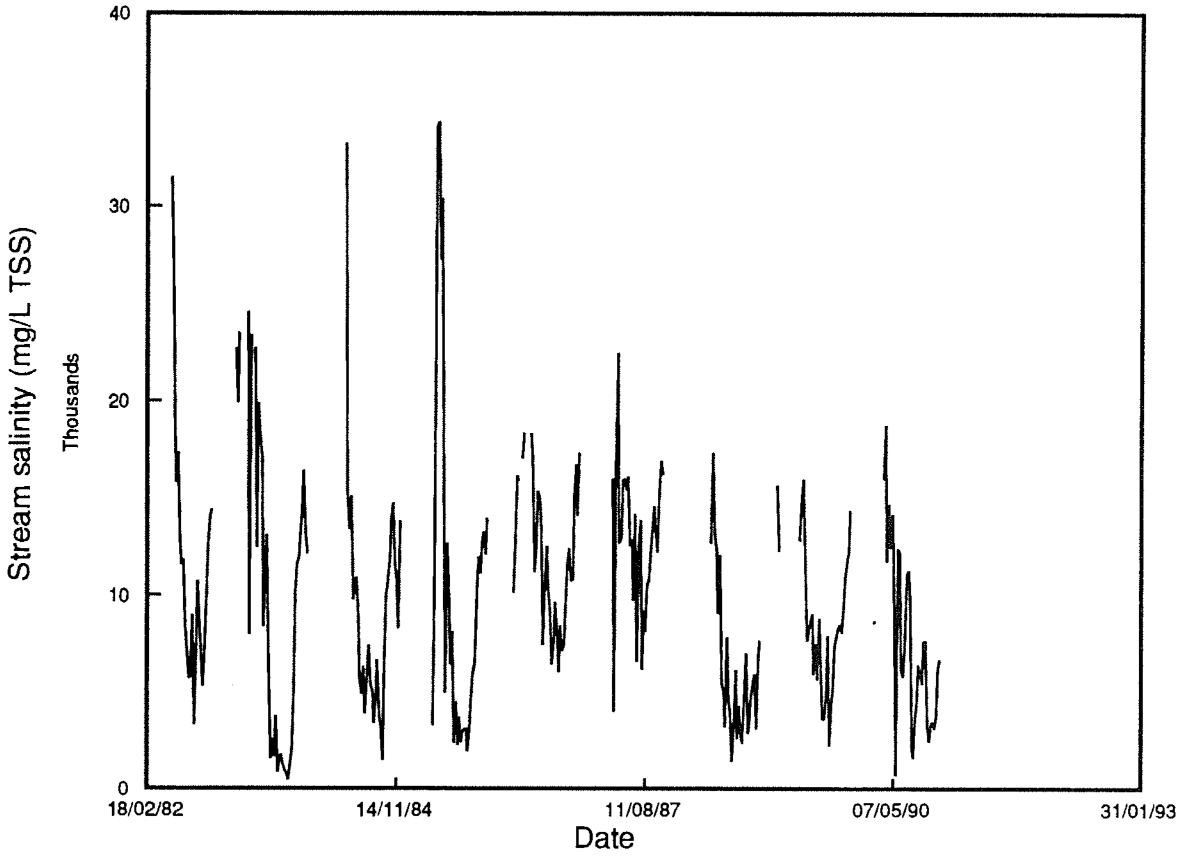

Figure 18 Weekly flow-weighted stream salinity during 1982-90

6.8 Reforestation and the Permanent Seep Area

The permanent seep area was measured from the aerial photographs taken in 1984 and 1989. The area in 1984 was 30.5 ha. In 1989 it had reduced to 25.5 ha. It appears reforestation may have reduced the permanent seep area.

7. DISCUSSION

7.1 Rainfall

The average annual rainfall during the study period (1983-90) was 13% lower than the long term average (1926-89). If long term average rainfall conditions had prevailed, it is likely groundwater levels would have risen further beneath the control i.e. pasture bores. On the other hand, should drier climate conditions prevail for south-west Western Australia (Pittock, 1988) due to the Greenhouse Effect, then the lower rainfall would assist in lowering groundwater levels.

7.2 Groundwater Level

There was no thinning or pruning of trees at this study site. The minimum groundwater level increased slightly between 1983 and 1985. The fact that groundwater levels did not fall may have been a consequence of the immaturity of the plantations. After 1985, the rate of decline of minimum groundwater level was slow but fairly uniform. Relative to pasture there has been a steady decline in groundwater level over the study period (Fig. 3). This decline is probably attributable to the continuous crown growth of the plantations.

7.3 Groundwater Salinity

Groundwater salinity beneath pasture has reduced 15% over eight years. If the present rate continues, the salinity would be below 1000 mg L^{-1} TSS by the year 2040. Most analyses of solute leaching from a soil indicate an exponential decay of salt with time (Mulqueen and Kirkham, 1972). However, Peck (1973) notes a near-linear decay in solute concentration in experiments on the displacement of a saline groundwater with increased but uniformly distributed recharge in an inclined soil slab. If this is the case then serious attention should be given to further analysis of the rate of solute export and groundwater and stream salinity decline in agricultural systems which are in hydrological equilibrium.

Groundwater salinity beneath reforestation has decreased 3% 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 (Conacher, 1982; Morris and Thomson, 1983; Williamson, 1986). The slight decrease in groundwater salinity implies that solute leaching from the aquifer beneath the reforestation is occurring at a slightly faster rate than increasing concentration due to evapotranspiration of the groundwater. 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. It appears this type of reforestation has limited impact on reducing groundwater salinity.

7.4 Streamflow and Stream Salinity

Analysis of the streamflow and water quality data supports the concept that the hydrology of the catchment consists of a deeper, permanent groundwater system, a seasonal shallow groundwater system and overland flow system (Sharma, et al., 1980; Stokes, 1985; Stokes and Loh, 1982). The hydrology of the south-west of Western Australia is characterised by low surface runoff, high seasonal subsurface flow and little permanent groundwater flow. However the surface runoff was 30% of the total streamflow over the study period.

On Maringee Farm, surface runoff was generated from the seep area, close to the stream and gullys. During winter, a seasonal shallow groundwater system develops around the permanent seep area and results in greater surface runoff during storm events. The seasonal fresh groundwater system contributed significantly to streamflow with only small salt loads (57% of flow and 8% of salt). Similar results were found in the lower rainfall area of

Darling Range (Public Works Department of W.A., 1981; Stokes and Loh, 1982). Wood (1924) argued that the primary source of stream salts was deep groundwater. The results from this catchment (13% of flow and 88% of salt over the study period) tend to confirm this. As a consequence of clearing, the groundwater table rose, resulting in a permanent seep area along the stream line. The deep groundwater system discharges to this area throughout the year. However, streamflow does not occur during the dry months because evapotranspiration exceeds the discharge from the deep groundwater system. There is no surface runoff or shallow subsurface flow during the dry months.

Daily chemographs (Appendix H) show the observed stream salinity is sometimes higher than the groundwater salinity (18000 mg L^{-1} TSS), particularly at the onset of winter. This is attributed to the concentration of salt at or near the seep area, which occurs as a result of evapotranspiration of the groundwater discharge during the summer months. This process is typical of cleared catchments in the south-west of Western Australia.

Determining the proportions of salt and water in the three flow components is dependant upon the base flow separation procedure and on the salinity concentrations of the two subsurface flow components (C_u and C_g). In this study these two salinity concentrations (C_u and C_g) were considered constant but in reality they vary from year to year and also within a season (Stokes, 1985). The values of 500 mgL^{-1} TSS and 18000 mgL^{-1} TSS for C_u and C_g are considered reasonably accurate.

7.5 Use of the Reforestation as Salinity Control

The results demonstrate that reforestation is partially successful in lowering the saline groundwater table across the valley floor, but there is no evidence of reducing saline groundwater discharge to the stream. In the future there is a chance the replanted trees will transpire more water from the groundwater and hence reduce salt discharge to the stream. In general, the effectiveness of reforestation can be improved by increasing the proportion of the farmland planted, retaining higher stem densities, and by using faster growing trees or trees which transpire at a greater rate. The reforestation design should consider the water balance of the site, particularly the annual rainfall (Schofield, 1990b). This would have direct relevance to the large scale reforestation programme in the Wellington Dam catchment (Loh, 1988).

8. CONCLUSIONS

Based on the analyses and interpretation of data, the following conclusions can be drawn:

8.1 Groundwater Level

(i) Reforestation covering 18% of the farmland has lowered the minimum groundwater level by 0.4 m. The reduction relative to the pasture control was 3.6 m.

(ii) Reforestation reduced the maximum groundwater level by 1.0 m and by 2.2 m relative to the pasture control.

(iii) During the study period, rainfall was 13% lower than the long term average. Under long term average rainfall conditions, the rate of decline of minimum groundwater level beneath reforestation could have been less.

8.2 Groundwater Flow

(i) Groundwater flow was towards the stream.

(ii) Although reforestation reduced groundwater levels it did not alter the direction of flow.

8.3 Groundwater Salinity

(i) The spatial variation of groundwater salinity beneath reforestation was low.

(ii) During the study period the groundwater salinity beneath reforestation area decreased by about 3%. This decrease was contrary to early expectations.

(iii) The groundwater salinity beneath pasture decreased by about 15% over the study period. This result merits further investigation of solute leaching under agriculture in moderate to high rainfall zones.

(iv) The effectiveness of reforestation in reducing groundwater salinity appears to be limited, but further monitoring is required to determine longer term effects.

8.4 Streamflow

(i) Over the study period surface runoff constituted 30% of total streamflow. This is relatively high. The large area of permanent saturation is likely to be the reason for this high contribution.

(ii) A relatively shallow, seasonal groundwater system made up 57% of total streamflow.

(iii) The deep, permanent groundwater system provided 13% of total streamflow.

(iv) To date there is no evidence that reforestation has reduced any of the three streamflow components.

8.5 Stream Salinity

(i) Stream salinity was highest during autumn and spring flows and lowest during winter high flows.

(ii) About 8% of total stream salt load comes from shallow subsurface flow.

(iii) About 88% of the stream salt is discharged from the deep groundwater system.

9. RECOMMENDATIONS

- Reforestation appears to be a viable landuse option for reducing groundwater level and its further study is recommended.

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

- Bore salinity sampling should continue in order to monitor future groundwater salinity behaviour, under both pasture and reforestation.

- To assist interpretation of the groundwater data, tree covers should be measured at approximately 5 year intervals.

- Measurement of streamflow and quality should be continued to determine the longer term effects of trees on groundwater, streamflow and salinity.

10. ACKNOWLEDGEMENTS

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APPENDIX A

PLANTATION DETAILS OF THE MARINGEE FARM

Maringee Farms Reforestation Details

Plot	Year Planted	Species	Stem Density (stem/ha)		
			At Planting	1988	(%)
1	1981	E. accedens/	625	350	50
		E. camaldulensis 5th row			90
2	1981	E. accedens/	625	300	40
		E. camaldulensis 5th row			90
3	1981	E. sargentii/	625	250	30
		E. camaldulensis 5th row			90
4	1981	E. accedeno/	625	100	10
		E. camaldulensis 5th row			30
5	1981	E. radiata	625	10	90
		E. saligna 5th row			5
6	1981	E. rudis/	625	500	90
		E. saligna 5th row			50
7	1981	E. camaldulensis	625	550	100
		saligna 5th row			50
8	1981	E. calophylla/	625	200	20
		E. camaldulensis 5th row			90
9	1981	E. radiata/	625	250	30
		E. saligna			90
10	1981	E. calophylla/	625	250	30
		E. saligna 5th row			90
11	1981	E. wandoo/	625	500	80
		E. maculata 5th row			60
12	1981	E. camaldulensis	625	300	50
13	1981	E. wandoo/	625	400	70
		E. leucoxylon 5th row			60
14	1982	E. wandoo/	625	250	50
		E. melliodora 5th row			10
15	1981	E. rudis/	625	350	70
		?			
16	1981	E. wandoo/	625	400	80
		E. maculata 5th row			20
17	1981	E. wandoo/	625	400	80
		E. rudis/			70
		E. camaldulensis 5th row			90
		E. leucoxylon 5th row			20
18	1981	E. rudis/	625	400	60
		E. camaldulensis 5th row			60
19	1981	E. wandoo/	625	400	70
		E. maculata 5th row			20
20	1981	E. wandoo/	625	400	60
		E. camaldulensis 5th row			90
21	1981	E. accedens/	625	500	80
		E. camaldulensis 5th row			90
22	1981	E. rudis/	625	450	70
		E. camaldulensis 5th row			70
23	1981	E. accedens/	625	400	60
		E. camaldulensis 5th row			70
24	1981	E. megacarpa/	625	150	10
		E. camaldulensis 5th row			90

Plot	Year Planted	Species	Stem Density	(stem/ha)	
			At Planting	1988	(%)
25	1981	E. megacarpa/	625	150	5
		E. kondininensis/			20
		E. camaldulensis 5th row			80
26	1981	E. accedens/	625	150	10
		E. megacarpa/			10
		E. maculata 5th row			90
27	1981	E. megacarpa/	625	100	5
		E. camaldulensis 5th row			80
28	1982	E. camaldulensis/	625	350	60
		E. globulus 5th row			40
29	1982	E. wandoo/	625	450	70
		E. saligna 5th row			80
30	1982	E. wandoo/	625	10	0
		E. resinifera/			0
		E. saligna 5th row			10
31	1982	E. microcorys/	625	30	5
		E. gamphocephela/			
		E. resinifera/			
		E. foccunda/			
		E. torquata/			
		E. eremploca/			
		E. calophylla/			
		E. saligna 5th row			
32	1982	E. brookerana/	625	10	0
		E. saligna 5th row			5
33	1982	E. E. mullerana/	625	50	10
		E. saligna 5th row			50
34	1982	E. resinifera	625	100	20
35	1982	E. resinifera/	625	30	5
		E. saligna 5th row			5
36	1982	E. wandoo/	625	450	70
		E. saligna 5th row			40
37	1982	E. wandoo/	625	300	60
		E. saligna 5th row			60
38	1982	E. calophylla/	625	250	40
		E. saligna 5th row			50
39	1982	E. wandoo/	625	200	40
		E. robusta 5th row			10
40	1982	E. camaldulensis/	625	250	50
		E. robusta 5th row			50
41	1982	E. rudis/	625	300	60
		E. saligna 5th row			20
42	1982	E. wandoo/	625	200	30
		E. saligna 5th row			20
43	1982	E. calophylla/	625	250	40
		E. saligna 5th row			30
44	1982	E. wandoo/	625		
		E. saligna 5th row			
45	1986	E. viminalis/	830		
		E. robida 5th row			
46	1986	E. melliodora/	830		
		E. robida 5th row			

APPENDIX B

GROUNDWATER OBSERVATION BORE DETAILS

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)
61218101	MA1	26/07/1982	Reforest	268.051	267.500	239.081	2.00	28.970	0.551	28.419
61218102	MA1A	26/07/1982	Reforest	268.112	267.530	266.412	1.00	1.700	0.582	1.118
61218103	MA1B	26/07/1982	Reforest	268.059	267.560	261.109	1.00	6.950	0.499	6.451
61218104	MA1C	26/07/1982	Reforest	268.115	267.600	255.615	1.00	12.500	0.515	11.985
61218105	MA2	26/07/1982	Reforest	259.083	258.450	242.283	2.00	16.800	0.633	16.167
61218106	MA2A	26/07/1982	Reforest	258.956	258.480	257.256	1.00	1.700	0.476	1.224
61218107	MA2B	26/07/1982	Reforest	258.959	258.480	254.209	1.00	4.750	0.479	4.271
61218108	MA2C	26/07/1982	Reforest	259.065	258.470	252.295	1.00	6.770	0.595	6.175
61218109	MA2D	26/07/1982	Reforest	259.001	258.450	247.471	1.00	11.530	0.551	10.979
61218110	MA3	26/07/1982	Reforest	258.236	257.757	250.636	2.00	7.600	0.479	7.121
61218111	MA3A	26/07/1982	Reforest	258.312	257.787	256.312	1.00	2.000	0.525	1.475
61218112	MA3B	26/07/1982	Reforest	258.197	257.747	253.697	1.00	4.500	0.450	4.050
61218113	MA4	26/07/1982	Reforest	258.706	258.147	242.106	2.00	16.600	0.559	16.041
61218114	MA4A	26/07/1982	Reforest	258.668	258.147	256.968	1.00	1.700	0.521	1.179
61218115	MA4B	26/07/1982	Reforest	258.616	258.147	252.118	1.00	6.500	0.471	6.029
61218116	MA4C	26/07/1982	Reforest	258.552	258.147	248.122	1.00	10.430	0.405	10.025
61218117	MA5	26/07/1982	Reforest	261.254	261.183	249.904	2.00	11.620	0.341	11.279
61218118	MA5A	26/07/1982	Reforest	261.567	261.053	259.567	1.00	2.000	0.514	1.486
61218119	MA5B	26/07/1982	Reforest	261.503	261.003	255.303	1.00	4.200	0.500	3.700
61218120	MA5C	26/07/1982	Reforest	261.628	261.103	253.628	1.00	8.000	0.525	3.700
61218121	MB5	26/07/1982	Pasture	283.161	282.561	258.011	2.00	25.150	0.600	24.550
61218122	MB1A	26/07/1982	Pasture	283.098	282.598	272.098	1.00	11.000	0.500	10.500
61218123	MB1B	26/07/1982	Pasture	283.157	282.627	268.657	1.00	14.500	0.530	13.970
61218124	MB1C	26/07/1982	Pasture	283.023	282.543	265.523	1.00	17.500	0.480	17.020

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

B.O.T. :Bottom of tube

N.S.L. :Natural surface level

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)
61218125	MB2	26/07/1982	Reforest	269.744	269.204	256.644	2.00	13.100	0.540	12.560
61218126	MB2A	26/07/1982	Reforest	269.741	269.254	268.401	1.00	1.700	0.490	1.210
61218127	MB2B	26/07/1982	Reforest	269.646	269.206	262.646	1.00	7.000	0.440	6.560
61218128	MB2C	26/07/1982	Reforest	269.576	269.136	259.476	1.00	10.100	0.440	9.660
61218129	MB3	26/07/1982	Reforest	265.466	264.956	253.166	2.00	12.300	0.510	11.790
61218130	MB3A	26/07/1982	Reforest	265.450	264.870	262.450	1.00	3.000	0.580	2.420
61218131	MB3B	26/07/1982	Reforest	265.499	265.059	257.449	1.00	8.050	0.440	7.610
61218132	MB4	26/07/1982	Reforest	264.131	263.621	251.581	2.00	12.550	0.510	12.040
61218133	MB4A	26/07/1982	Reforest	264.139	263.689	261.139	1.00	3.000	0.450	2.550
61218134	MB4B	26/07/1982	Reforest	264.138	263.638	257.118	1.00	7.020	0.500	6.520
61218135	MB4C	26/07/1982	Reforest	264.209	263.759	255.629	1.00	8.580	0.450	8.130
61218136	MB5	26/07/1982	Reforest	265.240	264.790	250.840	2.00	14.400	0.450	13.950
61218137	MB5A	26/07/1982	Reforest	265.389	264.789	261.889	1.00	3.500	0.600	2.900
61218138	MB5B	26/07/1982	Reforest	265.408	264.808	258.908	1.00	6.500	0.600	5.900
61218139	MB5C	26/07/1982	Reforest	265.207	264.807	254.277	1.00	10.930	0.400	10.530
61218140	MB6	26/07/1982	Reforest	268.915	267.695	248.995	2.00	19.200	0.500	18.700
61218141	MB6A	26/07/1982	Reforest	268.257	267.787	266.557	1.00	1.700	0.470	1.230
61218142	MB6B	26/07/1982	Reforest	268.191	267.751	263.241	1.00	4.950	0.440	4.510
61218143	MB6C	26/07/1982	Reforest	268.176	267.756	255.676	1.00	12.500	0.420	12.080
61218144	MC1	26/07/1982	Pasture	284.995	284.385	266.545	2.00	18.450	0.610	17.840
61218145	MC1A	26/07/1982	Pasture	285.021	284.471	278.521	1.00	6.500	0.550	5.950
61218146	MC1B	26/07/1982	Pasture	284.856	284.426	274.856	1.00	10.000	0.430	9.570
61218147	MC1C	26/07/1982	Pasture	284.824	284.334	271.324	1.00	13.500	0.490	13.010
61218148	MC2	26/07/1982	Reforest*	274.271	273.721	260.651	2.00	13.620	0.550	13.070

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)
61218149	MC2A	26/07/1982	Reforest*	274.028	273.518	272.528	1.00	1.500	0.510	0.990
61218150	MC2B	26/07/1982	Reforest*	273.944	273.494	270.944	1.00	3.000	0.450	2.550
61218151	MC2C	26/07/1982	Reforest*	274.253	273.733	269.223	1.00	5.030	0.520	4.510
61218152	MC2D	26/07/1982	Reforest*	274.390	273.690	265.190	1.00	9.200	0.700	8.500
61218153	MC3	26/07/1982	Pasture	280.009	279.369	269.209	2.00	10.800	0.640	10.160
61218154	MC3A	26/07/1982	Pasture	279.983	279.543	276.003	1.00	3.980	0.440	3.540
61218155	MC3B	26/07/1982	Pasture	279.821	279.381	273.321	1.00	6.500	0.440	6.060
61218156	MD1	26/07/1982	Pasture	279.614	279.114	257.214	2.00	22.400	0.500	21.900
61218157	MD1A	26/07/1982	Pasture	279.574	279.074	268.574	1.00	11.000	0.500	10.500
61218158	MD1B	26/07/1982	Pasture	279.609	279.109	264.089	1.00	15.520	0.500	15.020
61218159	MD1C	26/07/1982	Pasture	279.608	279.108	259.608	1.00	20.000	0.500	19.500
61218160	MD2	26/07/1982	Reforest	269.300	268.800	249.100	2.00	20.200	0.500	19.700
61218161	MD2A	26/07/1982	Reforest	269.337	268.837	266.837	1.00	2.500	0.500	2.000
61218162	MD2B	26/07/1982	Reforest	269.315	268.845	262.845	1.00	6.470	0.470	6.000
61218163	MD2C	26/07/1982	Reforest	269.642	268.822	256.462	1.00	13.000	0.640	12.360
61218164	MD2D	26/07/1982	Reforest	269.197	268.737	253.727	1.00	15.470	0.460	15.010
61218165	MD3	26/07/1982	Reforest	266.509	265.909	239.989	2.00	26.520	0.600	25.920
61218166	MD3A	26/07/1982	Reforest	266.744	266.244	265.004	1.00	1.740	0.500	1.240
61218167	MD3B	26/07/1982	Reforest	266.588	266.134	262.548	1.00	4.040	0.450	3.590
61218168	MD3C	26/07/1982	Reforest	266.555	266.115	259.555	1.00	7.000	0.440	6.560
61218169	MD3D	26/07/1982	Reforest	266.571	266.201	255.051	1.00	11.520	0.550	10.970
61218170	MD3E	26/07/1982	Reforest	266.487	265.987	247.987	1.00	18.500	0.500	18.000
61218171	MD4	26/07/1982	Reforest	271.448	270.948	259.118	2.00	12.330	0.500	11.830
61218172	MD4A	26/07/1982	Reforest	271.333	270.783	269.333	1.00	2.000	0.550	1.450

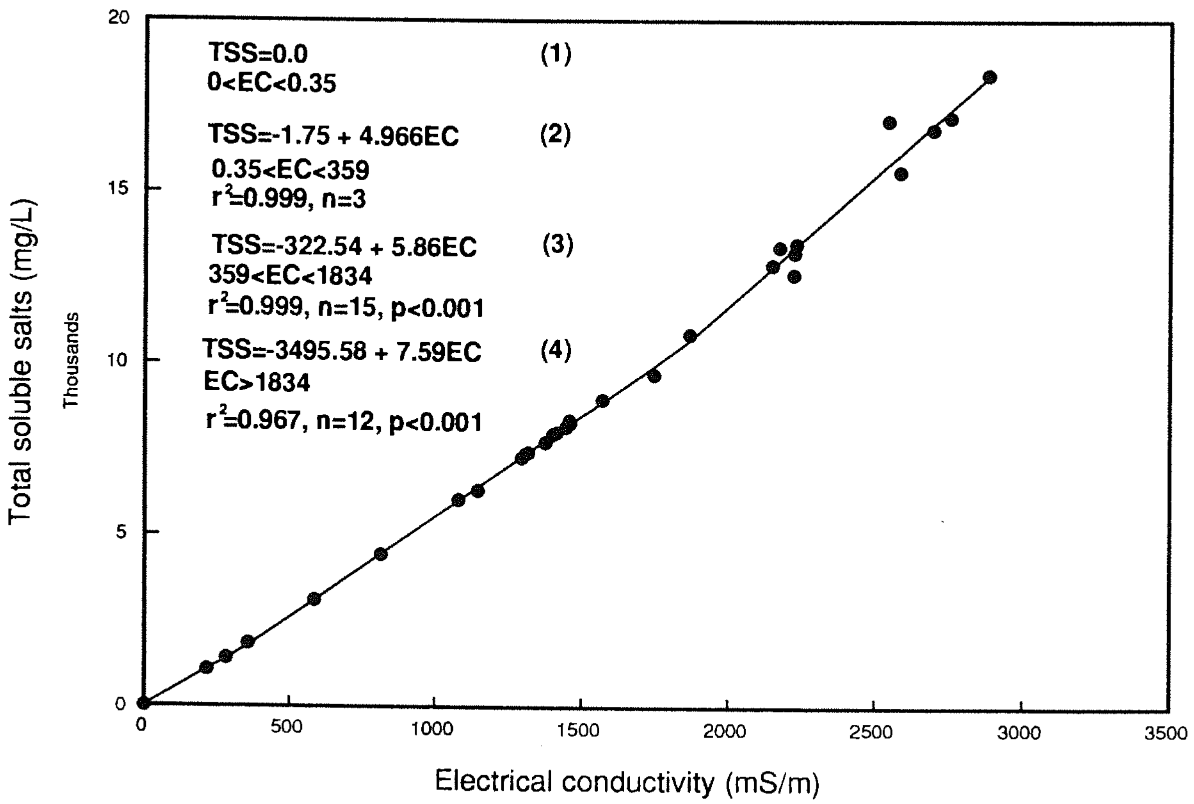
S.W.R.I.S. Bore Number	Drillers Bore Number	Commencement of Operation	Bore Classif-ication	Top of Inner Tube (AHD)	Natural Surface Level (AHD)	Bottom of Tube (AHD)	Length of Slotting (m)	Length of Inner Tube (m)	Height of T.O.I.T. Above N.S.L. (m)	Depth of B.O.T. Below N.S.L. (m)
61218173	MD4B	26/07/1982	Reforest	271.324	270.784	266.324	1.00	5.000	0.540	4.460
61218174	MD4C	26/07/1982	Reforest	271.316	270.806	263.316	1.00	8.000	0.510	7.490
61218175	MF1	26/07/1982	Reforest	259.026	258.528	245.676	2.00	13.350	0.498	12.852
61218176	MF1A	26/07/1982	Reforest	258.932	258.518	257.382	1.00	1.550	0.414	1.136
61218177	MF1B	26/07/1982	Reforest	259.073	258.528	251.073	1.00	8.000	0.545	7.455
61218178	MF1C	26/07/1982	Reforest	259.009	258.558	248.558	1.00	10.451	0.451	10.000
61218179	MF2	26/07/1982	Reforest	263.985	263.514	241.683	2.00	22.302	0.471	21.831
61218180	MF2A	26/07/1982	Reforest	264.084	263.624	261.584	1.00	2.500	0.460	2.040
61218181	MF2B	26/07/1982	Reforest	264.046	263.554	257.546	1.00	6.500	0.492	6.008
61218182	MF2C	26/07/1982	Reforest	263.939	263.554	249.489	1.00	14.451	0.385	14.065
61218183	MF3	26/07/1982	Reforest	264.405	263.765	240.655	2.00	23.750	0.640	23.110
61218184	MF3A	26/07/1982	Reforest	264.362	263.862	261.862	1.00	2.500	0.500	2.000
61218185	MF3B	26/07/1982	Reforest	264.370	263.870	258.870	1.00	5.500	0.500	5.000
61218186	MF3C	26/07/1982	Reforest	264.399	263.899	252.899	1.00	11.500	0.500	11.000
61218187	MF4	26/07/1982	Reforest	262.031	261.446	250.681	2.00	11.350	0.585	10.765
61218188	MF4A	26/07/1982	Reforest	262.059	261.566	260.309	1.00	1.750	0.493	1.257
61218189	MF4B	26/07/1982	Reforest	262.002	261.514	256.002	1.00	6.000	0.488	5.512

APPENDIX C

RELATIONSHIP BETWEEN SALINITY (TSS) AND ELECTRICAL CONDUCTIVITY

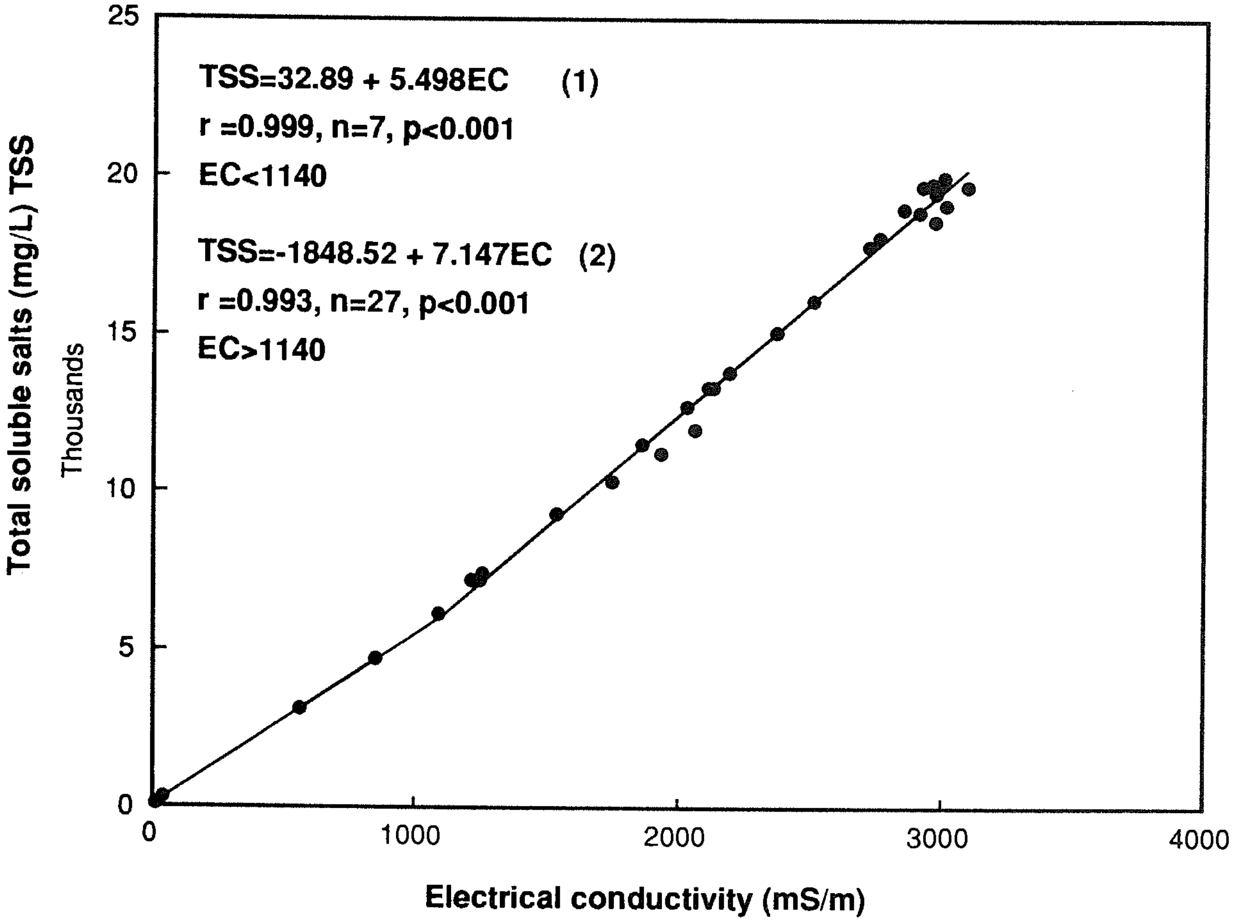
Relationship between TSS and EC

(S612026 Surface water)



Relationship between TSS and EC

(S612026 Groundwater)



APPENDIX D

CALCULATION OF ANNUAL STREAMFLOW AND SALT LOAD

COMPUTATION OF SALT LOAD

Electrical conductivity records (compensated at 25 degree centigrade) were transformed to salinity (Total Soluble Salts, TSS) by a rating curve described in Appendix C. From SWRIS (State Water Resource Information System) streamflow and salinity data were extracted for every 20 minute interval. Daily streamflow (Q_d) and flow-weighted stram salinity (S_d) were calculated as:

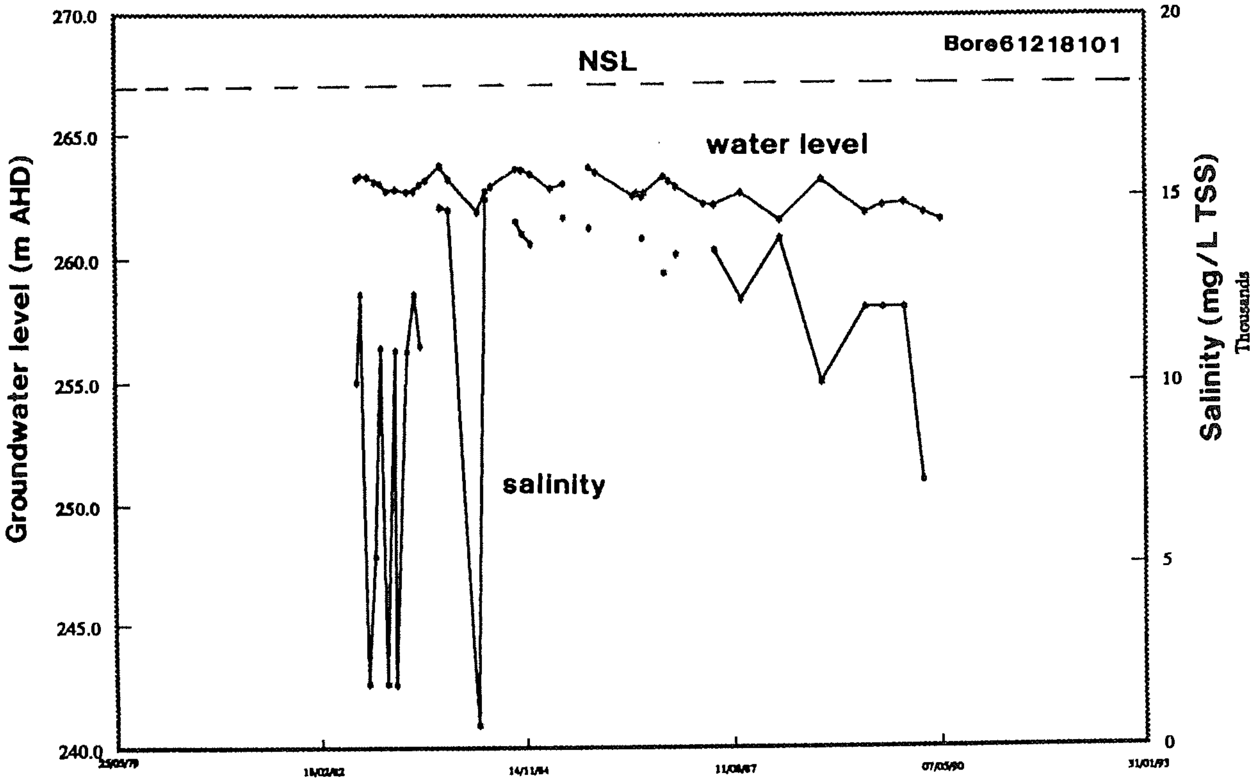
$$S_d = (\Sigma S_i * Q_i)/\Sigma Q_i \tag{C1}$$

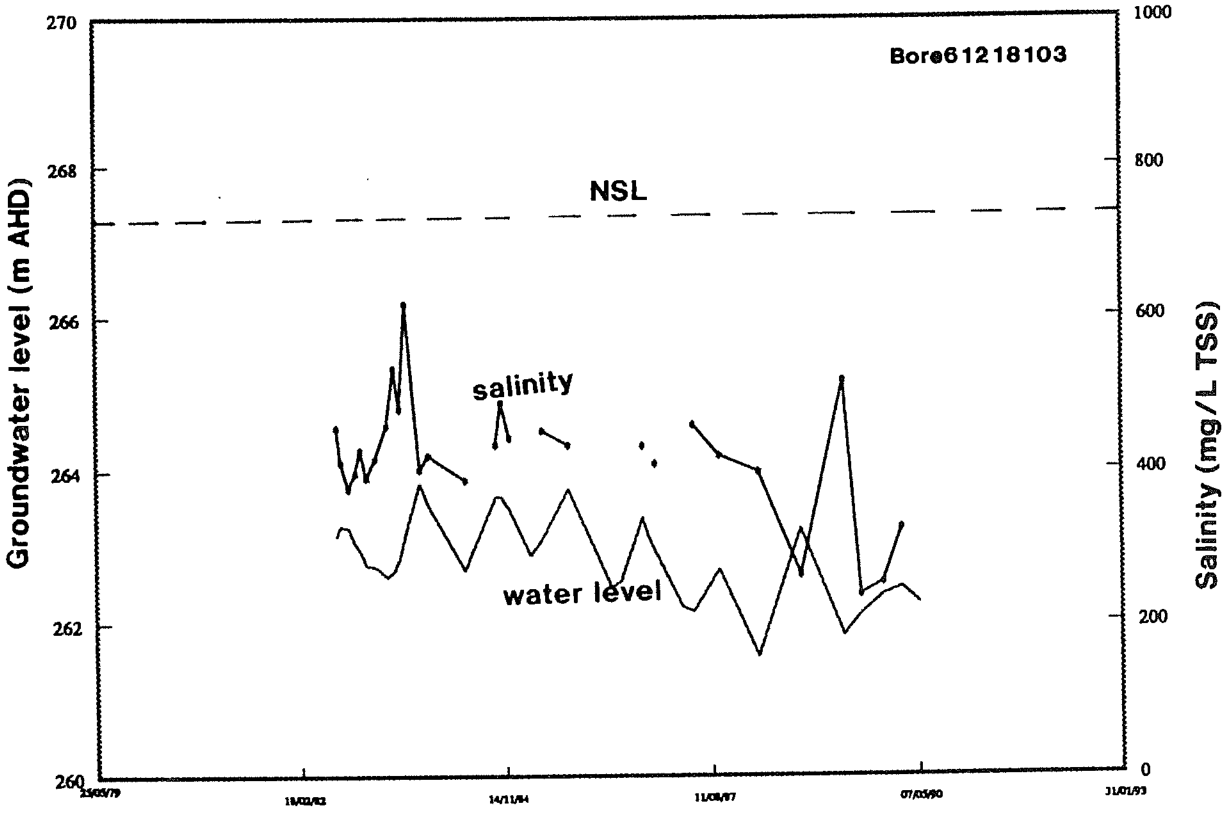
$$Q_d = \Sigma Q_i \tag{C2}$$

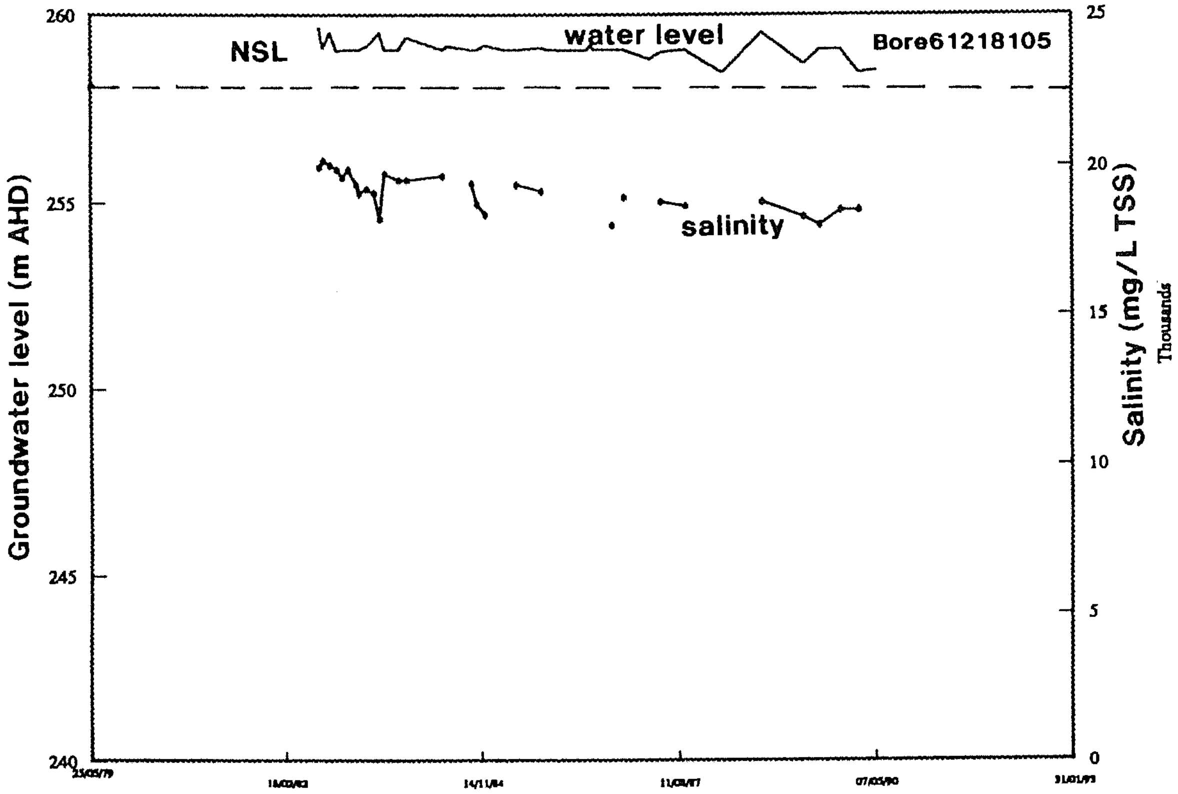
where S_i=instnateneous stream salinity, and Q_i=instanteneous streamflow. Non-continuous grab samples were used to fill the gaps between the continuous records. Using the above equations, flow, salt load and stream salinity were calculated for the required period (weekly, monthly and annual). The 'flow-weighted average stream salinity' is be referred as average stream salinity.

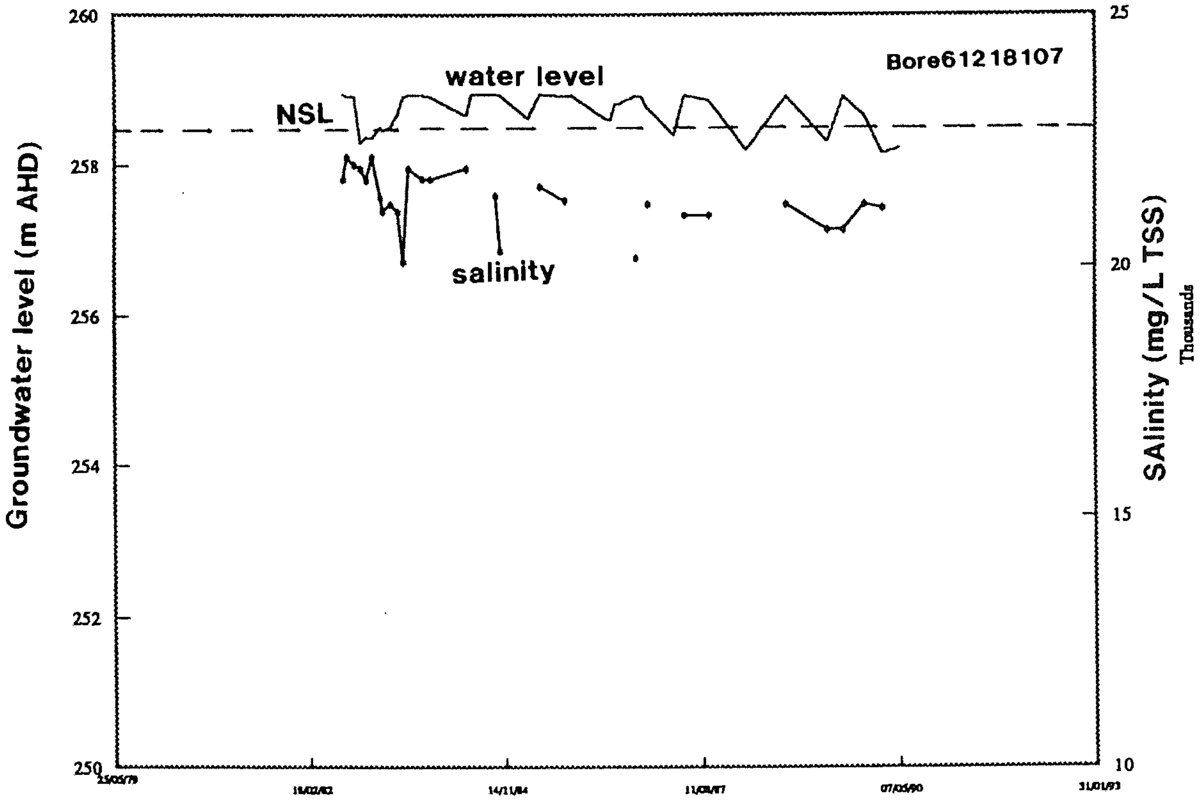
APPENDIX E

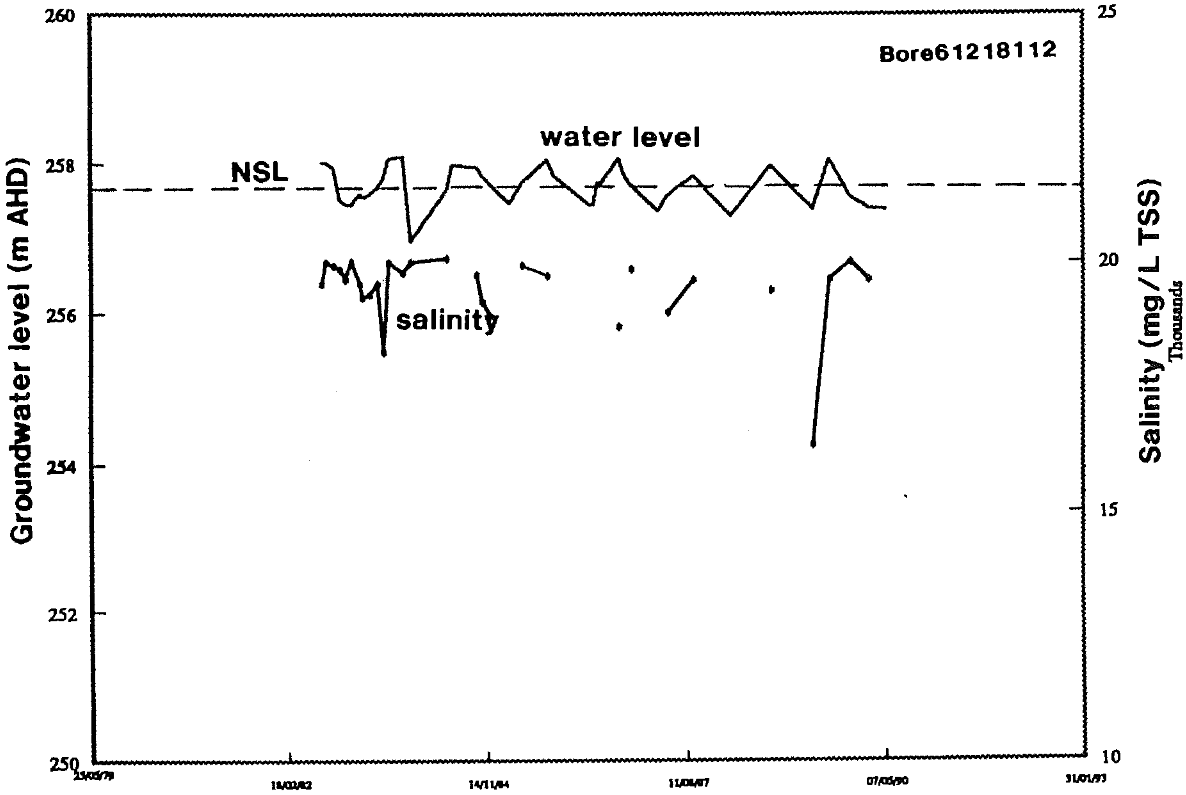
GROUNDWATER LEVEL AND SALINITY GRAPH

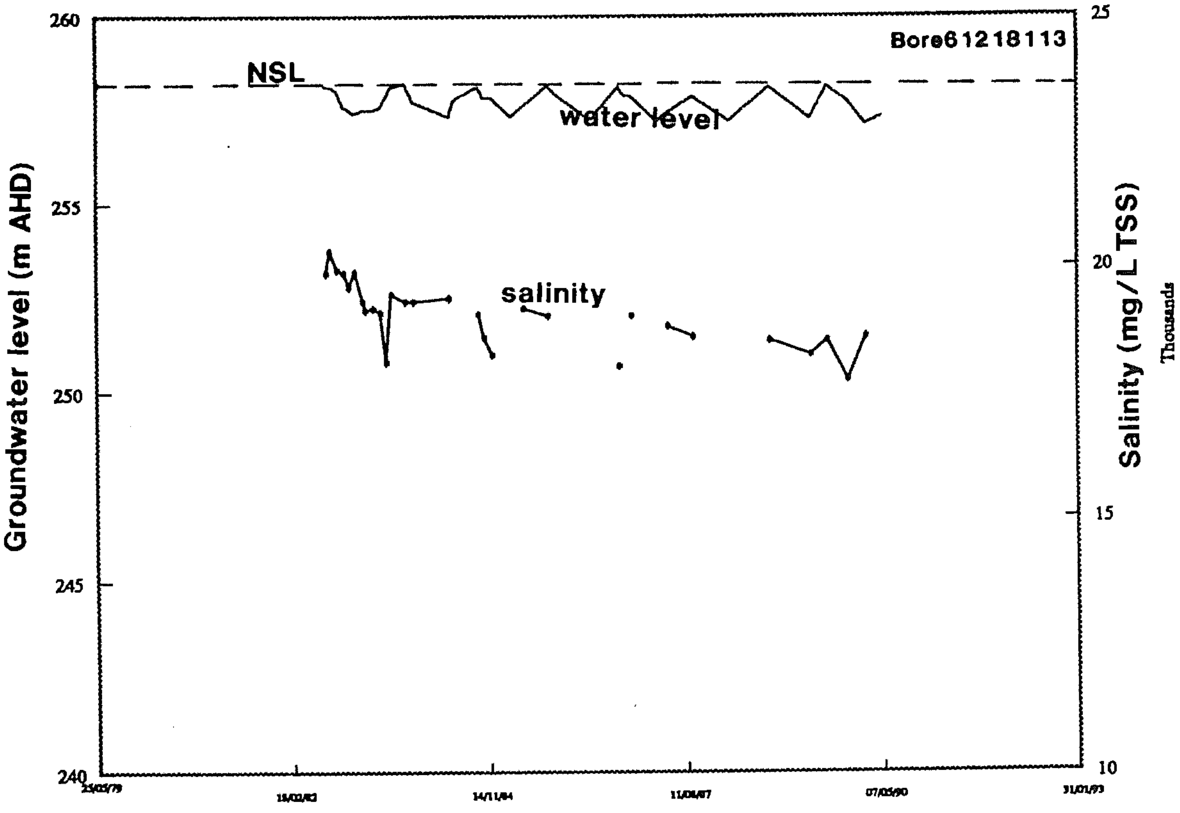

Bore61218101
NSL
water level
salinity
Groundwater level (m AHD)
270.0
265.0
260.0
255.0
250.0
245.0
240.0
Salinity (mg/L TSS)
Thousands
20
15
10
5
0
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93

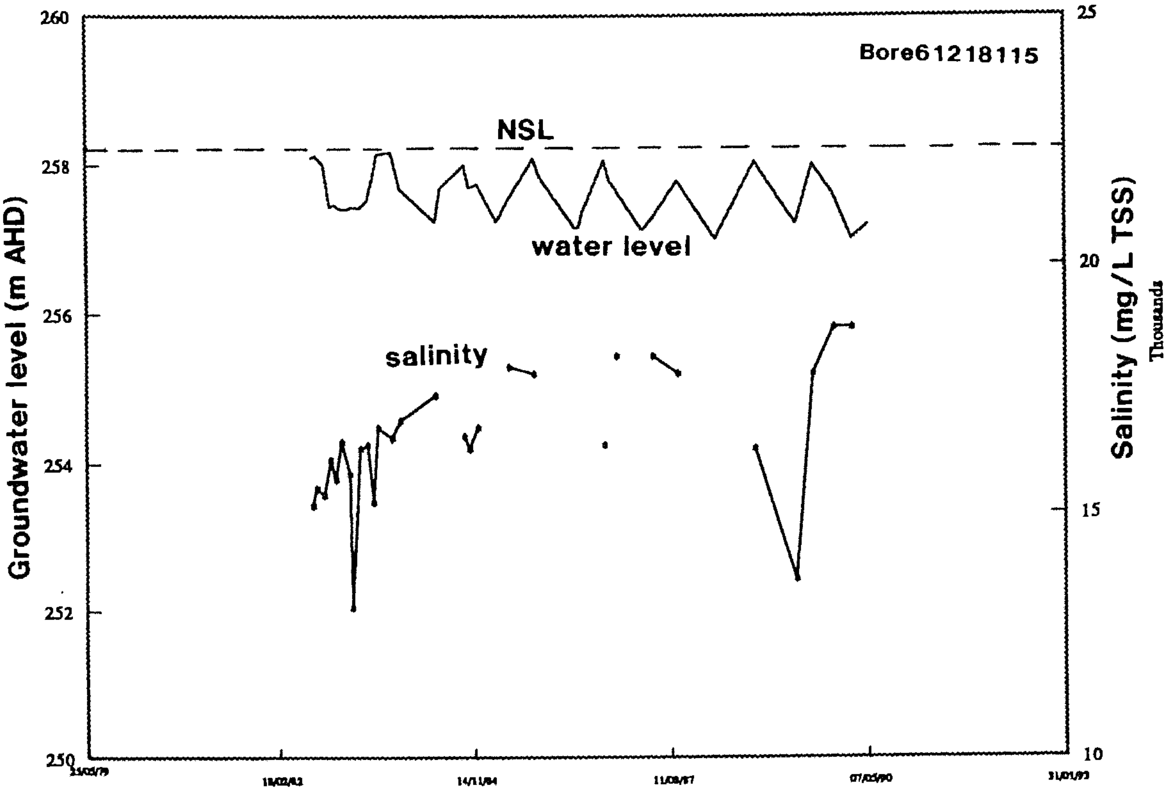

Bore61218103
NSL
salinity
water level
Groundwater level (m AHD)
270
268
266
264
262
260
Salinity (mg/L TSS)
1000
800
600
400
200
0
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93

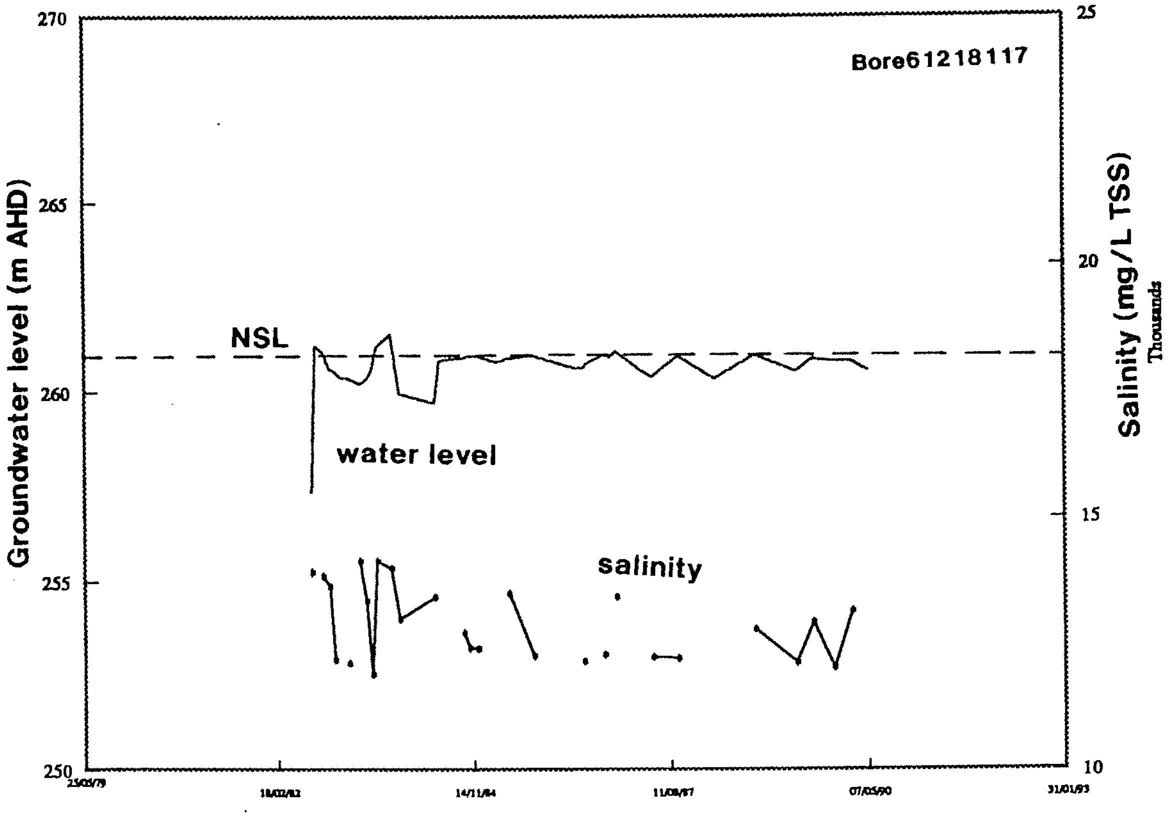

Bore61218105
NSL
water level
salinity
Groundwater level (m AHD)
Salinity (mg/L TSS)
Thousands
260
255
250
245
240
25
20
15
10
5
0
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93

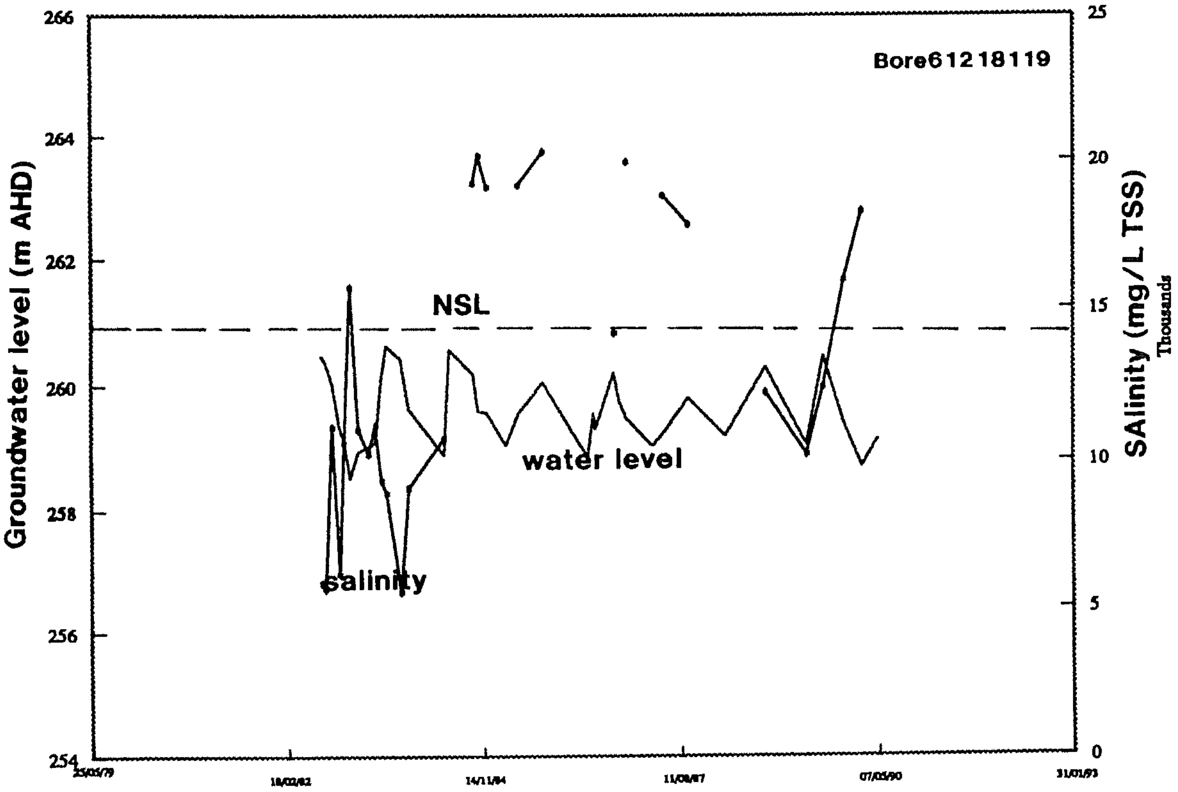

Bore61218107
NSL
water level
salinity
Groundwater level (m AHD)
SAlinity (mg/L TSS)
Thousands
260
258
256
254
252
250
25
20
15
10
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93

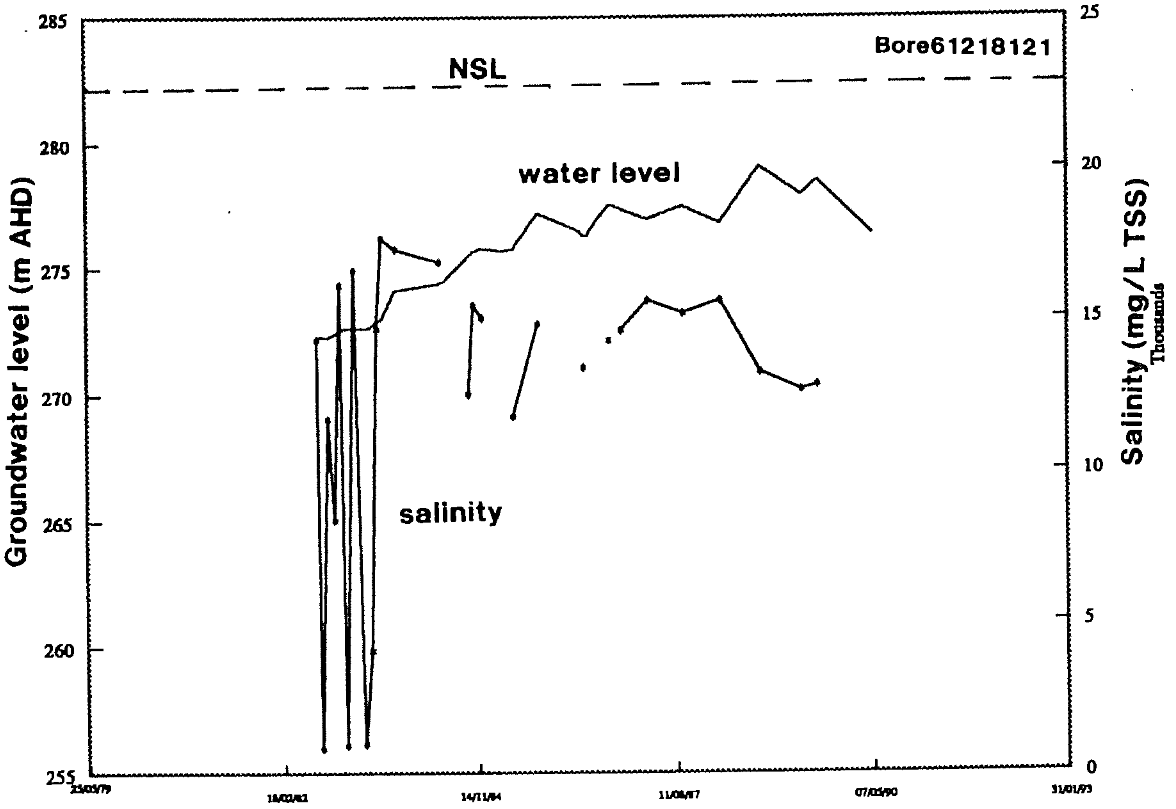

Bore61218112
water level
NSL
salinity
Groundwater level (m AHD)
260
258
256
254
252
250
Salinity (mg/L TSS)
Thousands
25
20
15
10
23/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93


Bore61218113
NSL
water level
salinity
Groundwater level (m AHD)
260
255
250
245
240
Salinity (mg/L TSS)
Thousands
25
20
15
10
23/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93


Bore61218115
NSL
water level
salinity
Groundwater level (m AHD)
Salinity (mg/L TSS)
Thousands
260
258
256
254
252
250
25
20
15
10
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93


Bore61218117
NSL
water level
salinity
Groundwater level (m AHD)
Salinity (mg/L TSS)
Thousands
270
265
260
255
250
25
20
15
10
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93


Bore61218119
NSL
water level
salinity
Groundwater level (m AHD)
SAlinity (mg/L TSS)
Thousands
266
264
262
260
258
256
254
25
20
15
10
5
0
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93


Bore61218121
NSL
water level
salinity
Groundwater level (m AHD)
Salinity (mg/L TSS)
Thousands
285
280
275
270
265
260
255
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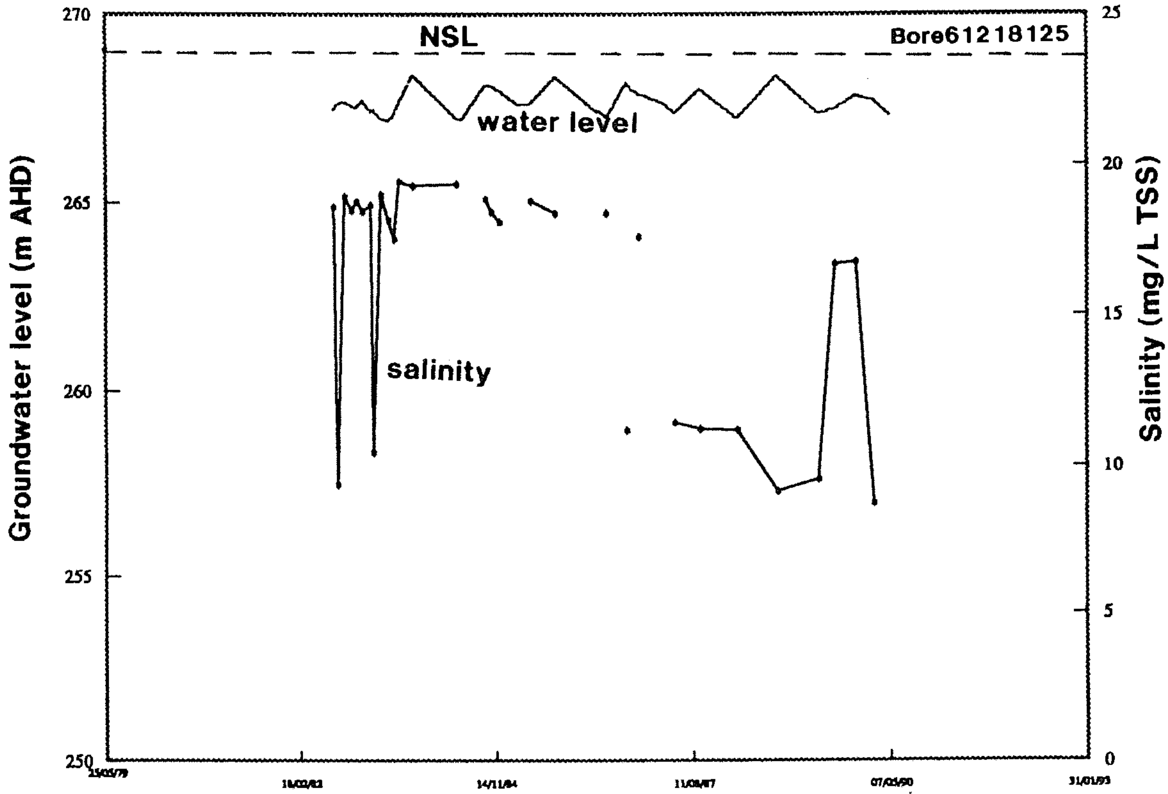
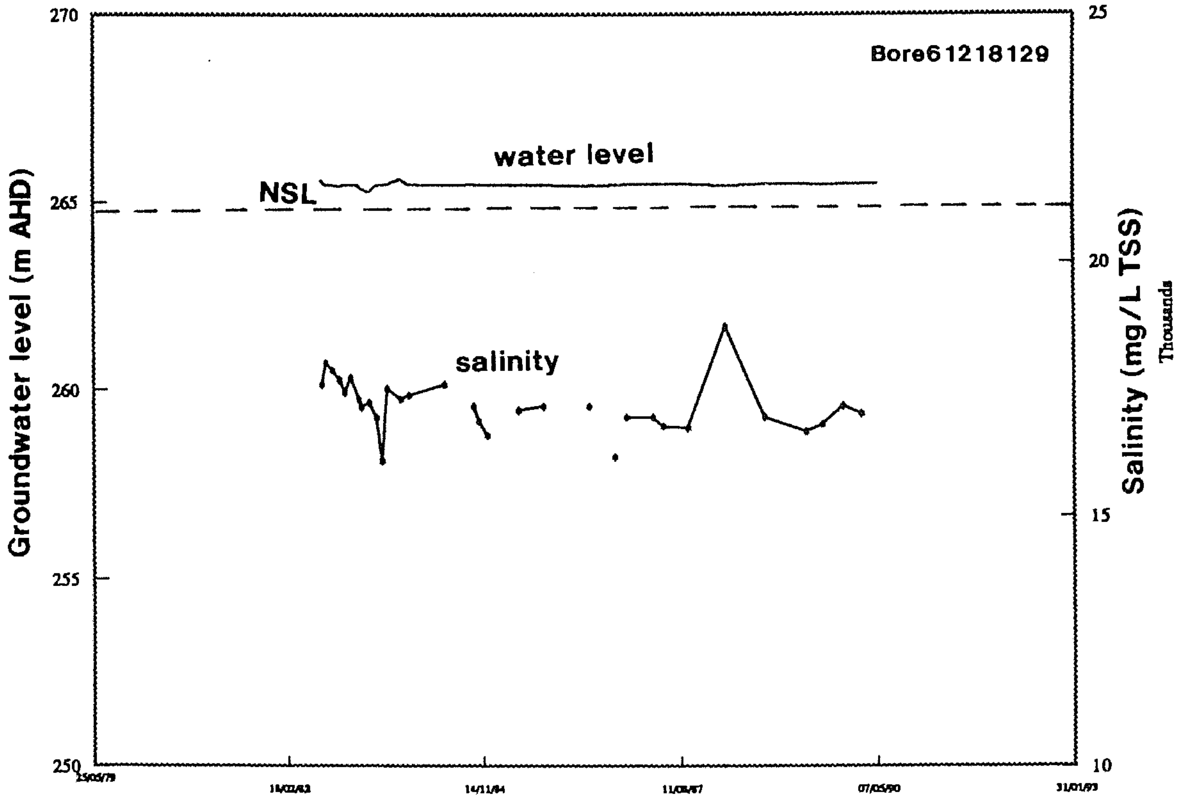
20
15
10
5
0
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93


NSL
Bore61218125
water level
salinity
Groundwater level (m AHD)
270
265
260
255
250
Salinity (mg/L TSS)
Thousands
25
20
15
10
5
0
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93


Bore61218129
water level
NSL
salinity
Groundwater level (m AHD)
270
265
260
255
250
Salinity (mg/L TSS)
Thousands
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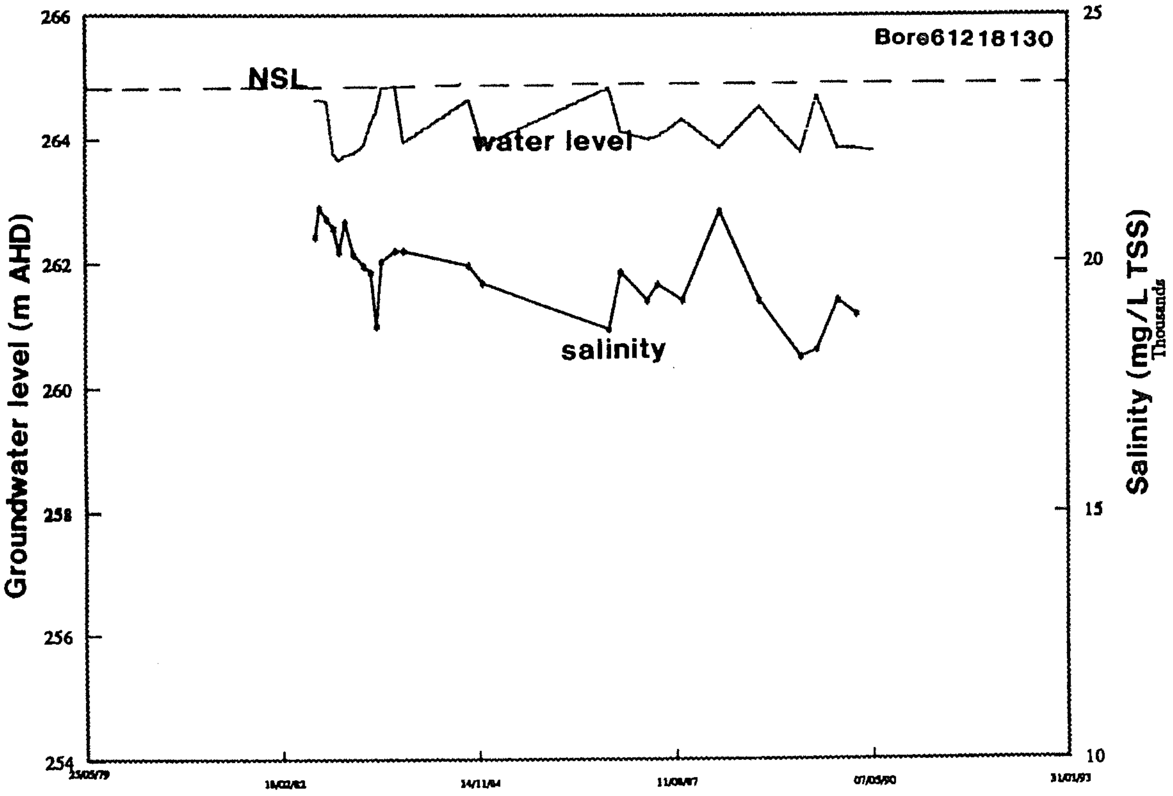
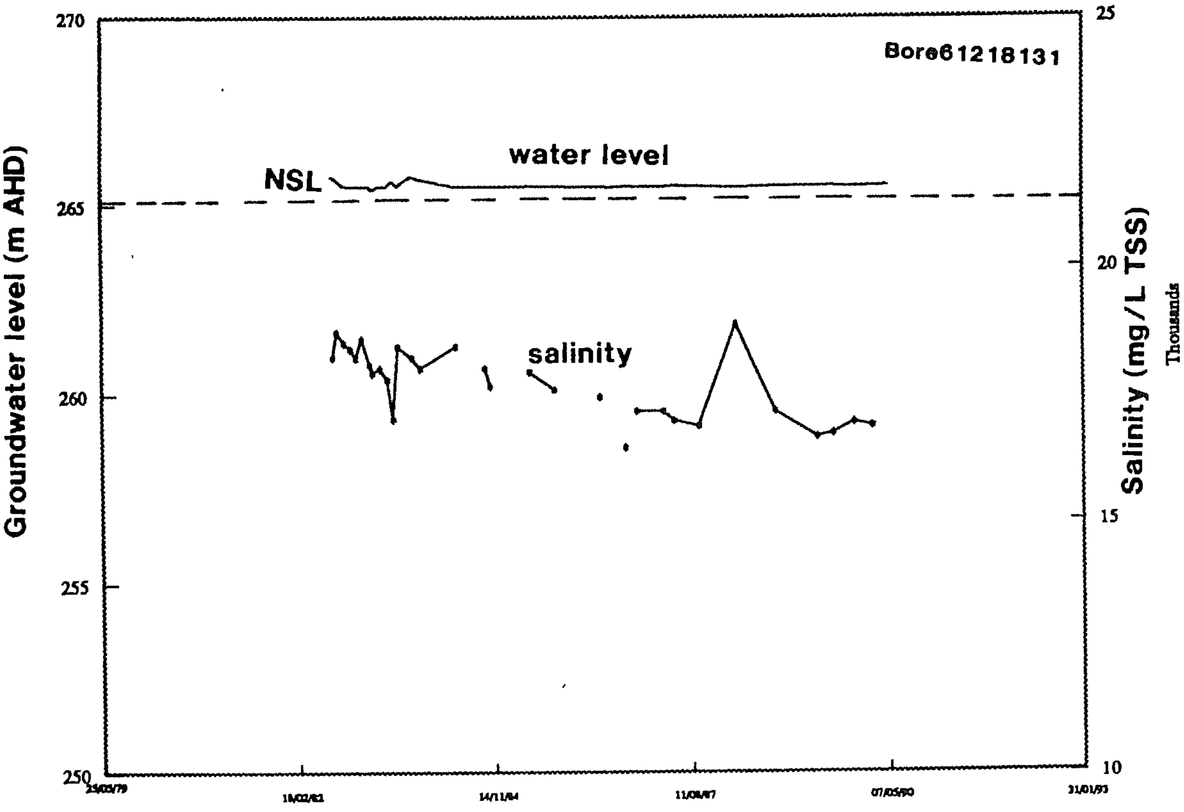
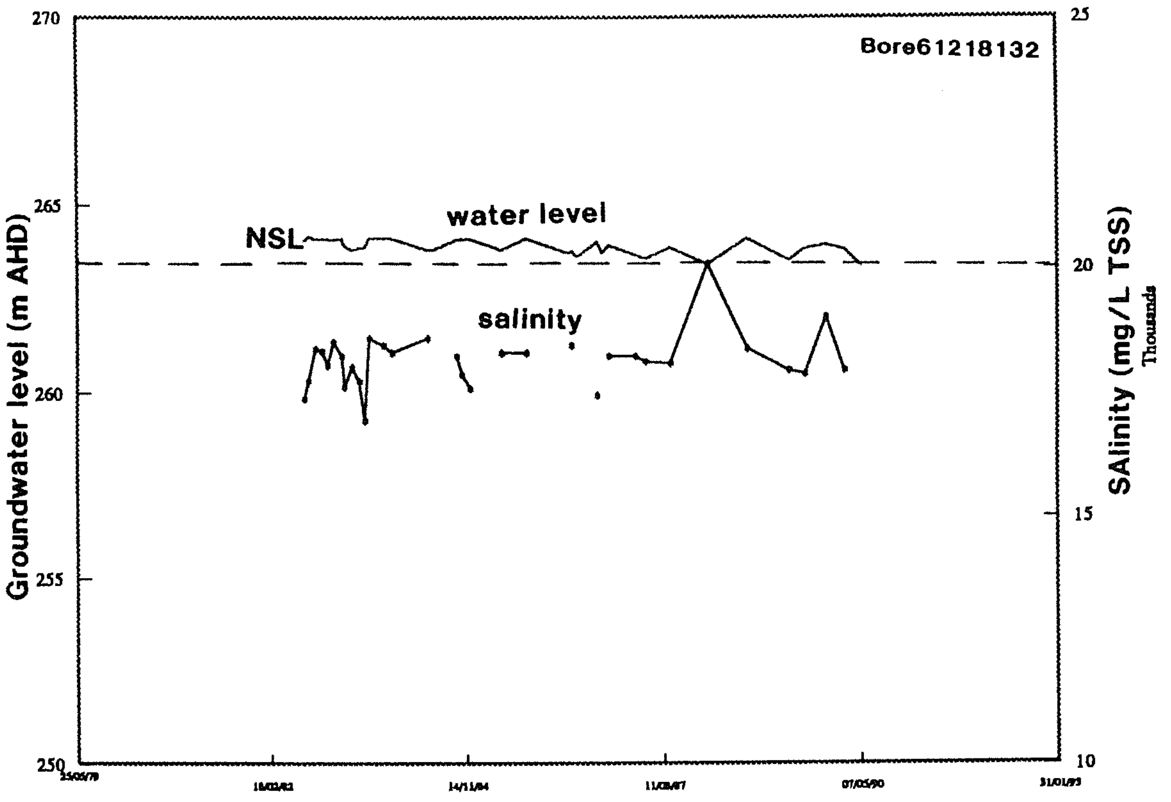
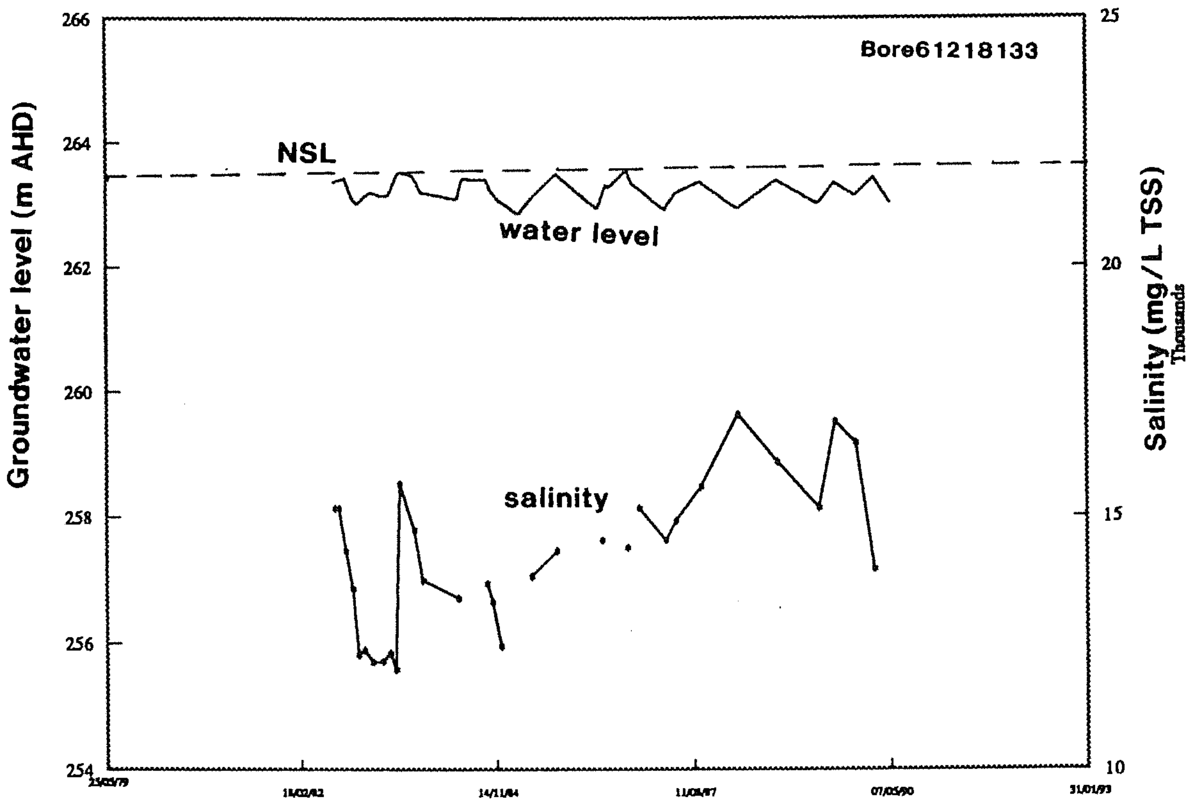
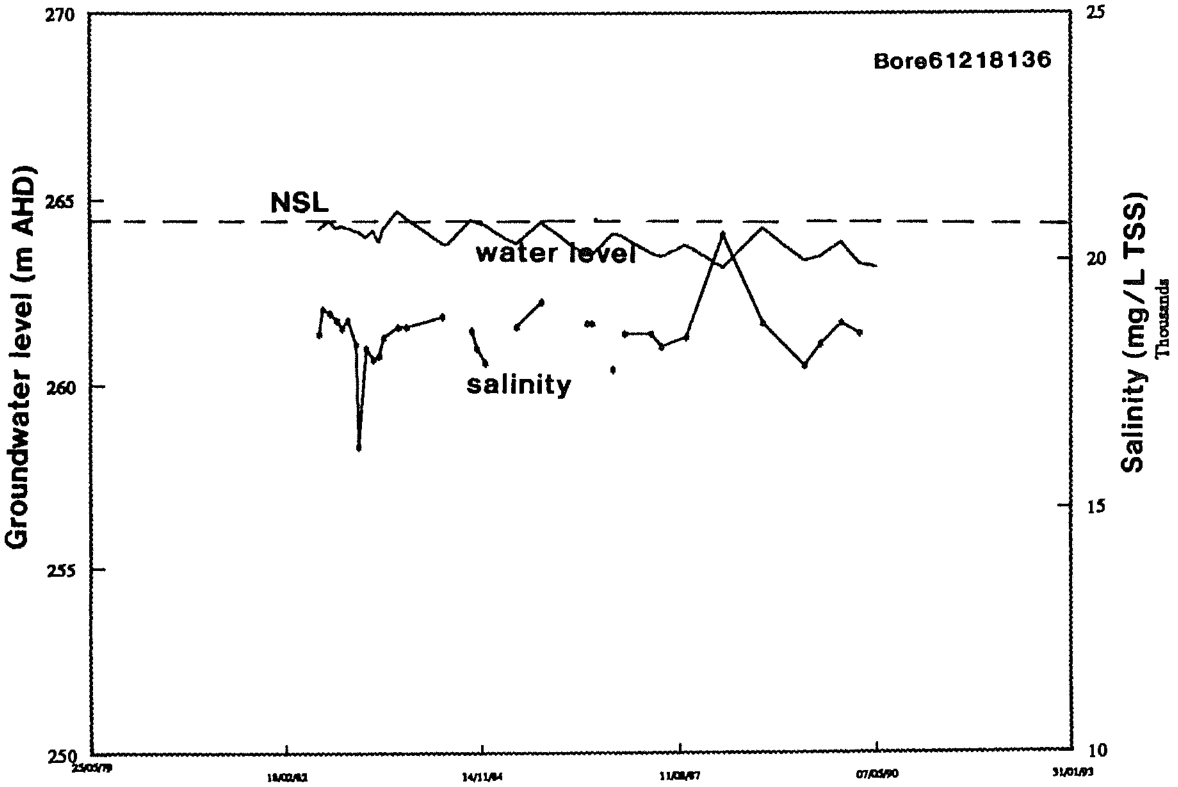
20
15
10
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93

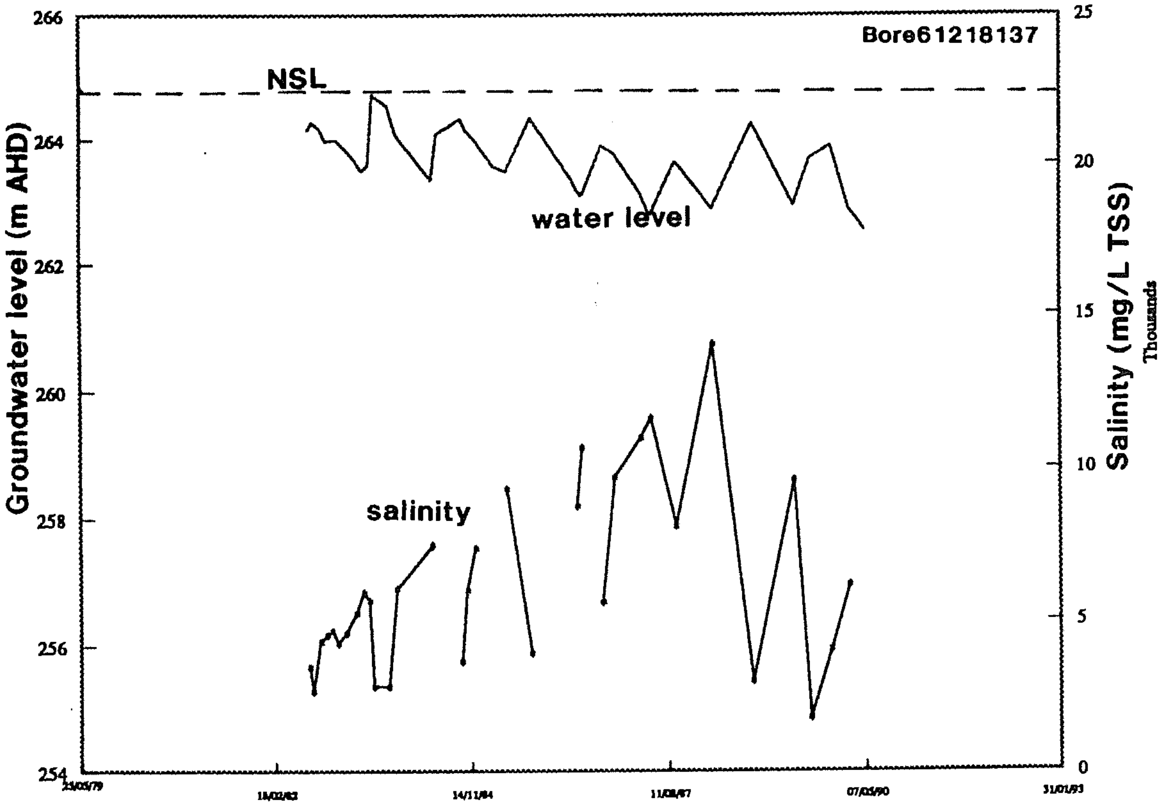

Bore61218130
NSL
water level
salinity
Groundwater level (m AHD)
Salinity (mg/L TSS)
Thousands
266
264
262
260
258
256
254
25
20
15
10
23/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93

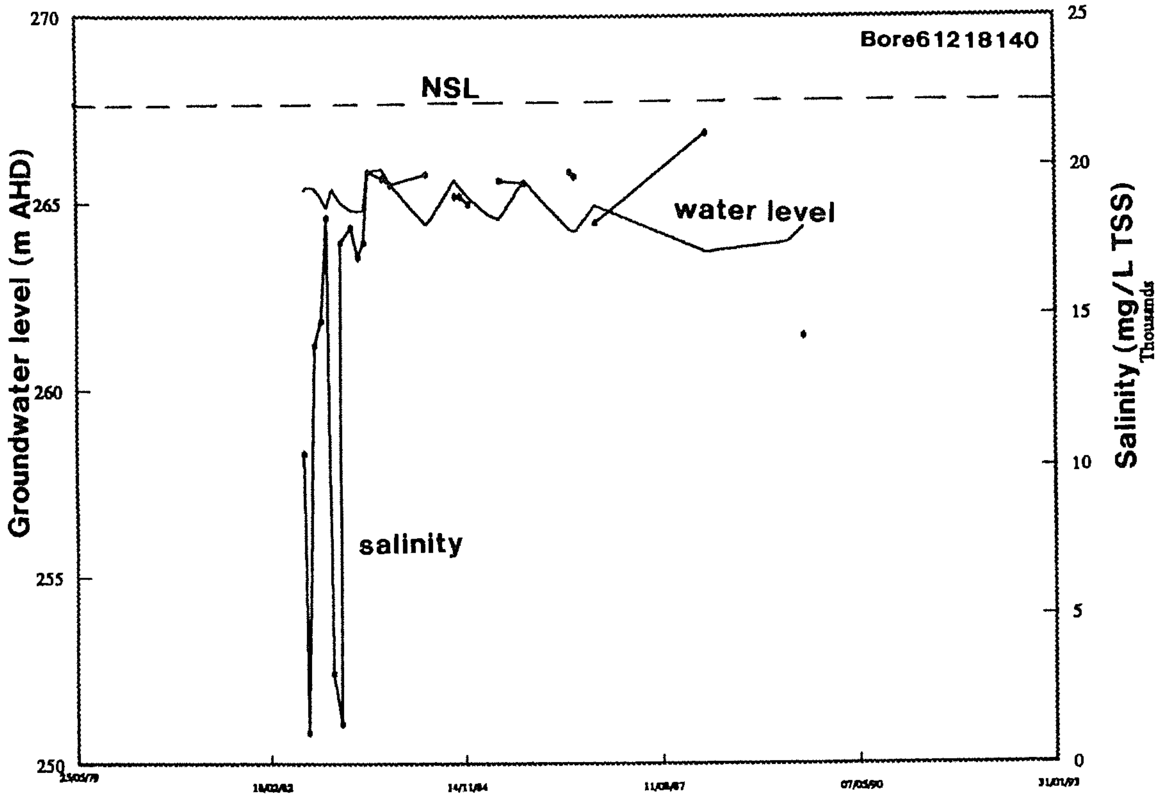

Bore61218131
water level
NSL
salinity
Groundwater level (m AHD)
Salinity (mg/L TSS)
Thousands
270
265
260
255
250
25
20
15
10
23/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93

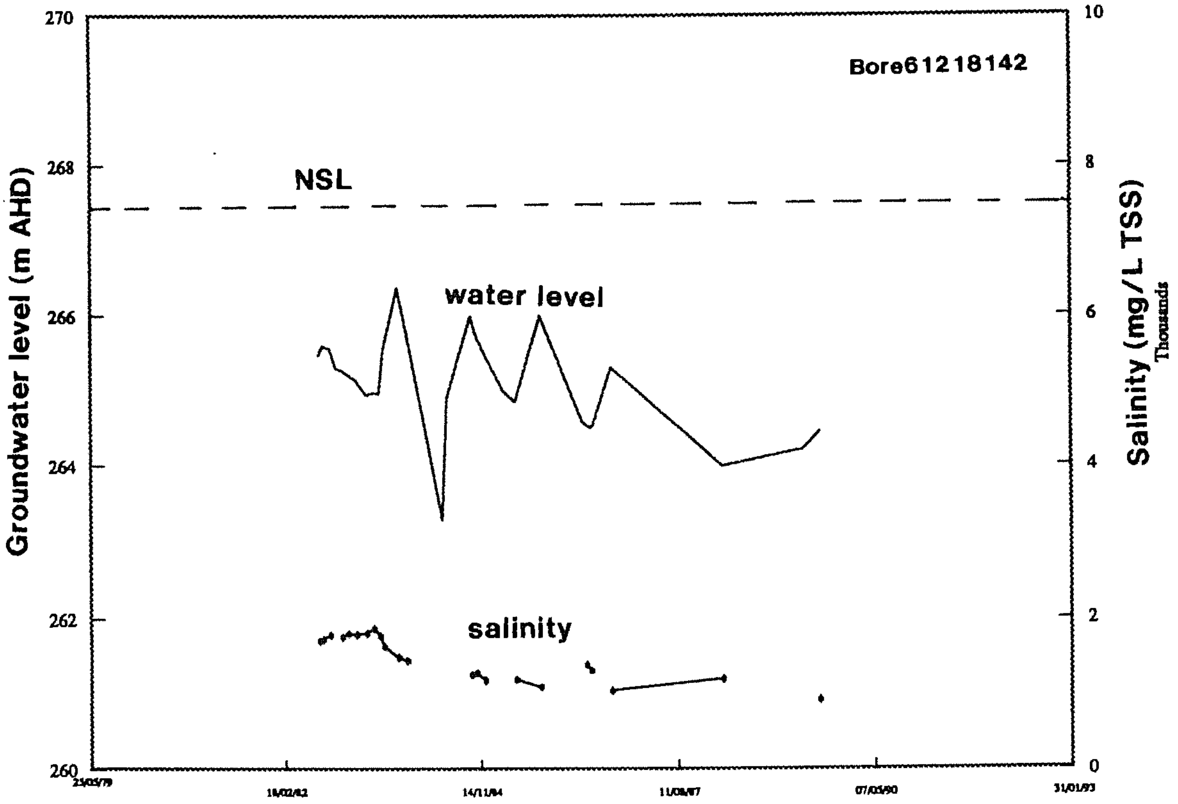

Bore61218132
Groundwater level (m AHD)
270
265
260
255
250
SAlinity (mg/L TSS)
Thousands
25
20
15
10
NSL
water level
salinity
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93

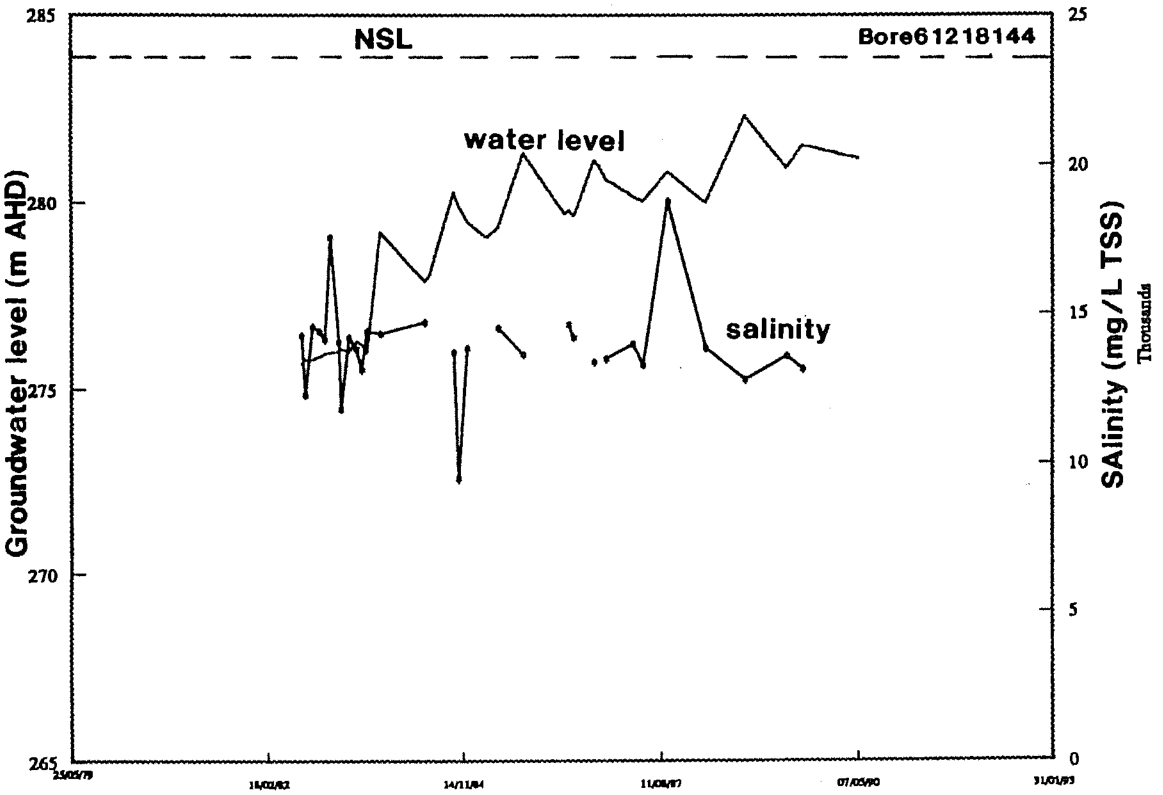

Bore61218133
Groundwater level (m AHD)
266
264
262
260
258
256
254
Salinity (mg/L TSS)
Thousands
25
20
15
10
NSL
water level
salinity
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93

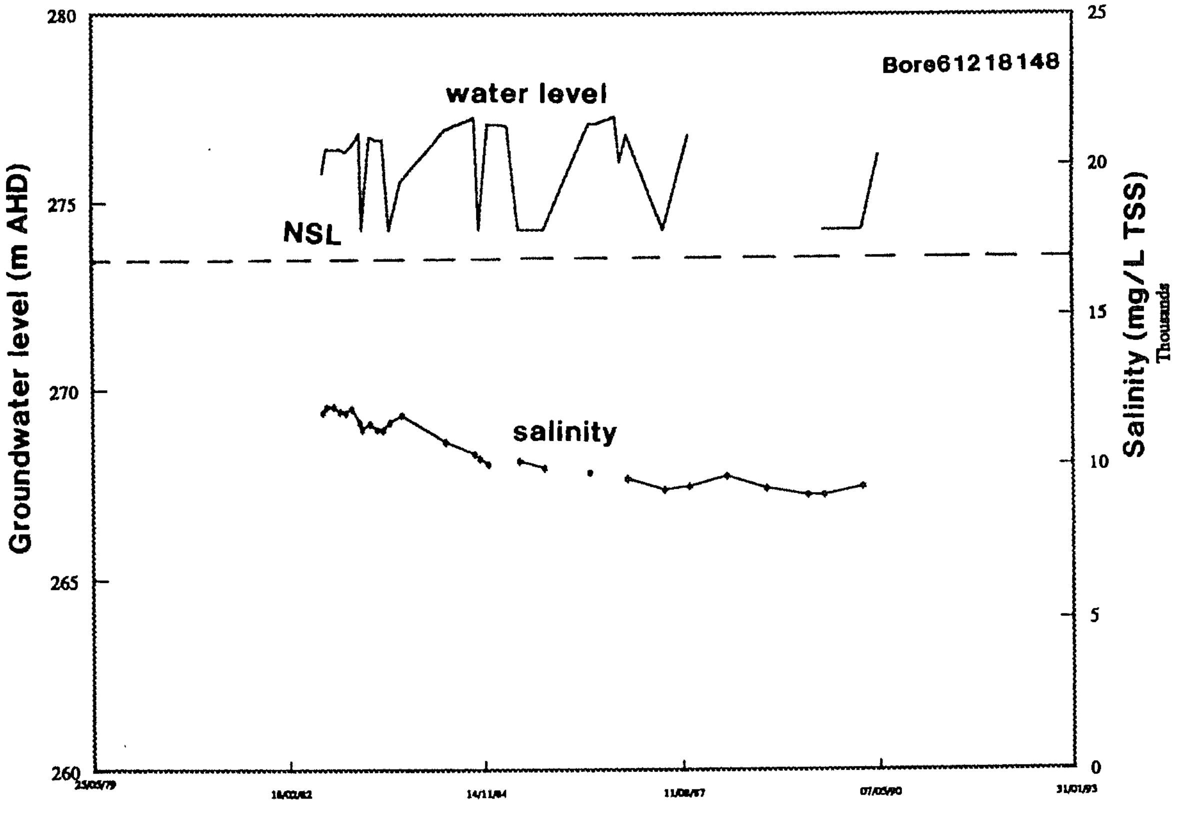

Bore61218136
270
265
260
255
250
25
20
15
10
NSL
water level
salinity
Groundwater level (m AHD)
Salinity (mg/L TSS)
Thousands
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93

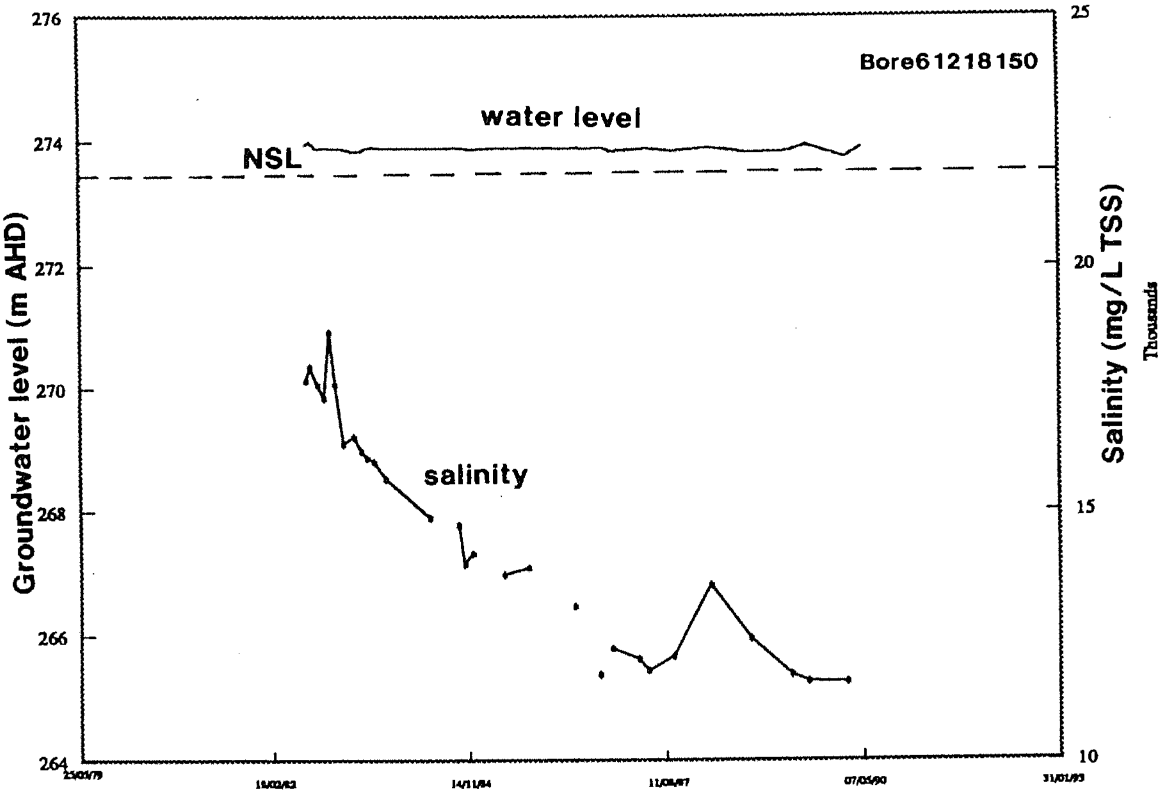

Bore61218137
266
264
262
260
258
256
254
25
20
15
10
5
0
NSL
water level
salinity
Groundwater level (m AHD)
Salinity (mg/L TSS)
Thousands
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93


Bore61218140
NSL
water level
salinity
Groundwater level (m AHD)
Salinity (mg/L TSS) Thousands
270
265
260
255
250
25
20
15
10
5
0
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93


Bore61218142
NSL
water level
salinity
Groundwater level (m AHD)
Salinity (mg/L TSS) Thousands
270
268
266
264
262
260
10
8
6
4
2
0
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93


NSL
Bore61218144
water level
salinity
Groundwater level (m AHD)
SAlinity (mg/L TSS)
Thousands
285
280
275
270
265
25
20
15
10
5
0
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93


Bore61218148
water level
NSL
salinity
Groundwater level (m AHD)
Salinity (mg/L TSS)
Thousands
280
275
270
265
260
25
20
15
10
5
0
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93


Bore61218150
water level
NSL
salinity
Groundwater level (m AHD)
276
274
272
270
268
266
264
Salinity (mg/L TSS)
Thousands
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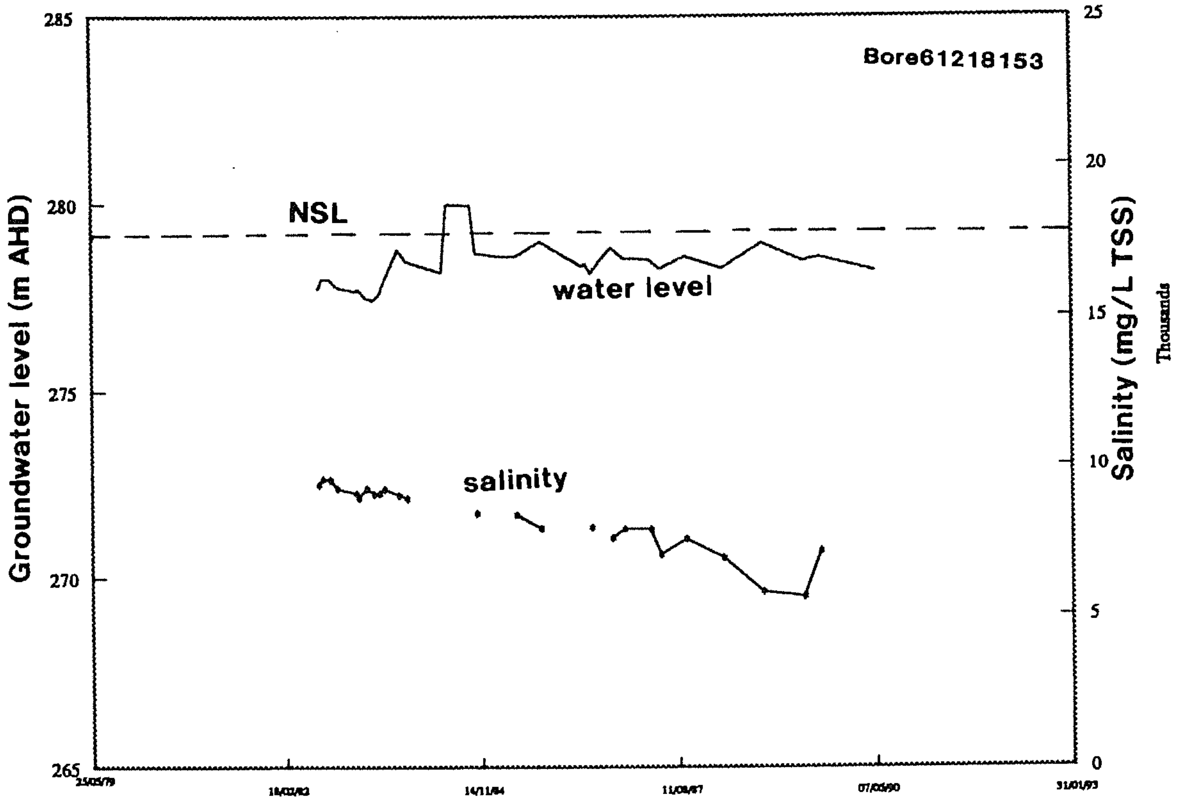
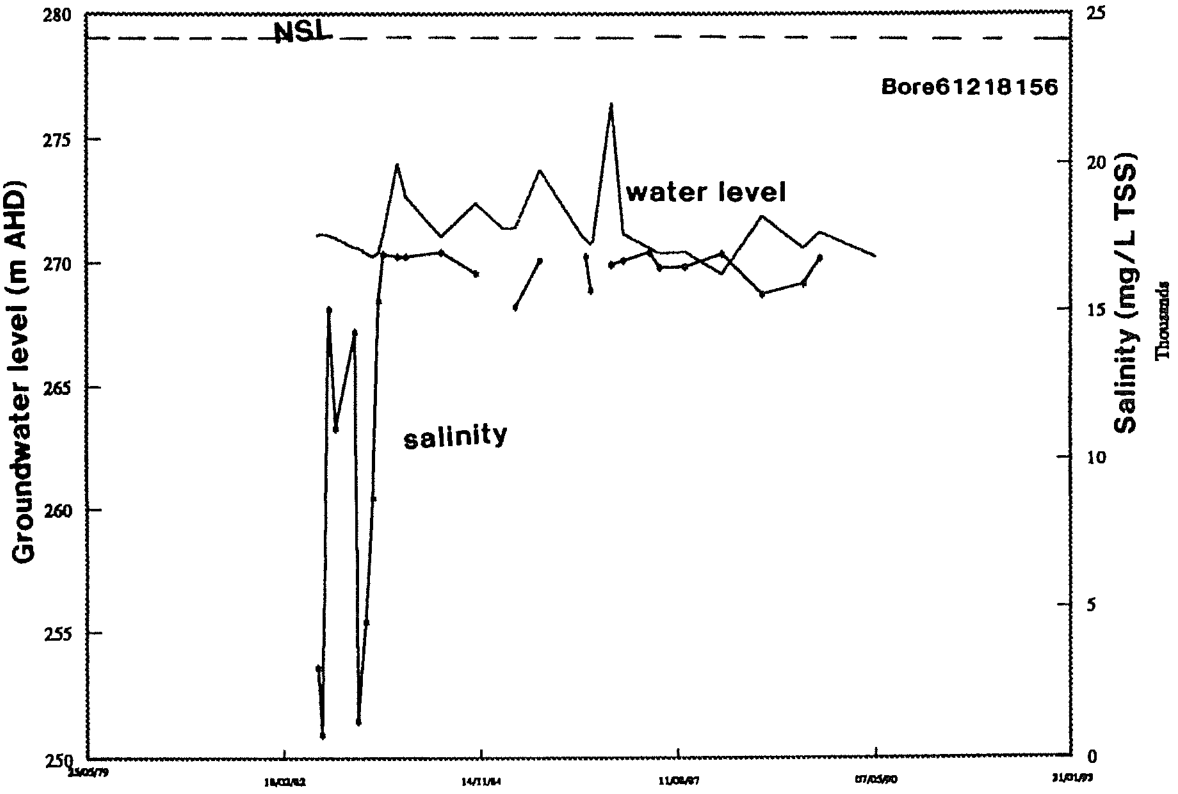
15
10
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93


Bore61218153
NSL
water level
salinity
Groundwater level (m AHD)
285
280
275
270
265
Salinity (mg/L TSS)
Thousands
25
20
15
10
5
0
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93


NSL
Bore61218156
water level
salinity
Groundwater level (m AHD)
Salinity (mg/L TSS)
Thousands
280
275
270
265
260
255
250
25
20
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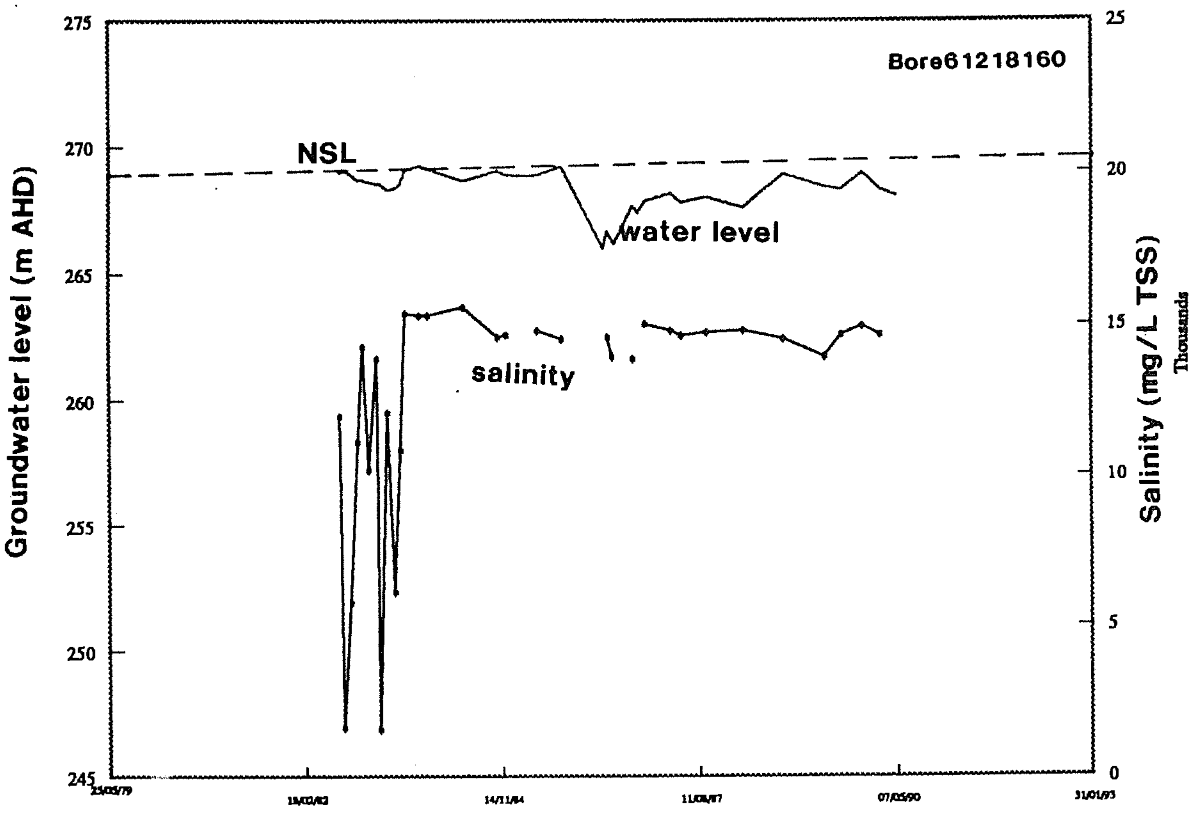
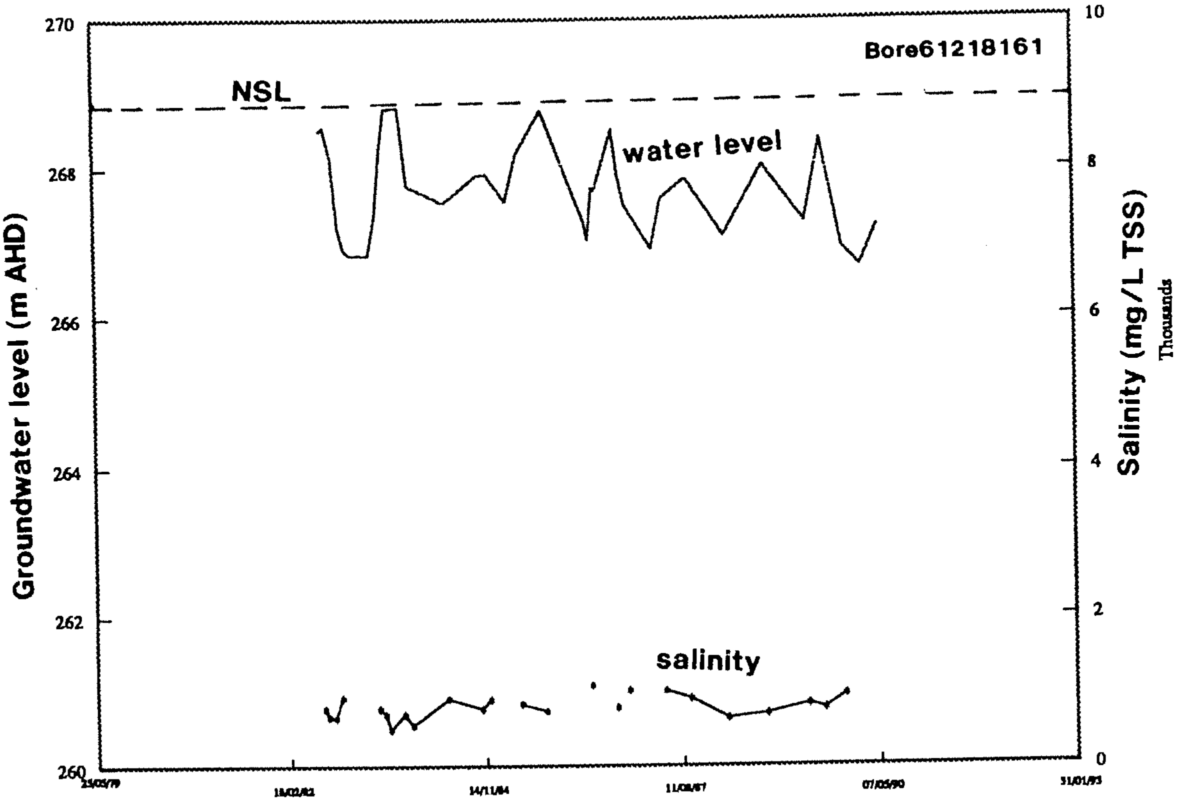
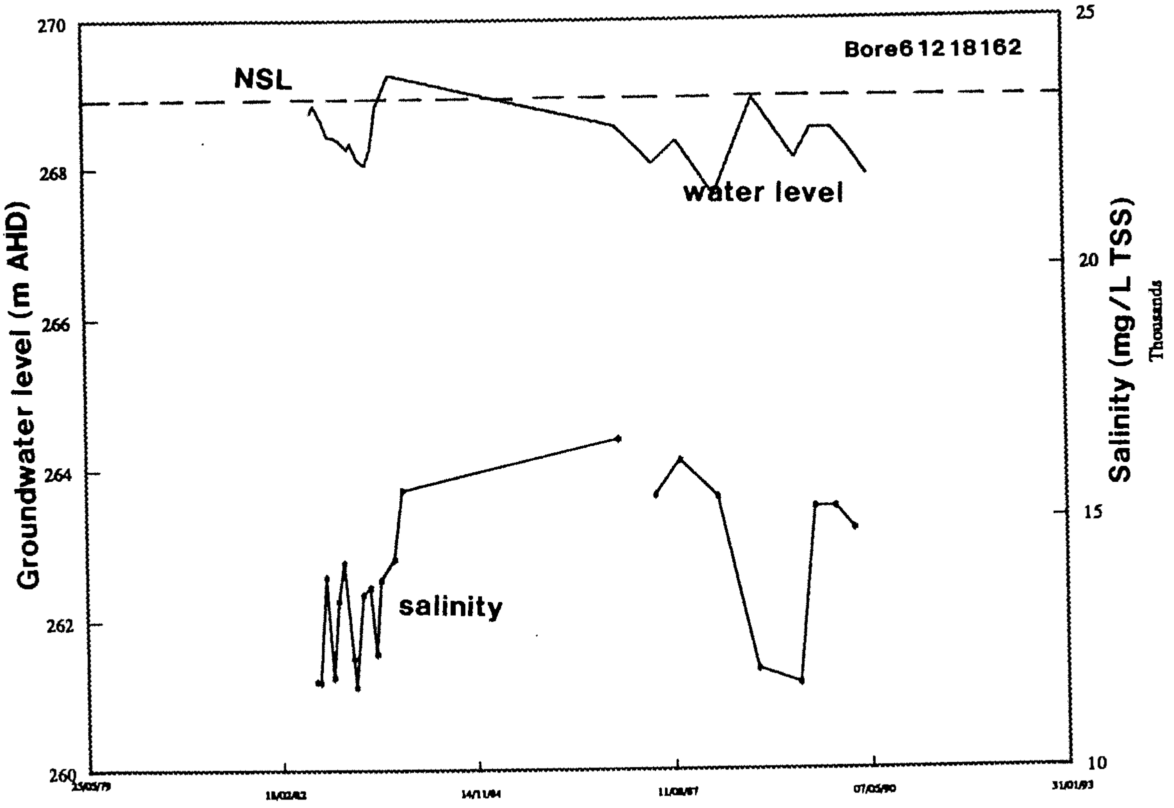
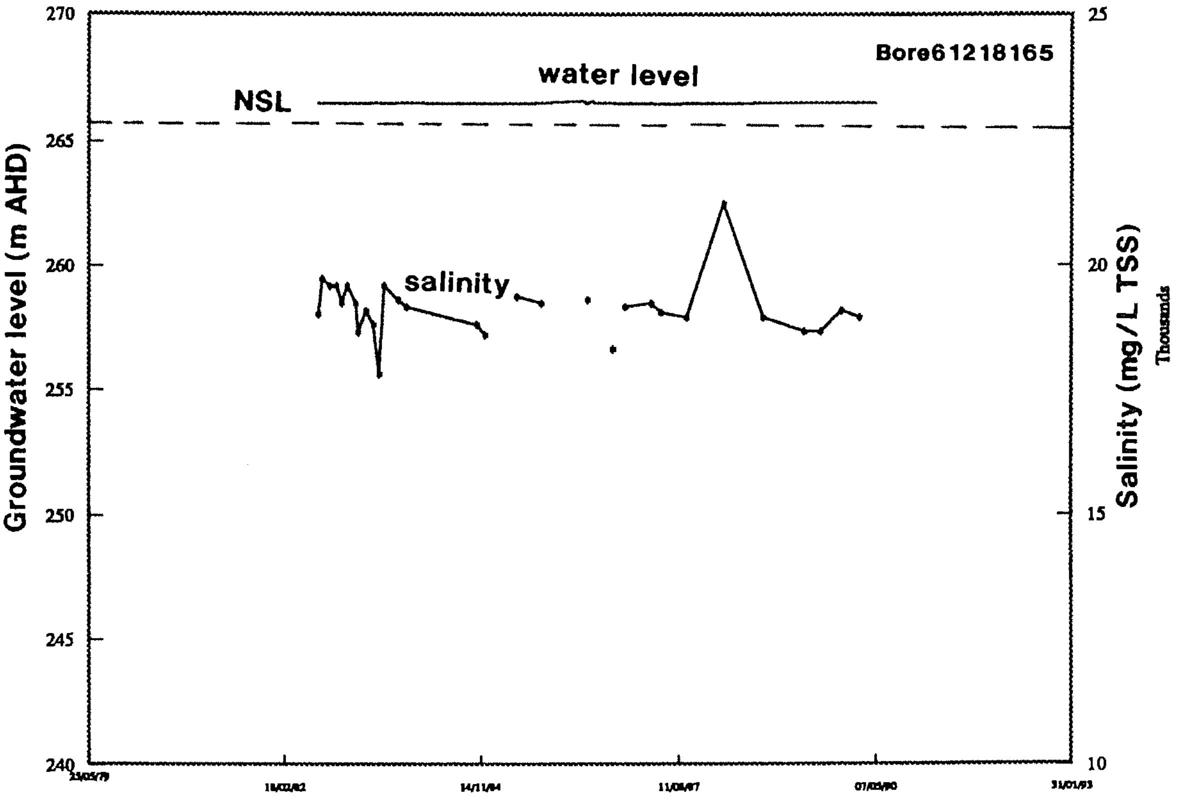
10
5
0
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93


Bore61218160
NSL
water level
salinity
Groundwater level (m AHD)
Salinity (mg/L TSS)
Thousands
275
270
265
260
255
250
245
25
20
15
10
5
0
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93


Bore61218161
NSL
water level
salinity
Groundwater level (m AHD)
Salinity (mg/L TSS)
Thousands
270
268
266
264
262
260
10
8
6
4
2
0
23/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93


Bore61218162
NSL
water level
salinity
Groundwater level (m AHD)
Salinity (mg/L TSS)
Thousands
270
268
266
264
262
260
25
20
15
10
23/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93


Bore61218165
water level
NSL
salinity
Groundwater level (m AHD)
270
265
260
255
250
245
240
Salinity (mg/L TSS)
Thousands
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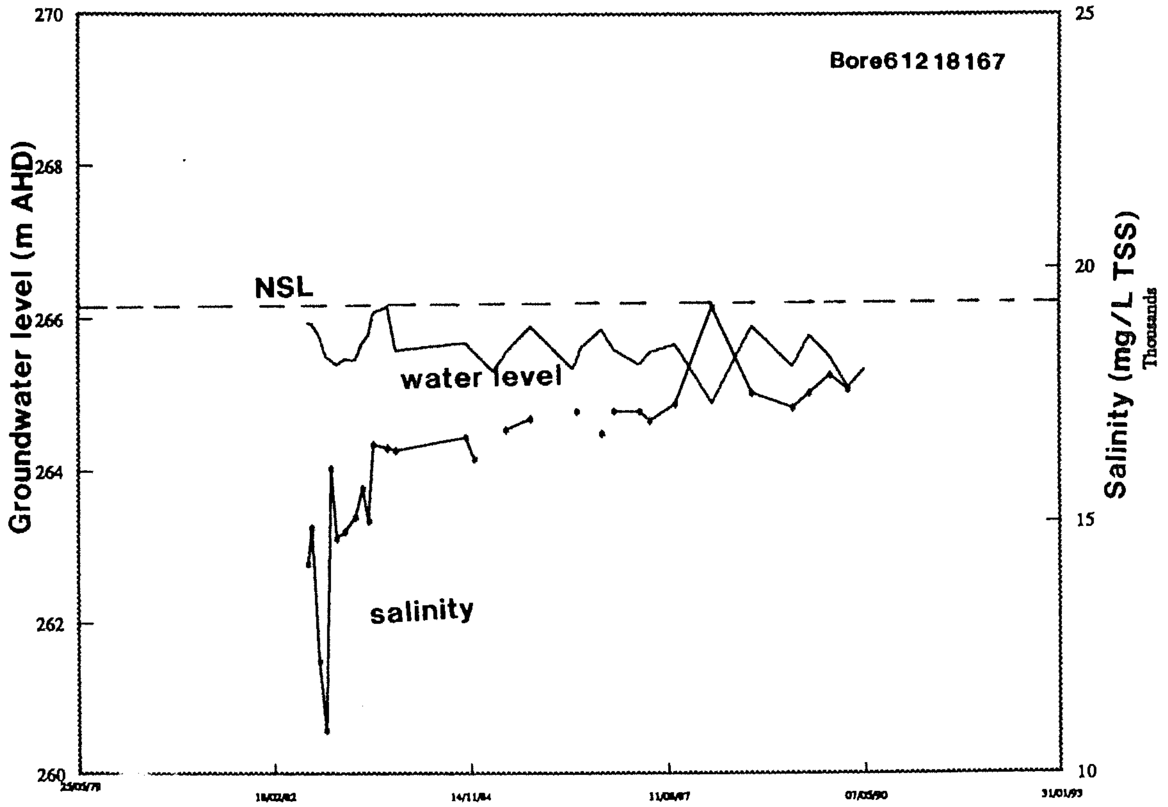
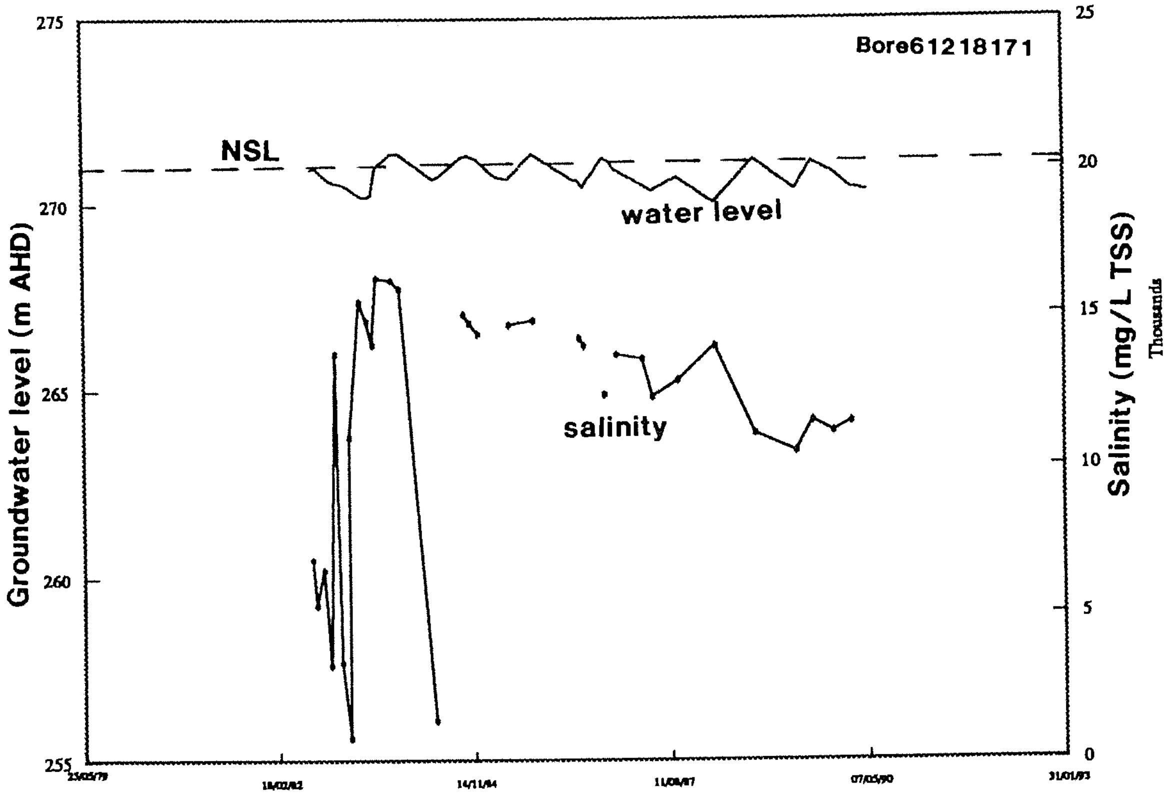
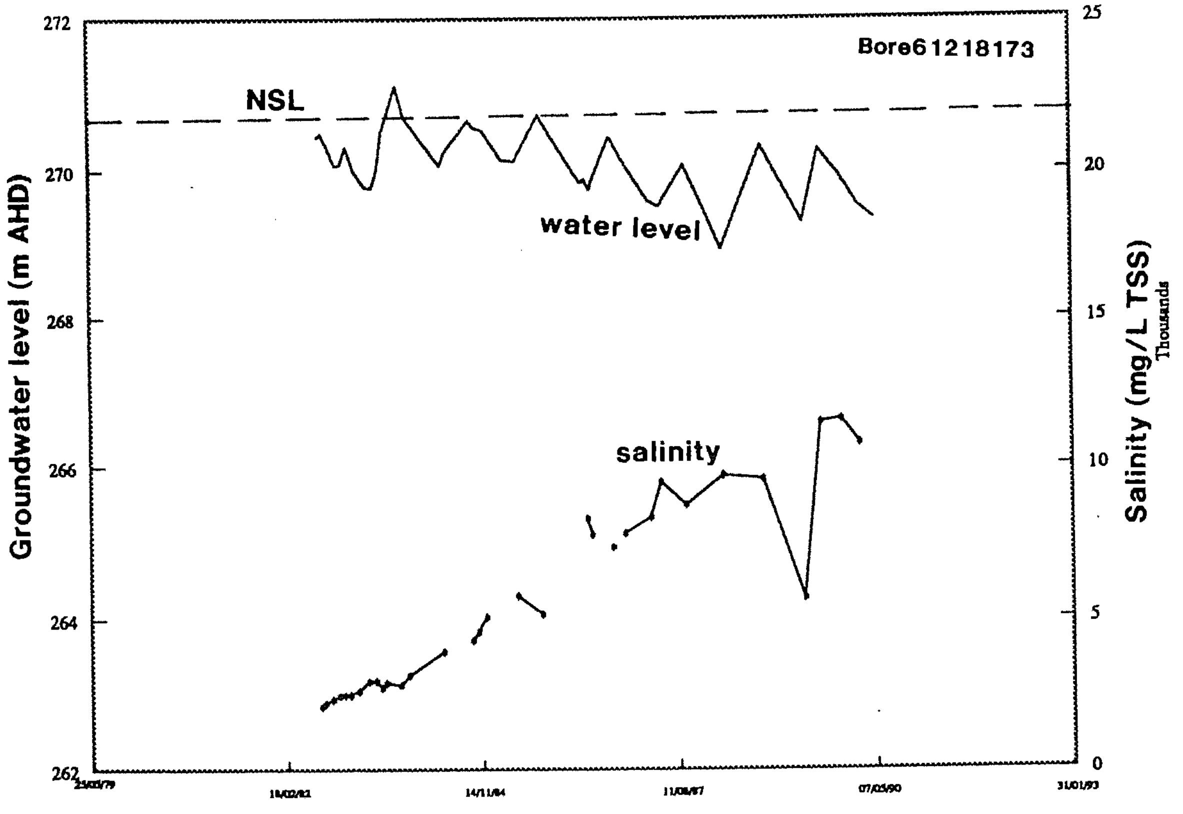
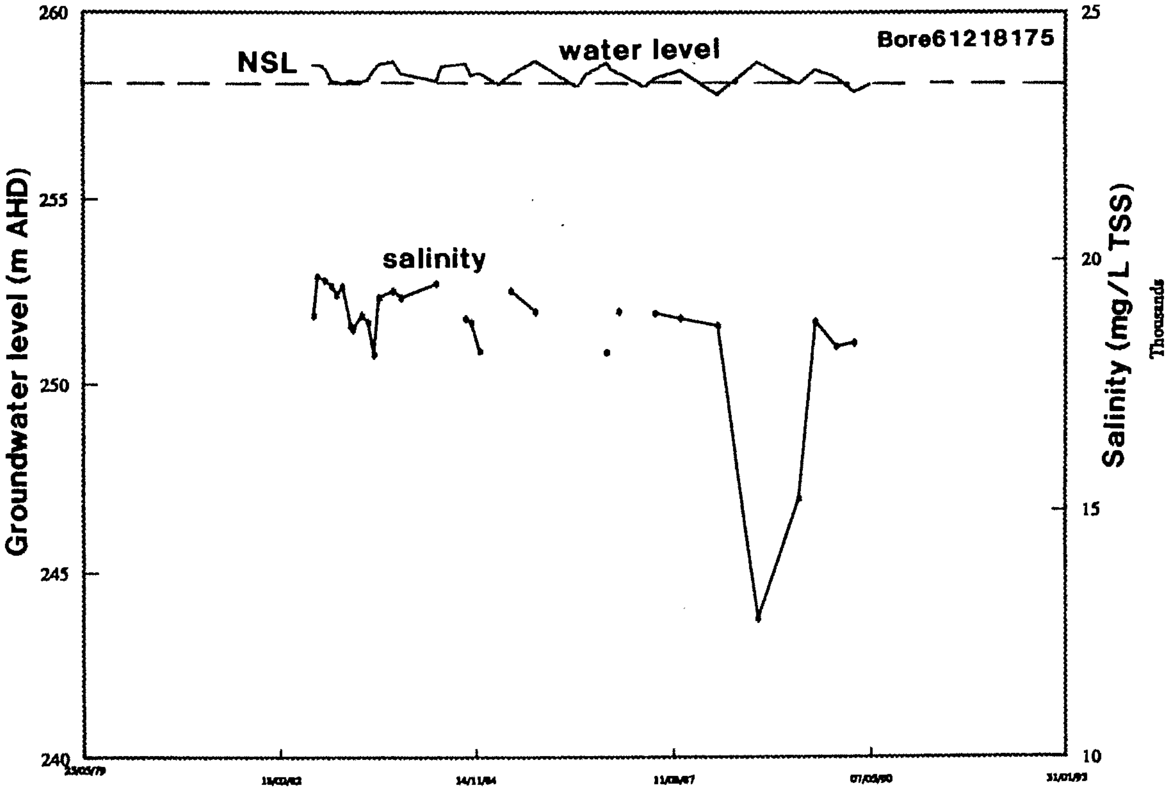
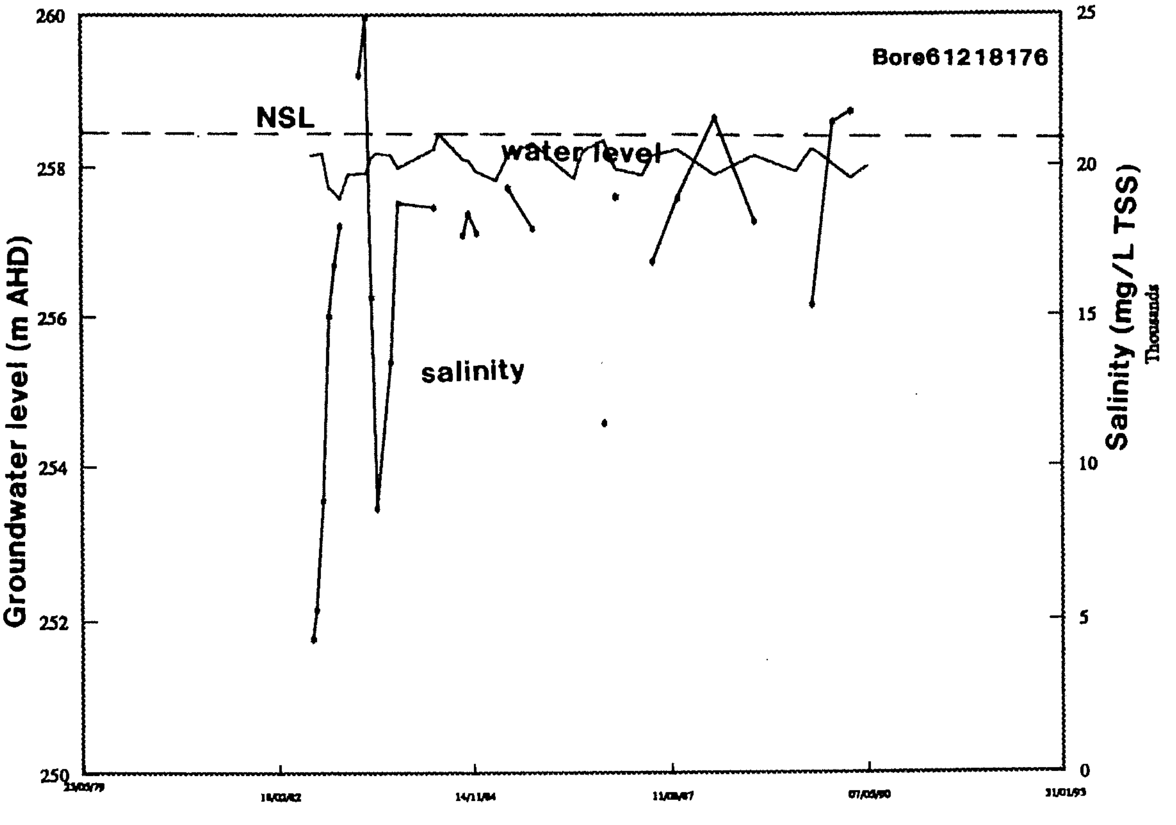
20
15
10
23/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93


Bore61218167
NSL
water level
salinity
Groundwater level (m AHD)
270
268
266
264
262
260
Salinity (mg/L TSS)
Thousands
25
20
15
10
23/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93


Bore61218171
NSL
water level
salinity
Groundwater level (m AHD)
Salinity (mg/L TSS)
Thousands
275
270
265
260
255
25
20
15
10
5
0
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93


Bore61218173
NSL
water level
salinity
Groundwater level (m AHD)
Salinity (mg/L TSS)
Thousands
272
270
268
266
264
262
25
20
15
10
5
0
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93


Bore61218175
NSL
water level
salinity
Groundwater level (m AHD)
Salinity (mg/L TSS)
Thousands
260
255
250
245
240
25
20
15
10
23/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93


Bore61218176
NSL
water level
salinity
Groundwater level (m AHD)
Salinity (mg/L TSS)
Thousands
260
258
256
254
252
250
25
20
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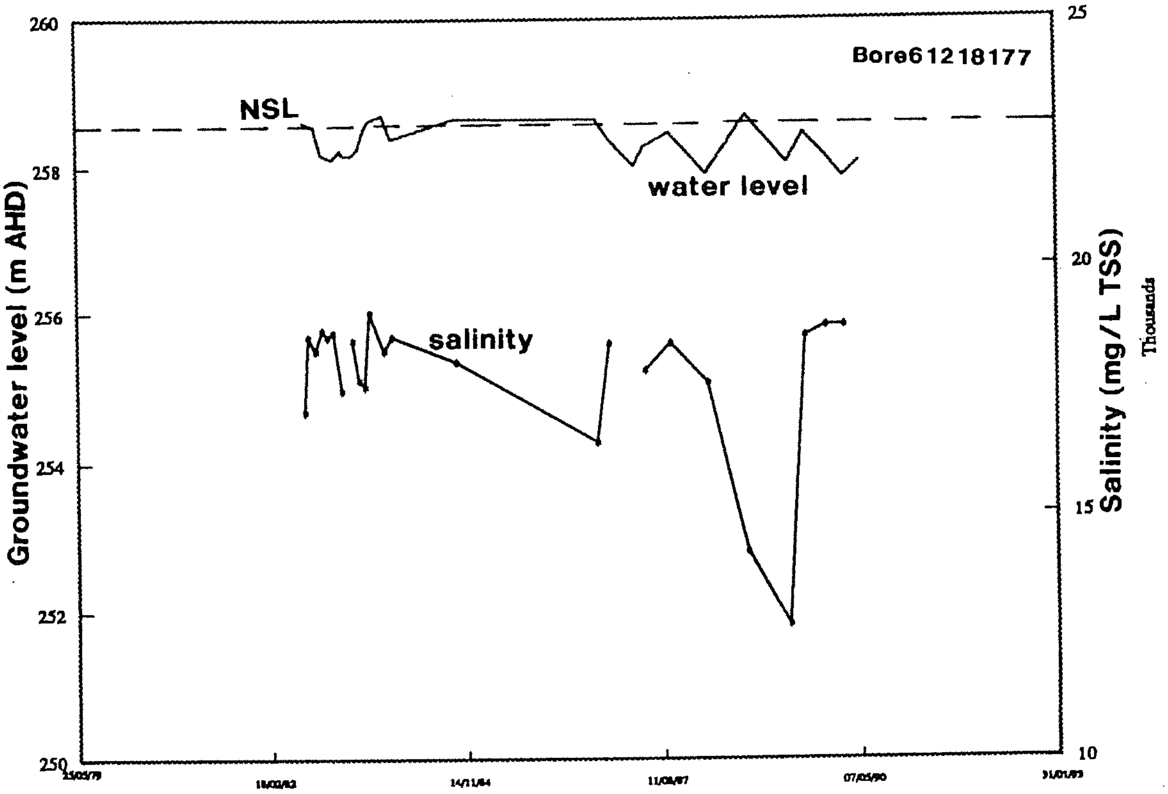
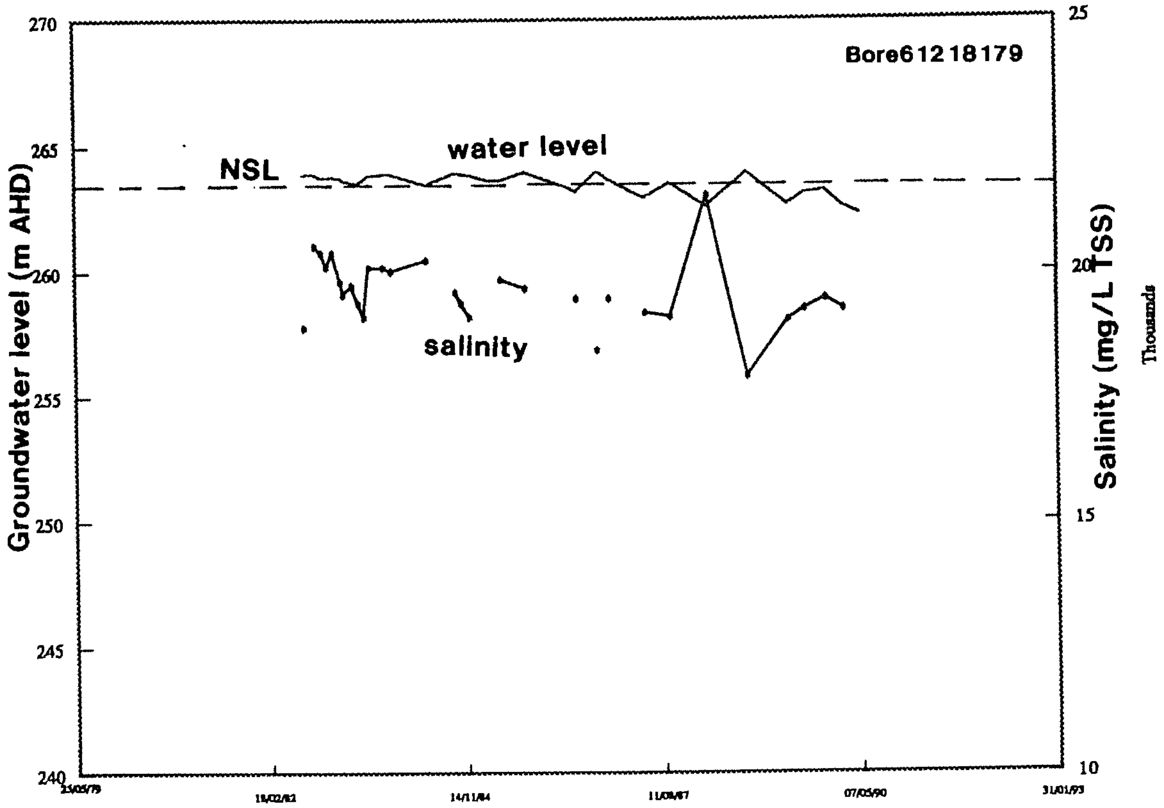
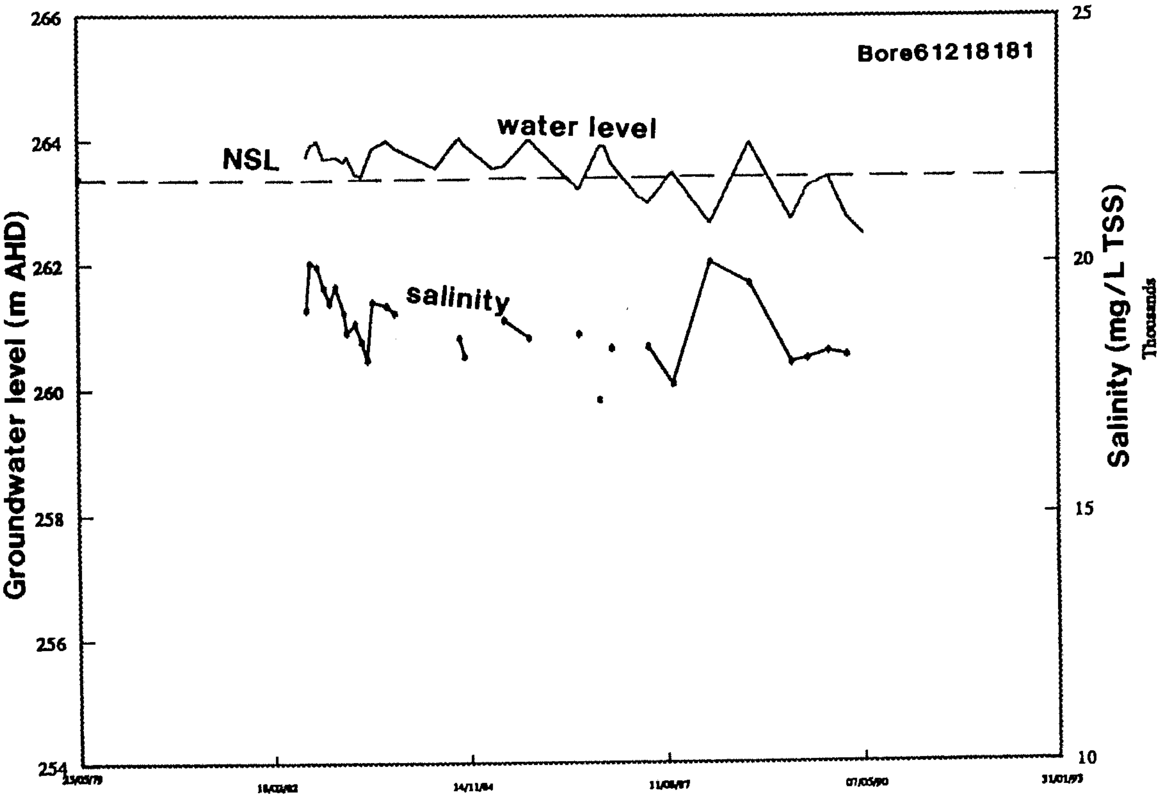
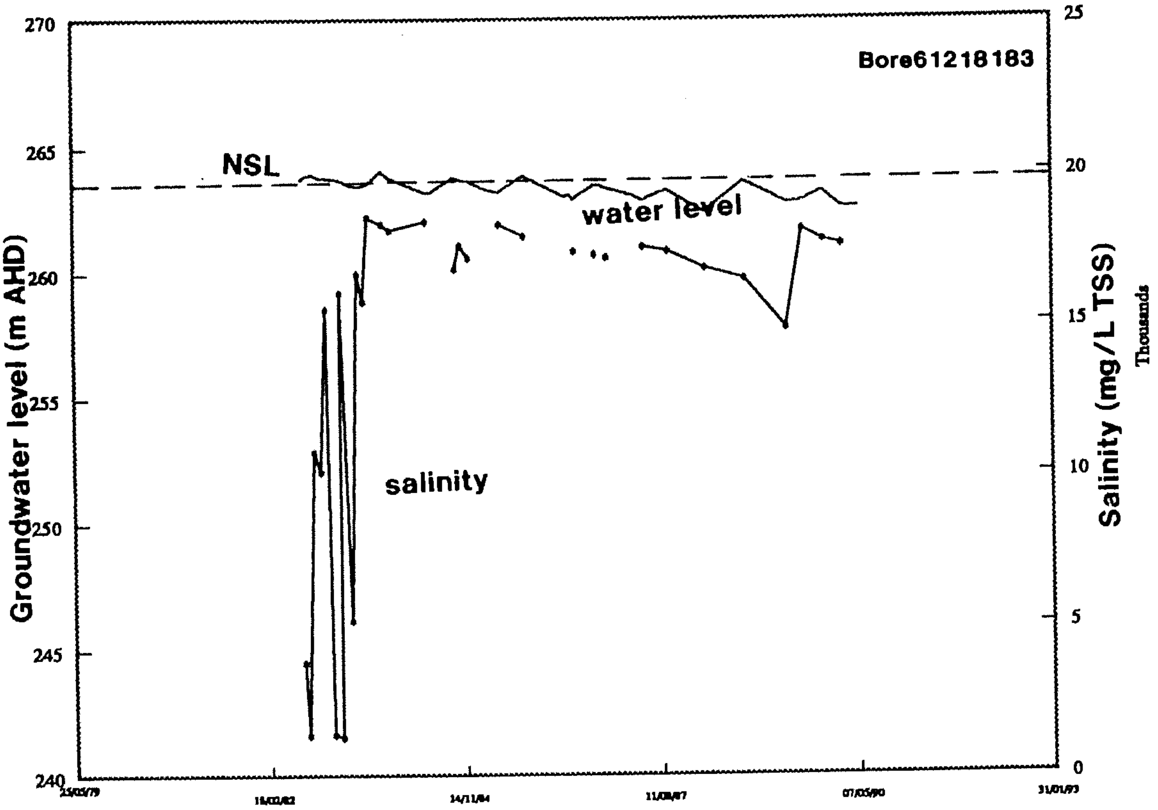
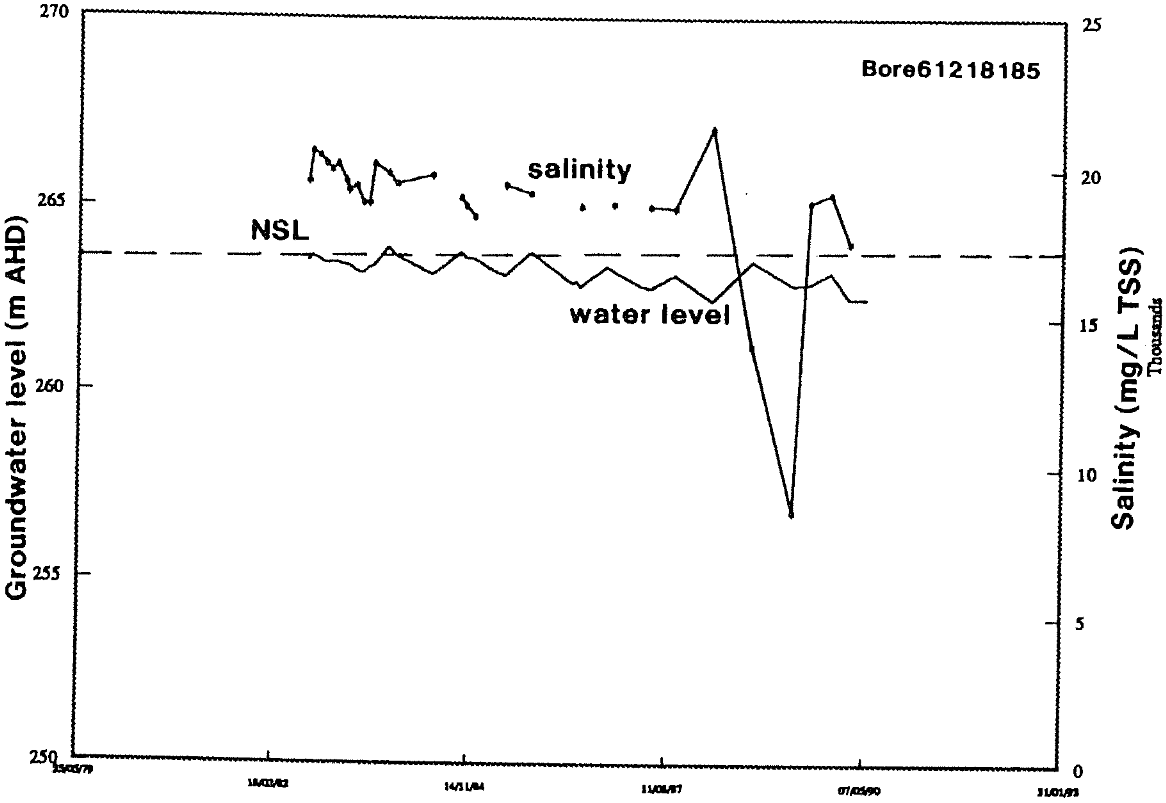
5
0
23/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93


Bore61218177
NSL
water level
salinity
Groundwater level (m AHD)
260
258
256
254
252
250
Salinity (mg/L TSS)
Thousands
25
20
15
10
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93


Bore61218179
water level
NSL
salinity
Groundwater level (m AHD)
270
265
260
255
250
245
240
Salinity (mg/L TSS)
Thousands
25
20
15
10
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93


Bore61218181
water level
NSL
salinity
Groundwater level (m AHD)
Salinity (mg/L TSS)
Thousands
266
264
262
260
258
256
254
25
20
15
10
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93


Bore61218183
NSL
water level
salinity
Groundwater level (m AHD)
Salinity (mg/L TSS)
Thousands
270
265
260
255
250
245
240
25
20
15
10
5
0
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93


Bore61218185
salinity
NSL
water level
Groundwater level (m AHD)
Salinity (mg/L TSS)
Thousands
270
265
260
255
250
25
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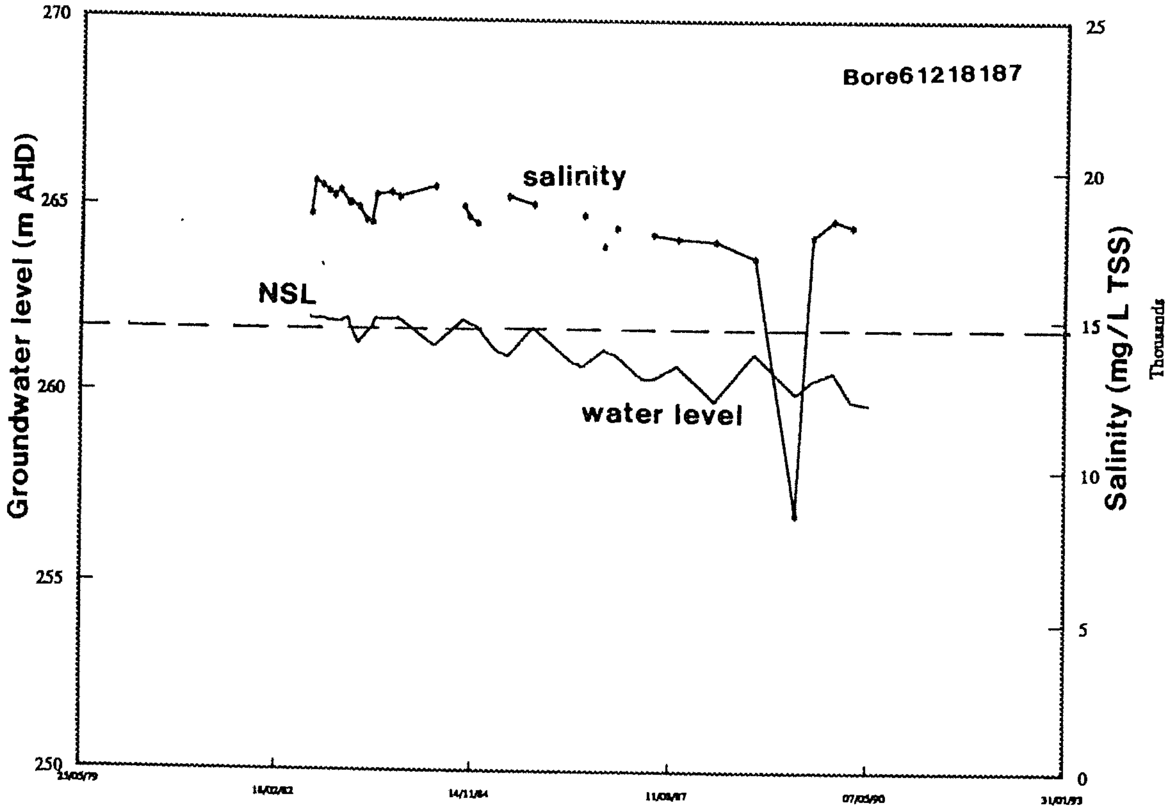
5
0
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93


Bore61218187
salinity
NSL
water level
Groundwater level (m AHD)
Salinity (mg/L TSS)
Thousands
270
265
260
255
250
25
20
15
10
5
0
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93

APPENDIX F

ANNUAL MINIMUM AND MAXIMUM GROUNDWATER LEVELS

PASTURE AND REFORESTED BORES

Annual minimum groundwater level (m AHD) of all pasture bores

Bore No.	1983	1984	1985	1986	1987	1988	1989	1990
G61218121	272.601	274.401	275.681	276.261	276.911	276.761	277.901	276.341
G61218144	275.985	277.895	279.075	279.645	280.015	279.995	280.925	281.195
G61218153	277.449	278.189	278.619	278.159	278.279	278.309	278.499	278.229

Annual minimum groundwater level (m AHD) of all reforested bores

Bore No.	1983	1984	1985	1986	1987	1988	1989	1990
G61218107	258.359	258.659	258.619	258.609	258.409	258.209	258.319	258.159
G61218112	256.957	257.647	257.467	257.447	257.357	257.297	257.387	257.377
G61218115	257.418	257.248	257.248	257.168	257.128	257.018	257.218	257.018
G61218125	267.174	267.224	267.614	267.294	267.394	267.244	267.384	267.334
G61218130	263.740	263.890	263.890	264.130	264.000	263.850	263.790	263.800
G61218133	263.119	263.069	262.849	262.939	262.919	262.939	263.009	263.029
G61218136	263.860	263.790	263.815	263.490	263.440	263.140	263.330	263.160
G61218175	258.096	258.176	258.086	258.026	258.016	257.826	258.086	257.876
G61218181	263.421	263.556	263.556	263.196	262.976	262.646	262.706	262.466
G61218185	263.190	263.180	263.160	262.870	262.820	262.490	262.910	262.560
G61218187	261.331	261.281	261.031	260.731	260.411	259.831	260.031	259.741

Annual maximum groundwater level (m AHD) of all pasture bores

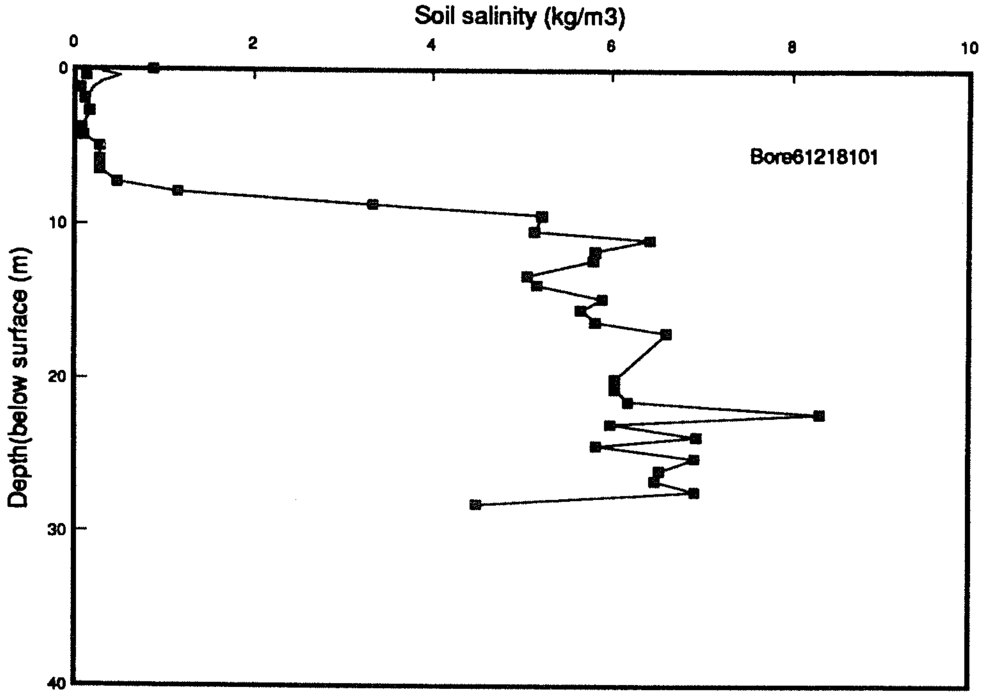
Bore No.	1983	1984	1985	1986	1987	1988	1989	1990
G61218121	274.111	275.781	277.161	277.506	277.441	279.061	278.511	276.341
G61218144	279.195	280.265	281.345	281.140	280.835	282.305	281.545	281.195
G61218153	278.799	279.989	279.029	278.854	278.619	278.969	278.609	278.229

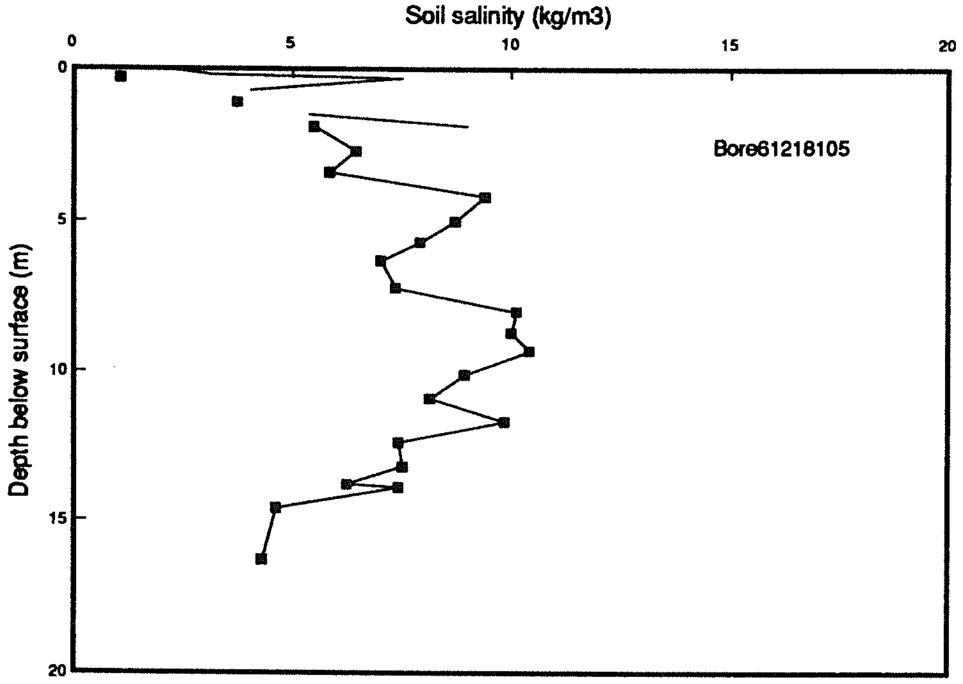
Annual maximum groundwater level (m AHD) of all reforested bores

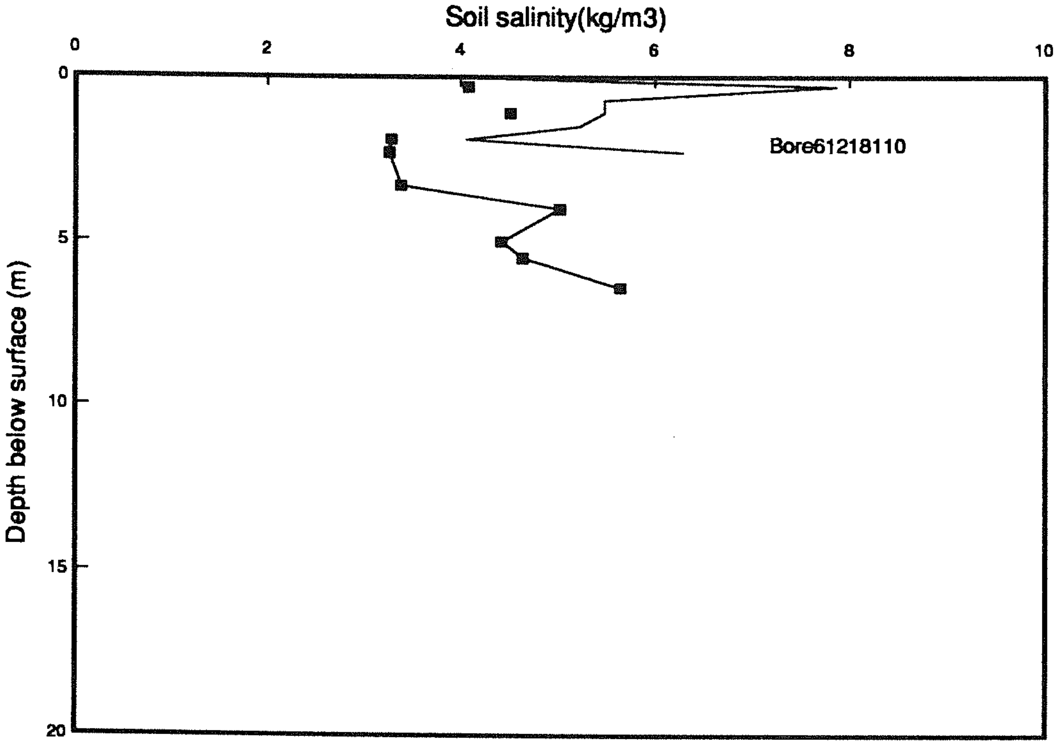
Bore No.	1983	1984	1985	1986	1987	1988	1989	1990
G61218107	258.929	258.939	258.937	258.919	258.925	258.909	258.909	258.229
G61218112	258.097	257.977	258.047	258.067	257.827	257.967	258.047	257.397
G61218115	258.177	258.008	258.098	258.068	257.798	258.048	258.018	257.208
G61218125	268.424	268.164	268.364	268.204	268.044	268.394	267.844	267.744
G61218130	264.850	264.630	264.630	264.830	264.320	264.520	264.700	263.850
G61218133	263.524	263.409	263.489	263.539	263.359	263.379	263.339	263.439
G61218136	264.690	264.460	264.395	264.040	263.770	264.210	263.840	263.240
G61218175	258.696	258.646	258.706	258.656	258.466	258.676	258.476	258.086
G61218181	263.997	264.046	264.016	263.896	263.476	263.956	263.396	262.746
G61218185	263.890	263.770	263.780	263.420	263.200	263.560	263.270	262.570
G61218187	262.011	261.991	261.781	261.211	260.791	261.121	260.631	259.831

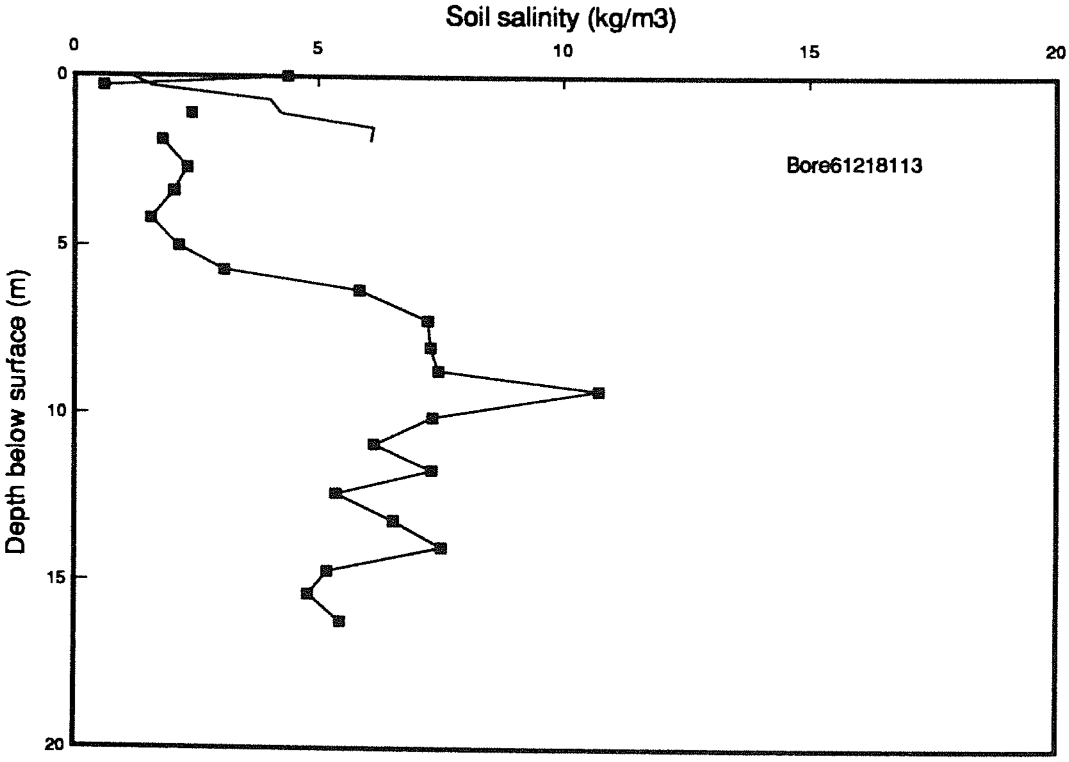
APPENDIX G

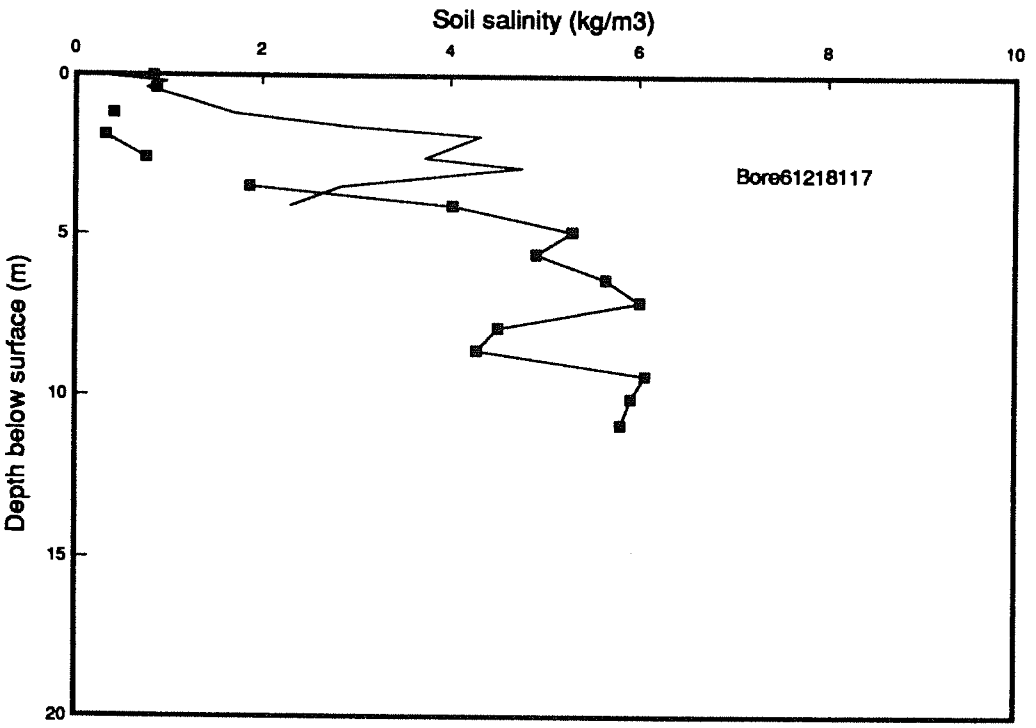
SOIL SALINITY PROFILES BETWEEN 1982 AND 1989

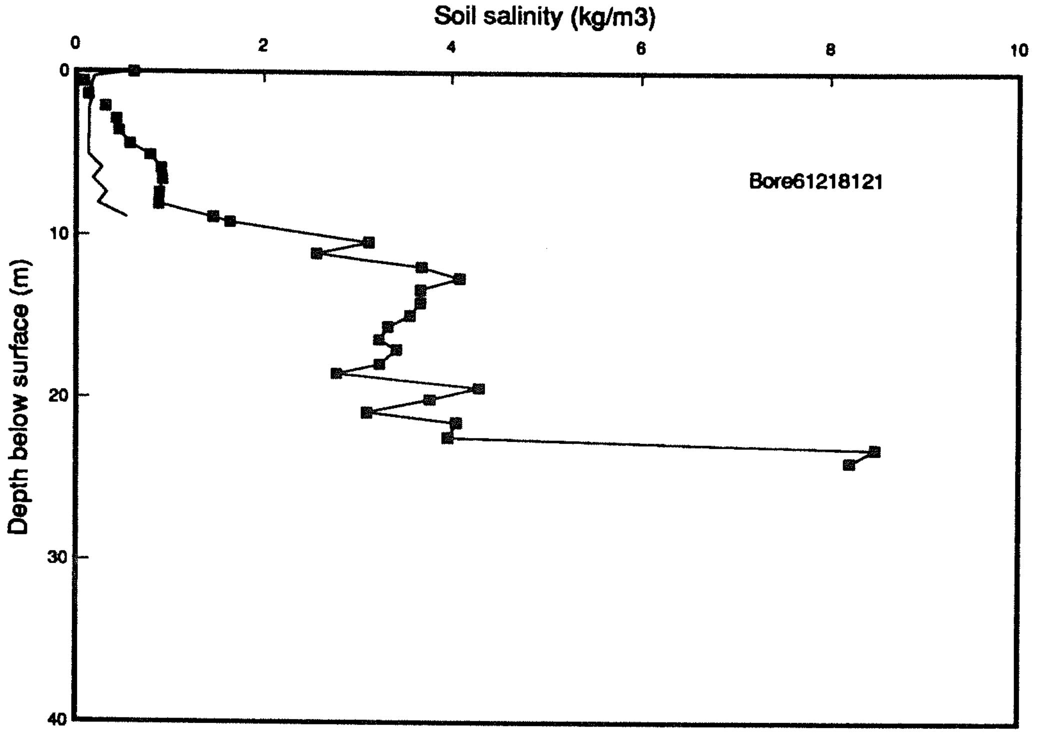

Soil salinity (kg/m3)
0
2
4
6
8
10
Depth(below surface (m)
0
10
20
30
40
Bore61218101

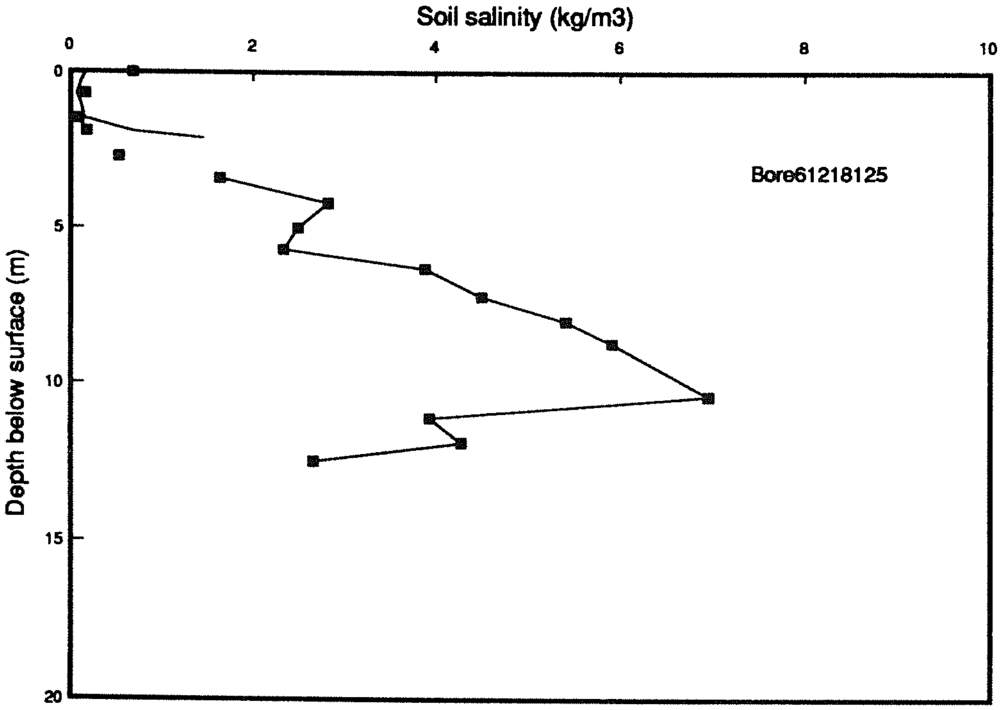

Soil salinity (kg/m3)
0
5
10
15
20
Depth below surface (m)
0
5
10
15
20
Bore61218105

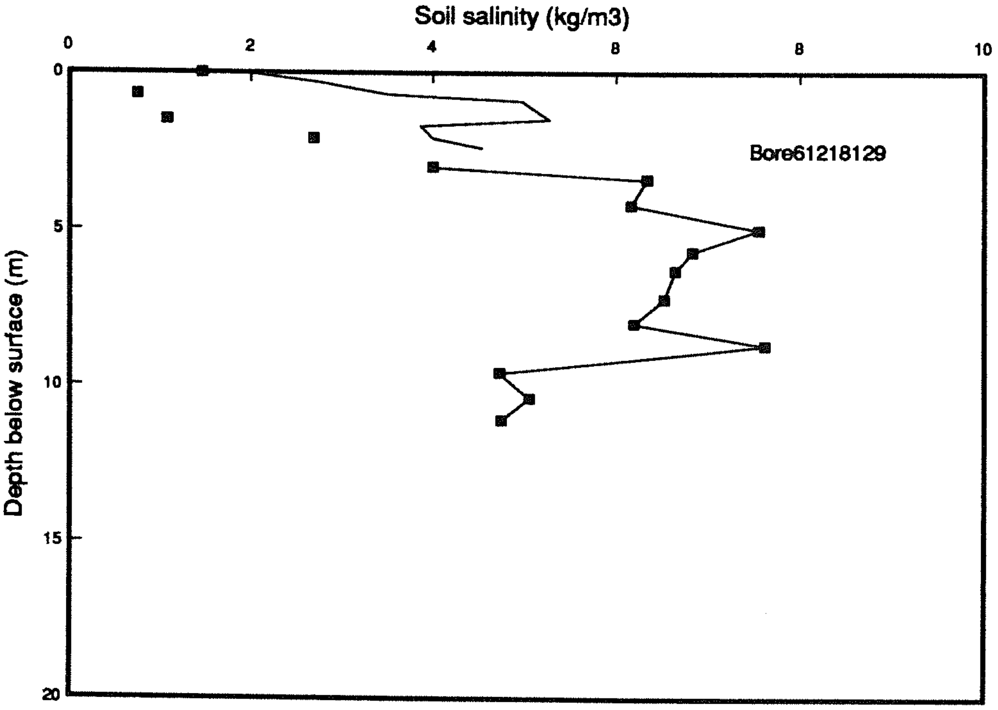

Soil salinity(kg/m3)
0
2
4
6
8
10
0
5
10
15
20
Depth below surface (m)
Bore61218110

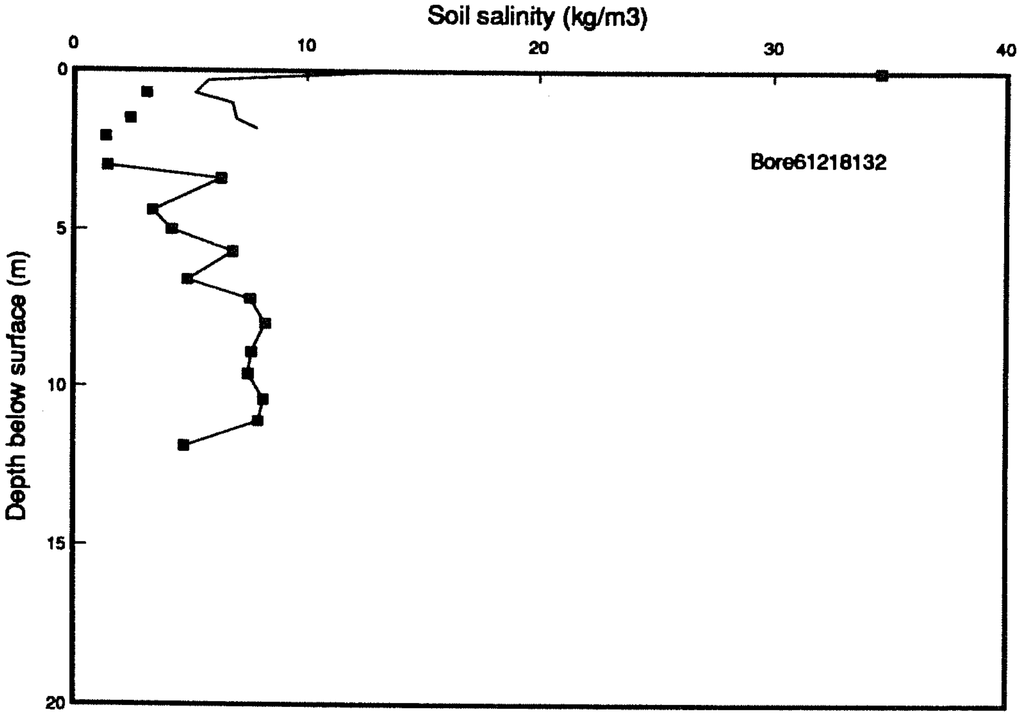

Soil salinity (kg/m3)
0
5
10
15
20
0
5
10
15
20
Depth below surface (m)
Bore61218113

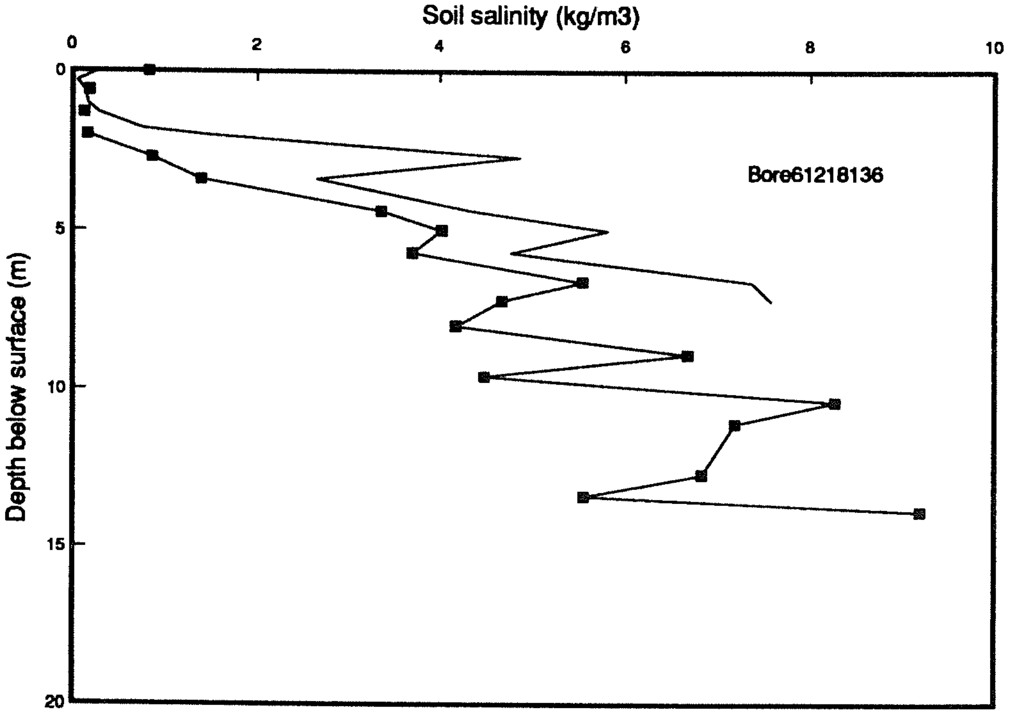

Soil salinity (kg/m3)
0
2
4
6
8
10
0
5
10
15
20
Depth below surface (m)
Bore61218117

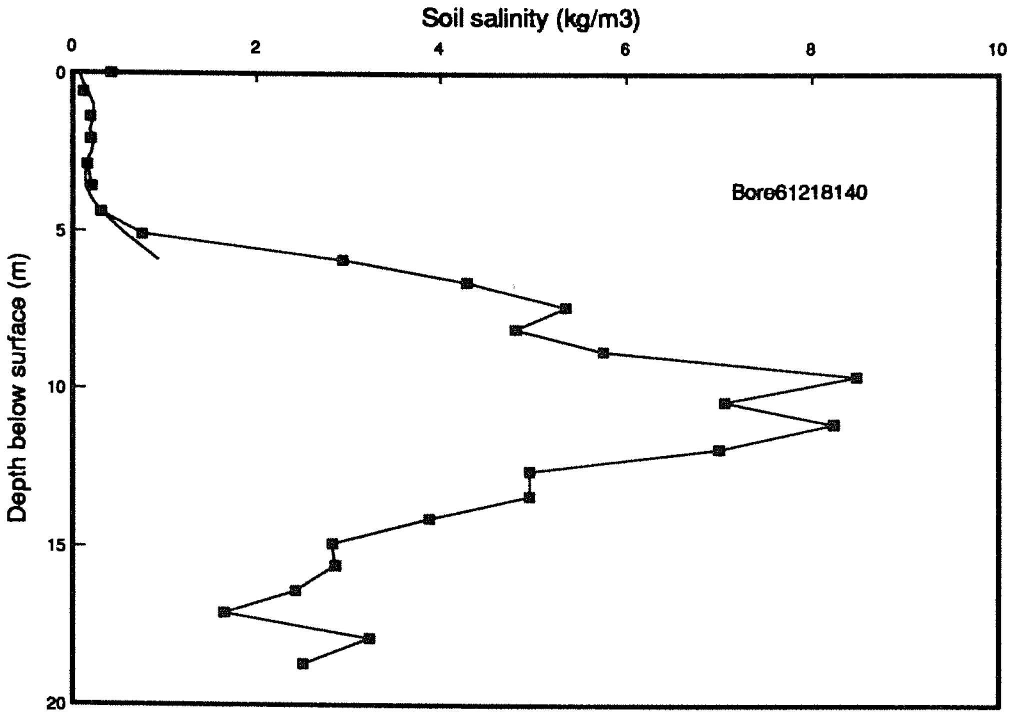

Soil salinity (kg/m3)
0
2
4
6
8
10
0
10
20
30
40
Depth below surface (m)
Bore61218121


Soil salinity (kg/m3)
0
2
4
6
8
10
0
5
10
15
20
Depth below surface (m)
Bore61218125

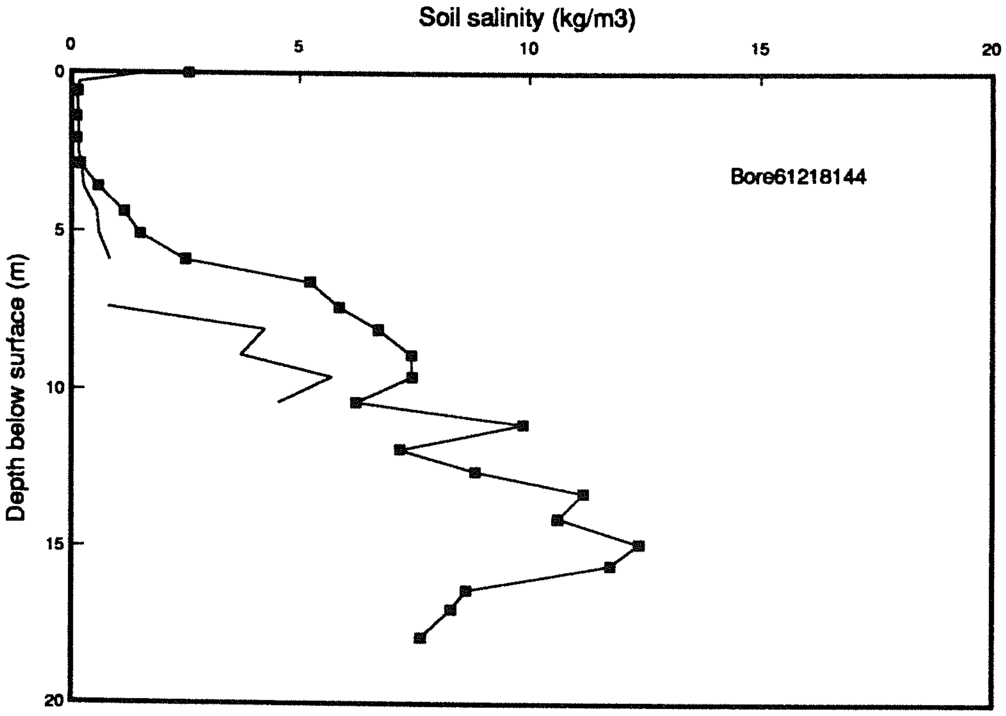

Soil salinity (kg/m3)
0
2
4
6
8
10
0
5
10
15
20
Depth below surface (m)
Bore61218129


Soil salinity (kg/m3)
0
10
20
30
40
0
5
10
15
20
Depth below surface (m)
Bore61218132

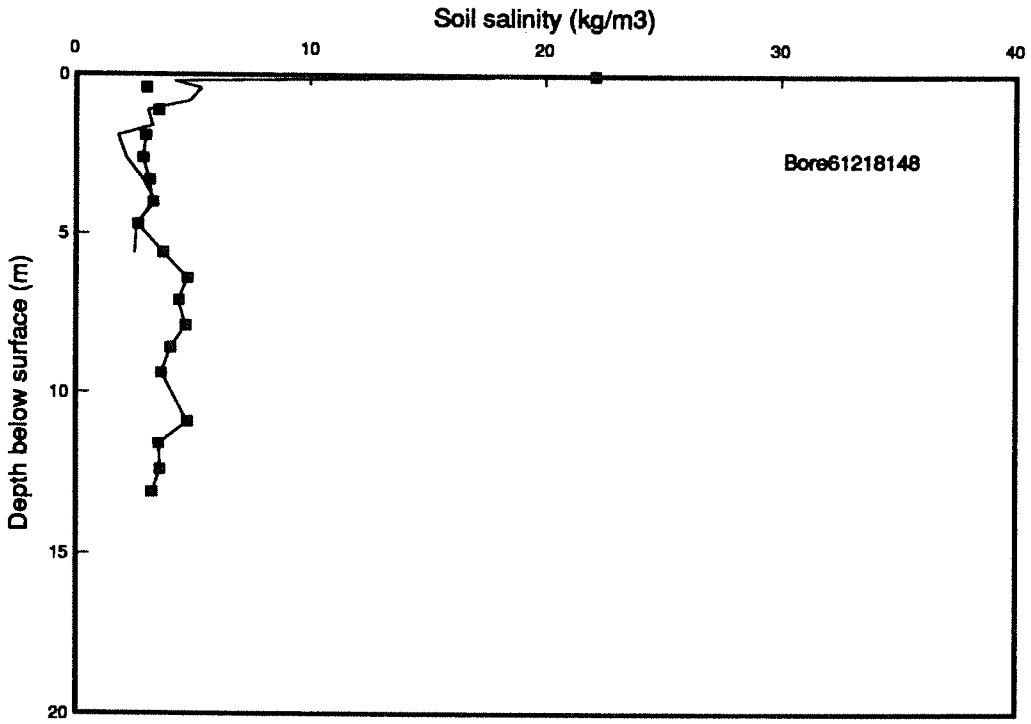

Soil salinity (kg/m3)
0
2
4
6
8
10
0
5
10
15
20
Depth below surface (m)
Bore61218136

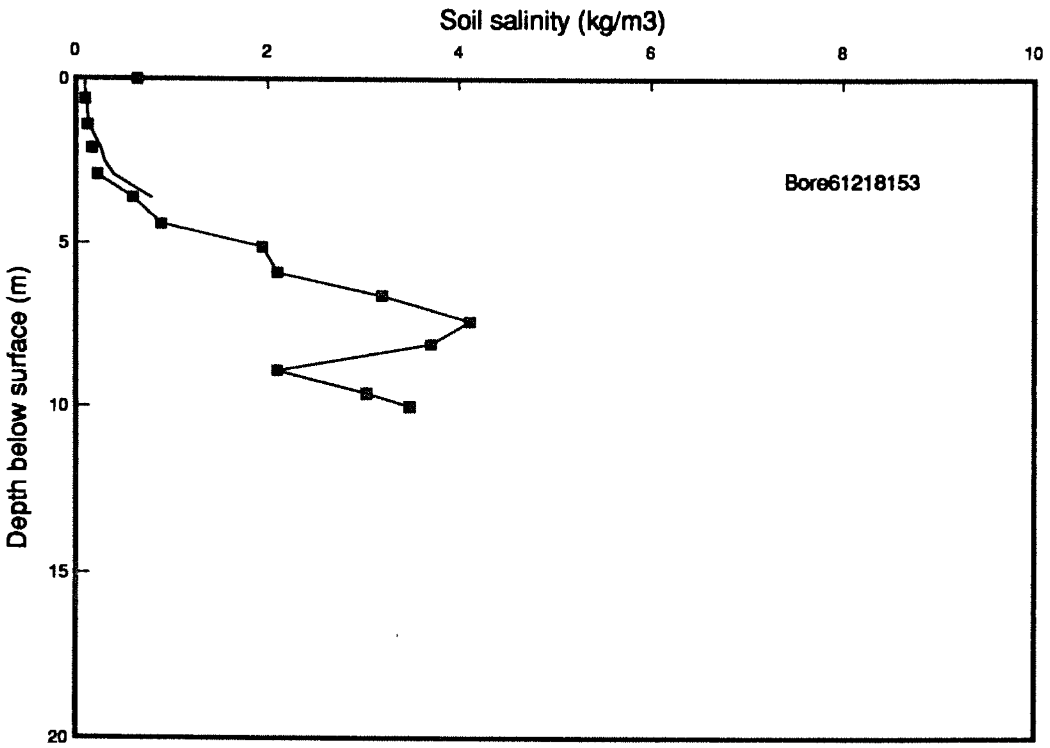


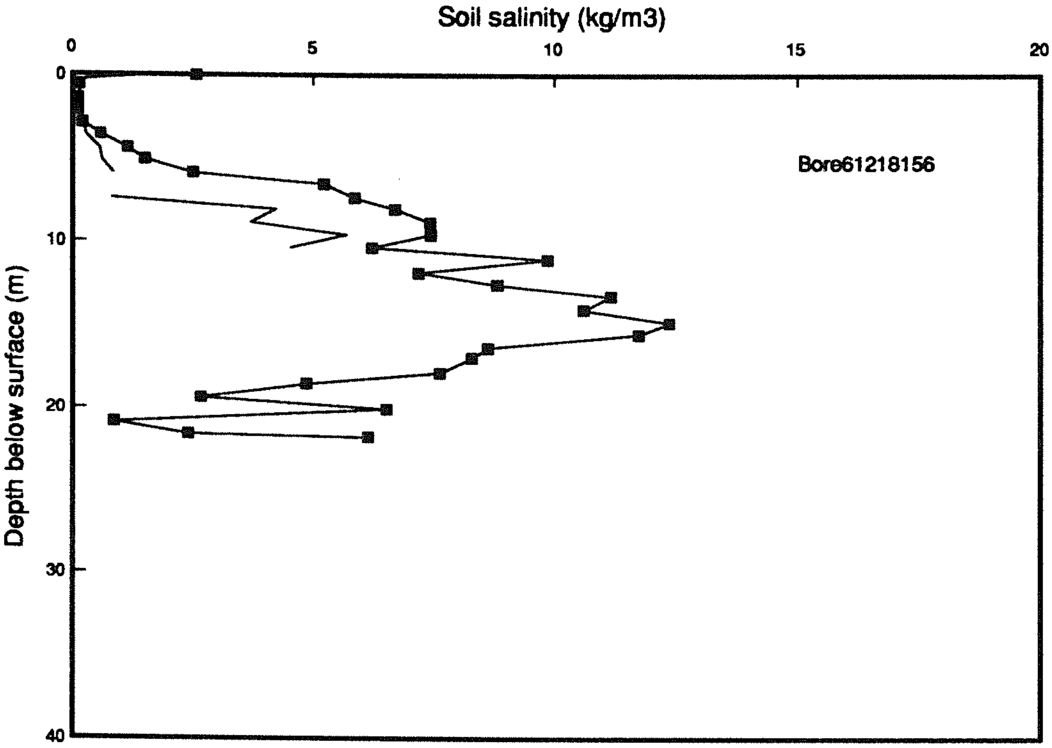
Soil salinity (kg/m3)
0
2
4
6
8
10
Depth below surface (m)
0
5
10
15
20
Bore61218140

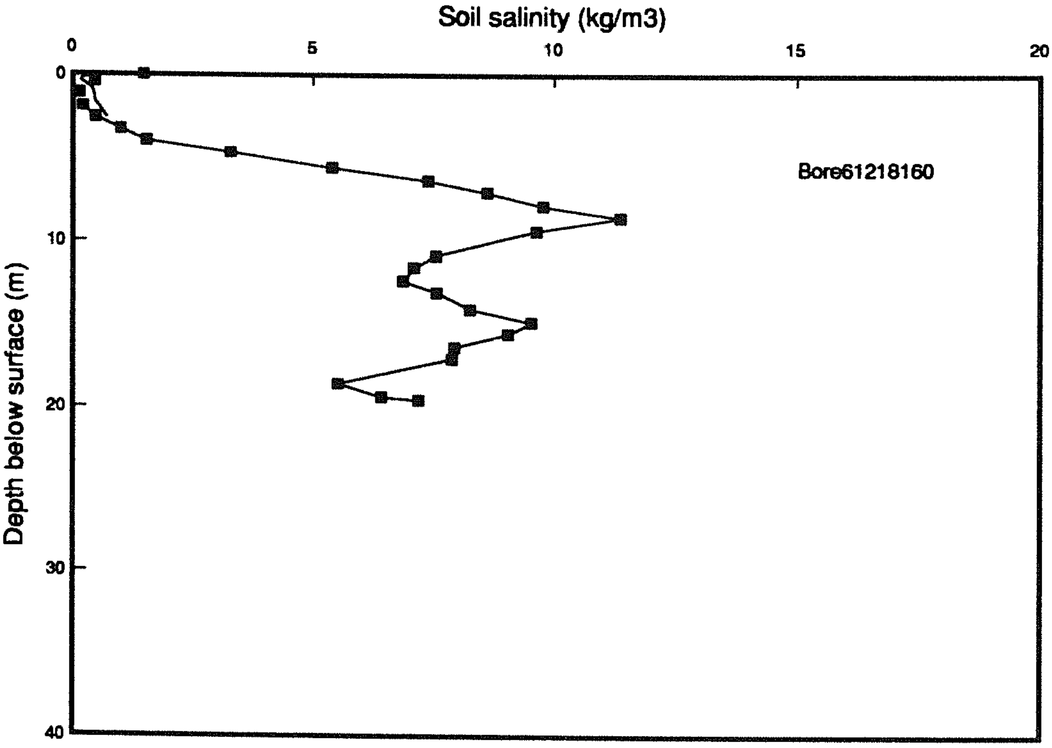


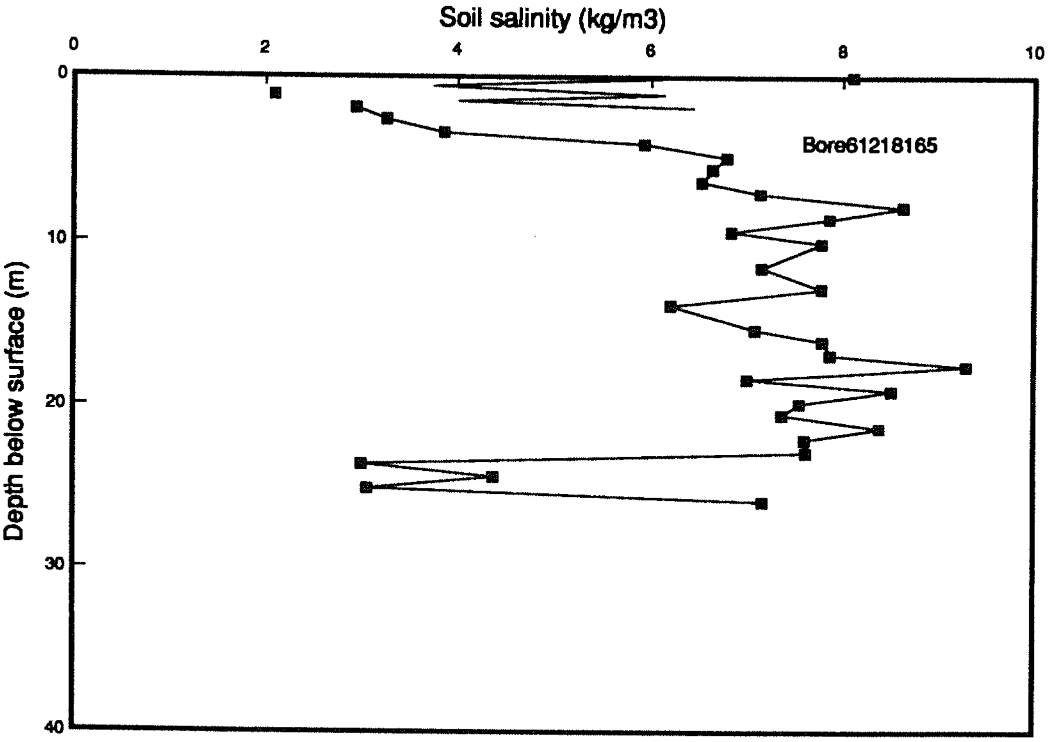
Soil salinity (kg/m3)
0
5
10
15
20
Depth below surface (m)
0
5
10
15
20
Bore61218144

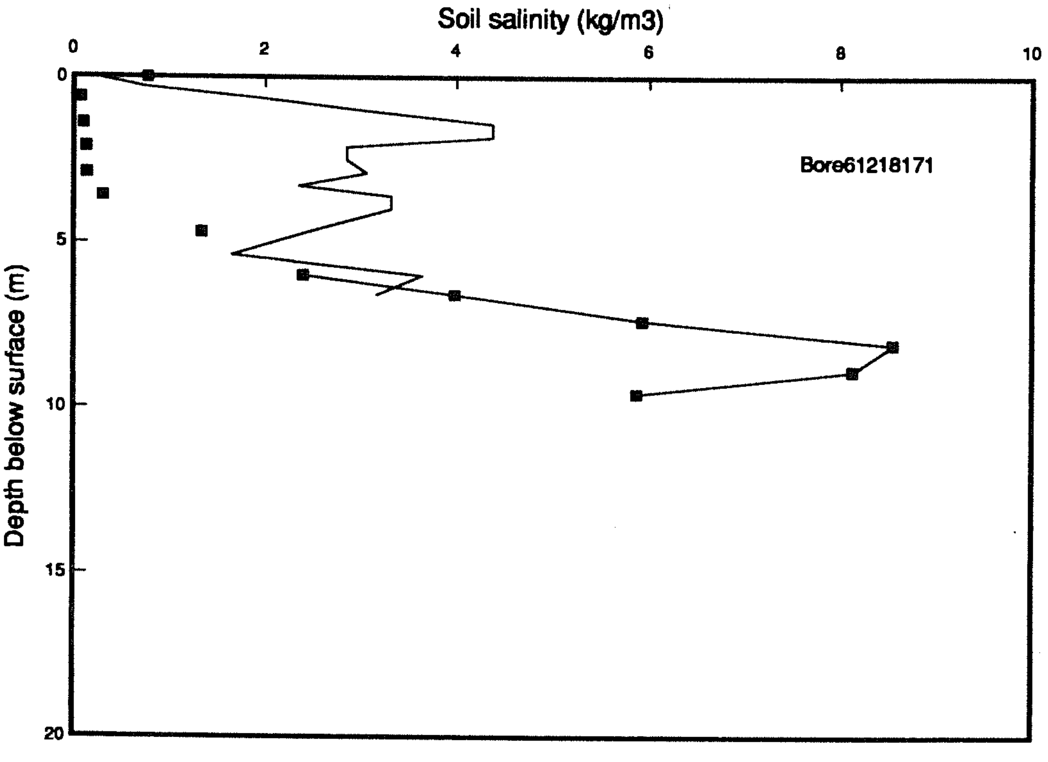

Soil salinity (kg/m3)
0
10
20
30
40
0
5
10
15
20
Depth below surface (m)
Bore61218148

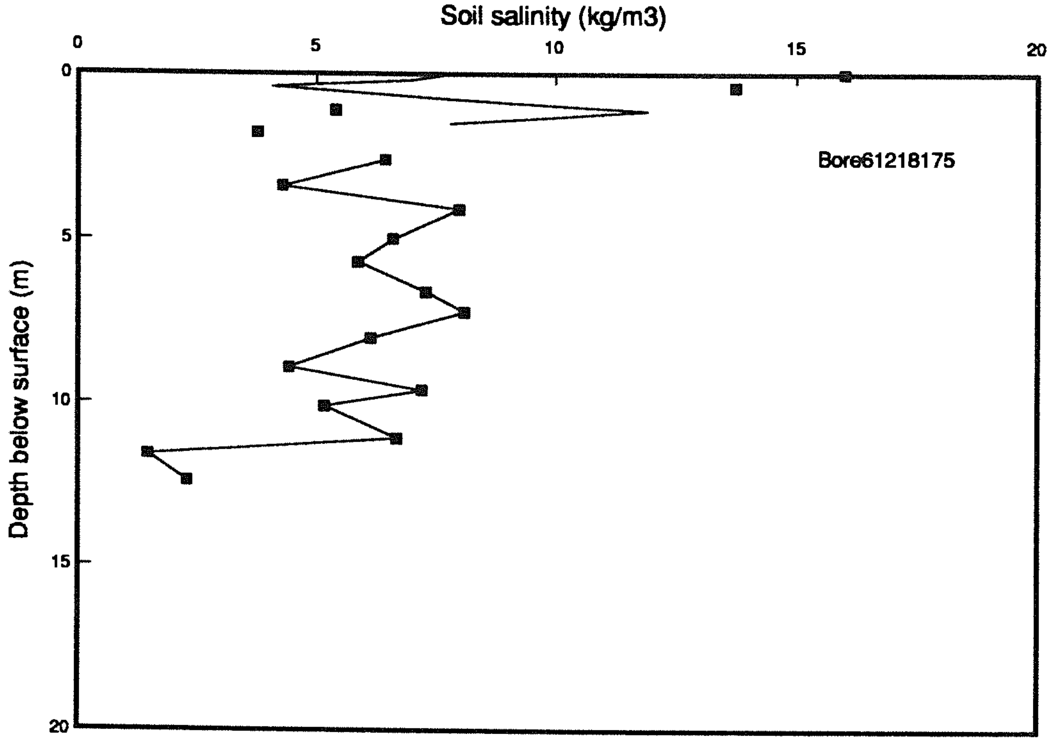

Soil salinity (kg/m3)
0
2
4
6
8
10
0
5
10
15
20
Depth below surface (m)
Bore61218153

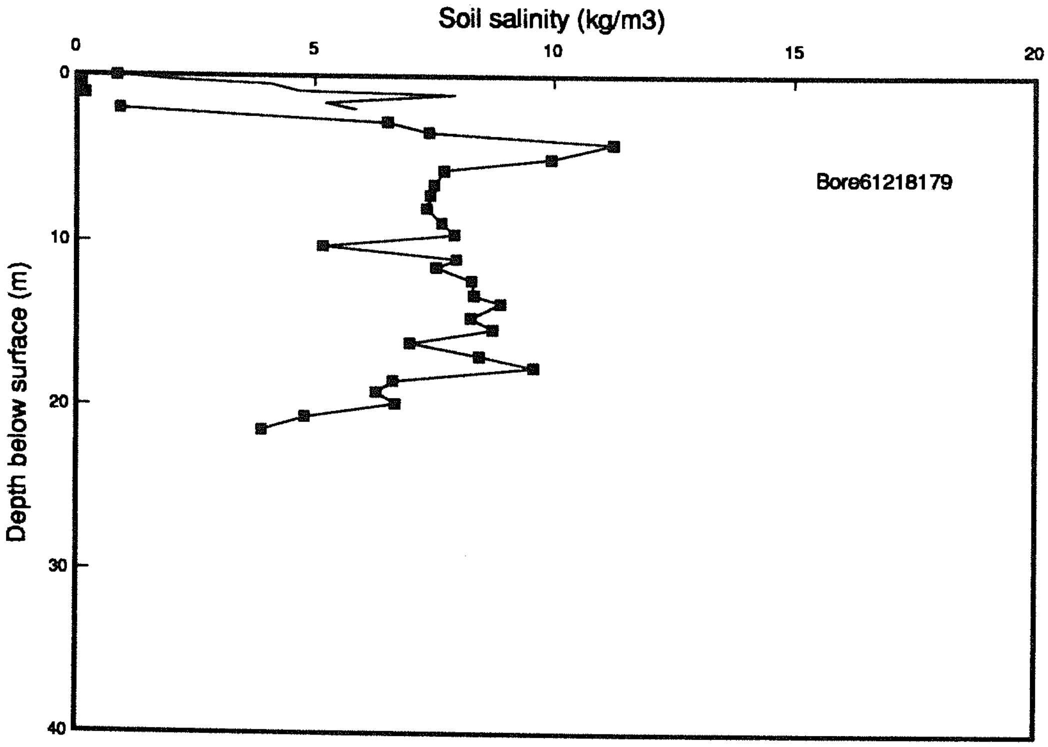

Soil salinity (kg/m3)
0
5
10
15
20
0
10
20
30
40
Depth below surface (m)
Bore61218156

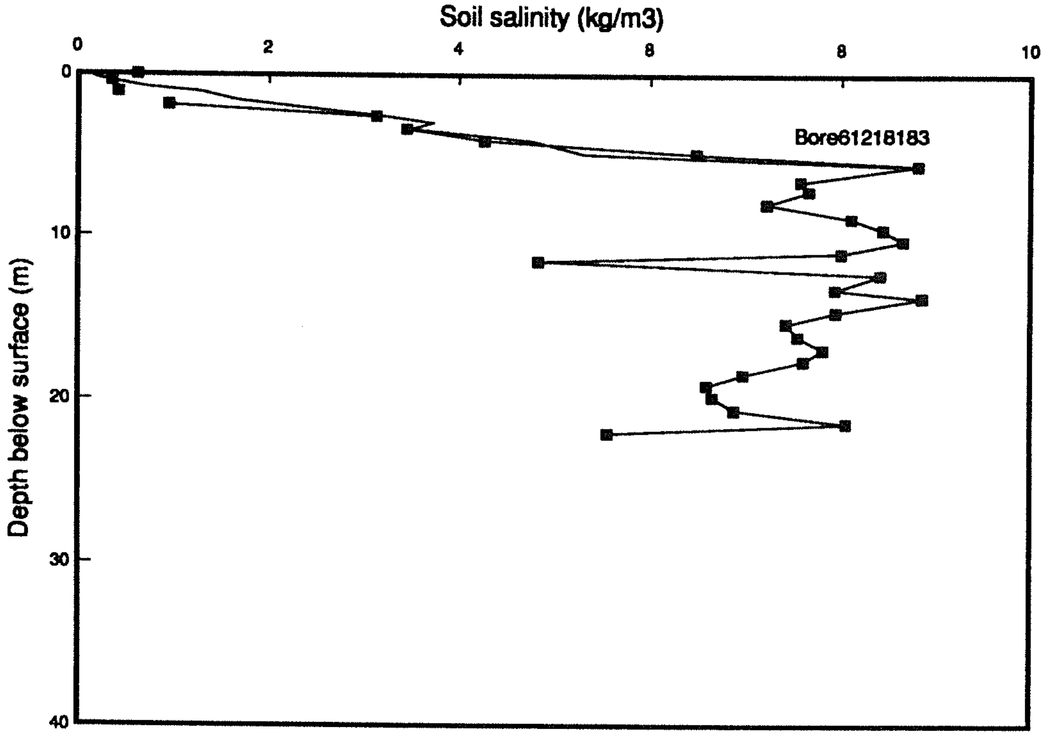

Soil salinity (kg/m3)
0
5
10
15
20
0
10
20
30
40
Depth below surface (m)
Bore61218160

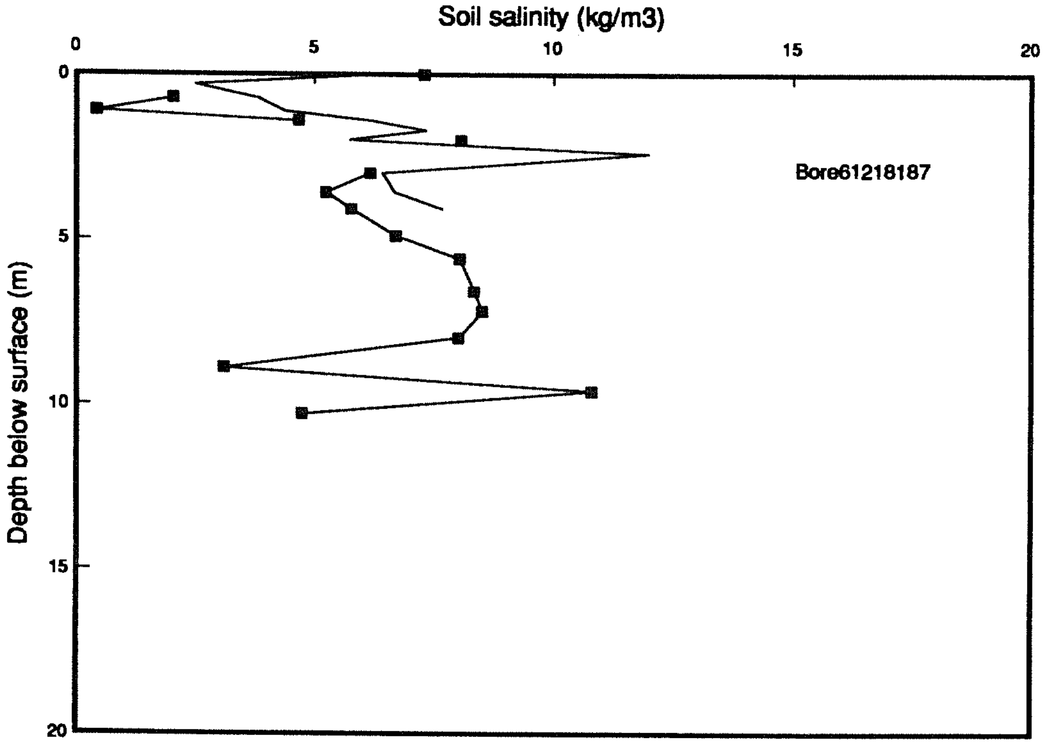

Soil salinity (kg/m3)
0
2
4
6
8
10
0
10
20
30
40
Depth below surface (m)
Bore61218165

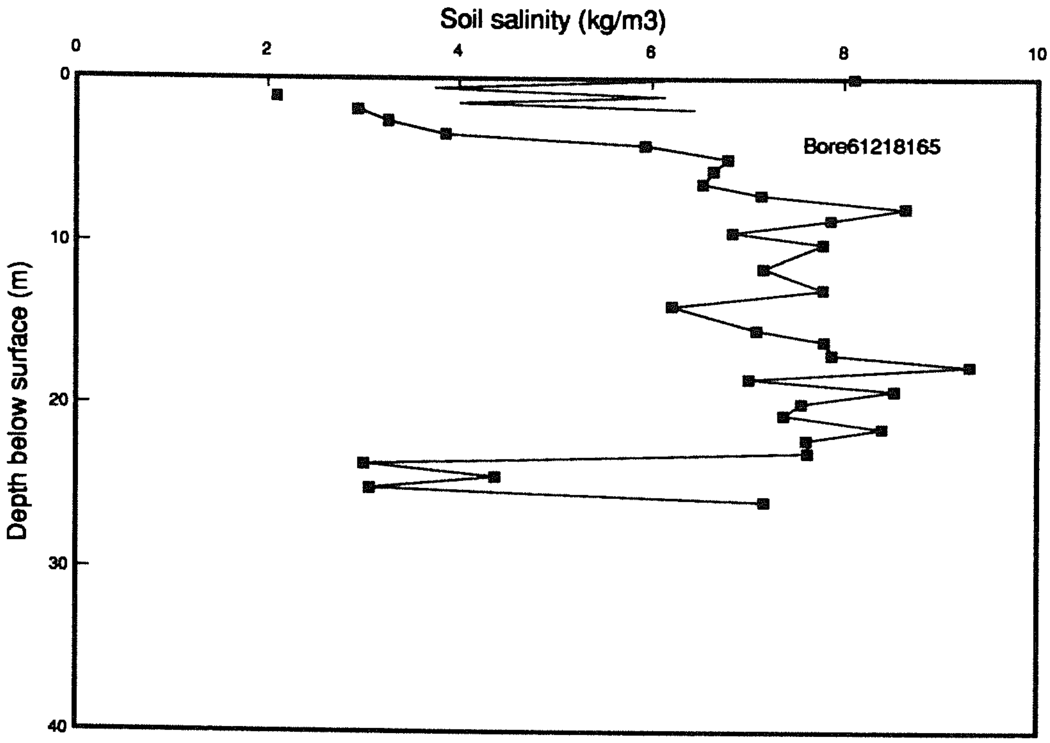

Soil salinity (kg/m3)
0
2
4
6
8
10
0
5
10
15
20
Depth below surface (m)
Bore61218171

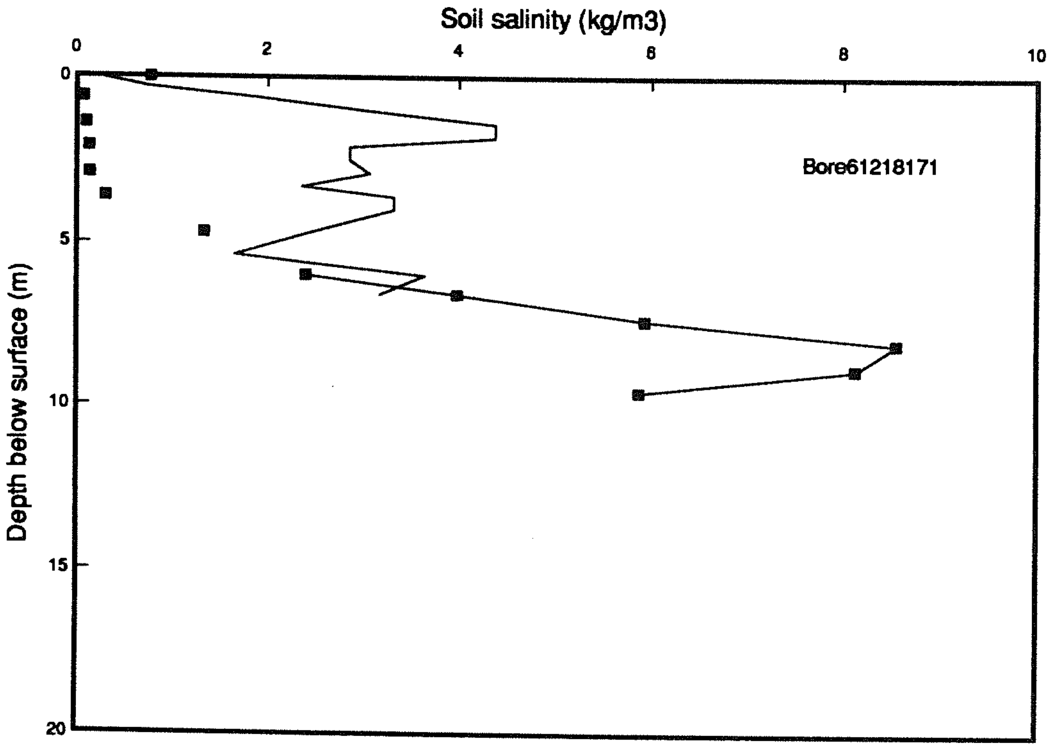

Soil salinity (kg/m3)
0
5
10
15
20
0
5
10
15
20
Depth below surface (m)
Bore61218175


Soil salinity (kg/m3)
0
5
10
15
20
0
10
20
30
40
Depth below surface (m)
Bore61218179


Soil salinity (kg/m3)
0
2
4
6
8
10
Bore61218183
Depth below surface (m)
0
10
20
30
40

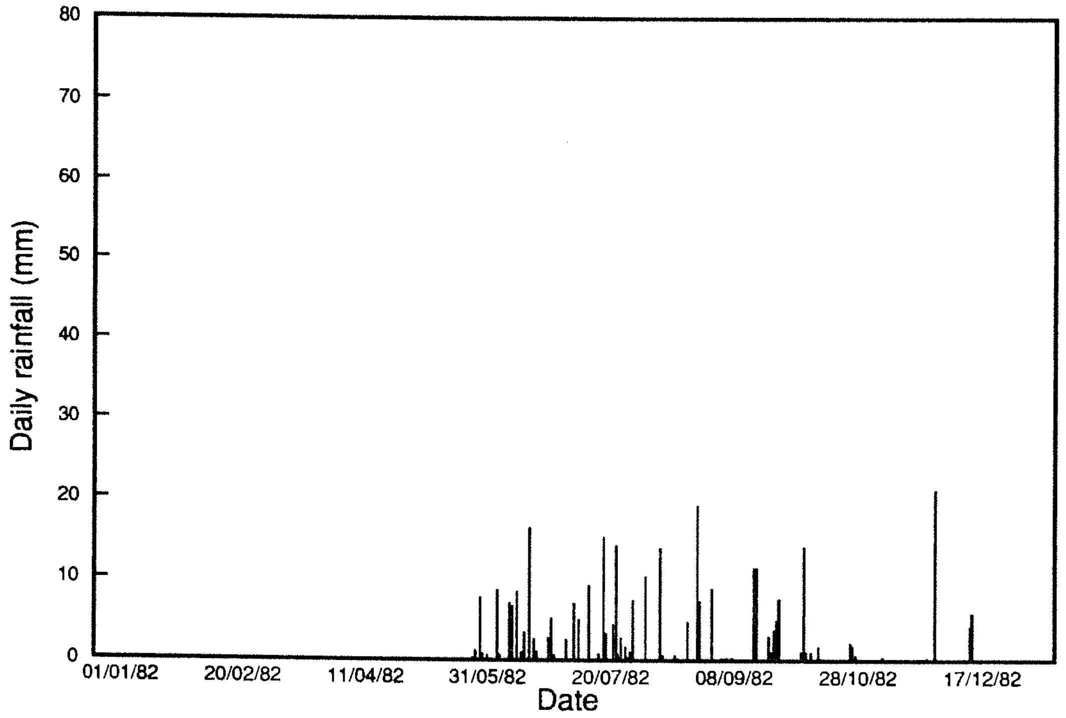

Soil salinity (kg/m3)
0
5
10
15
20
Bore61218187
Depth below surface (m)
0
5
10
15
20

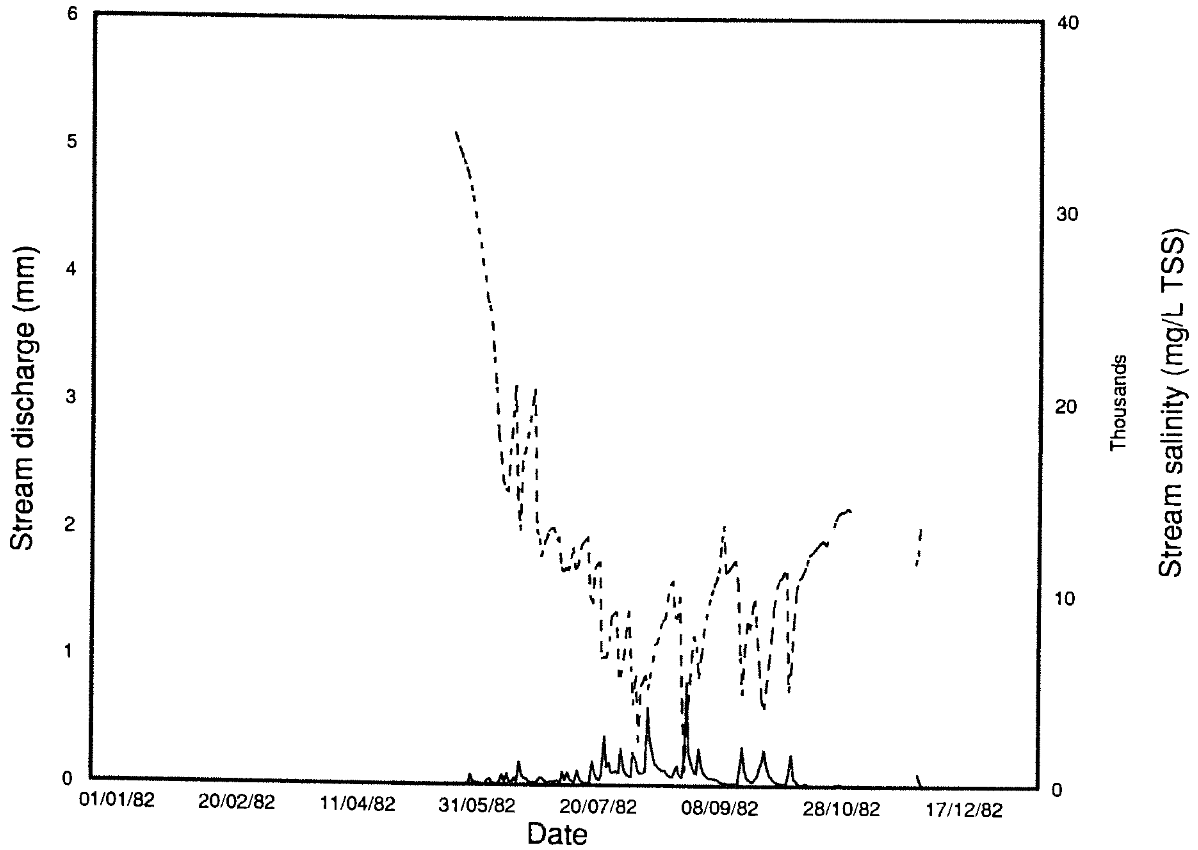

Soil salinity (kg/m3)
0
2
4
6
8
10
0
10
20
30
40
Depth below surface (m)
Bore61218165

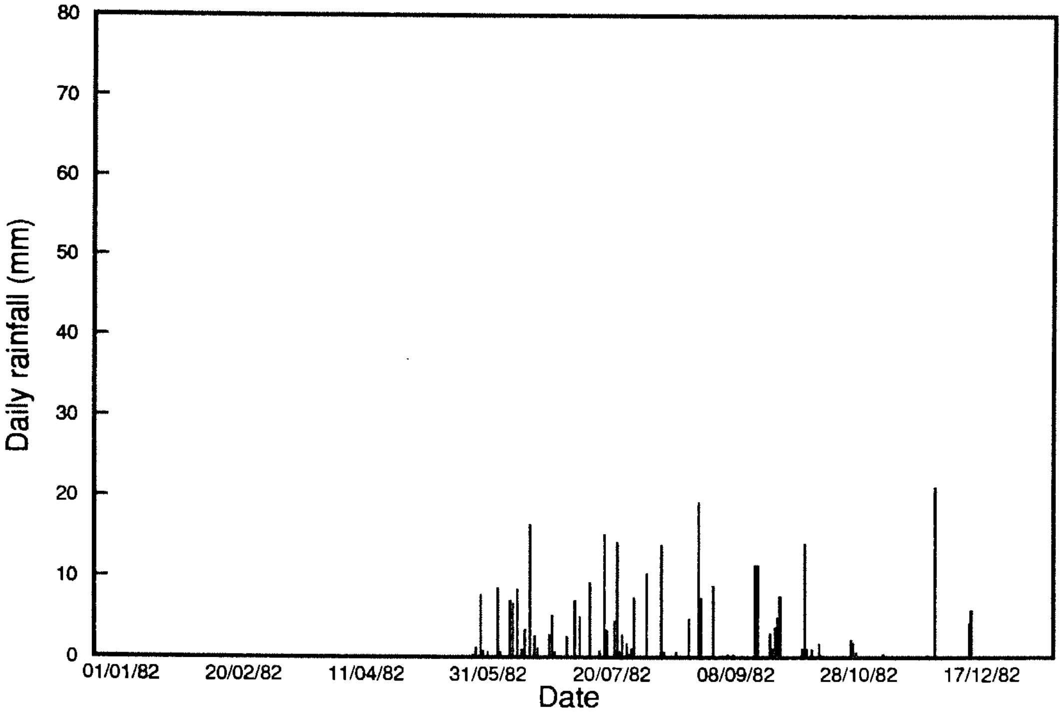

Soil salinity (kg/m3)
0
2
4
6
8
10
0
5
10
15
20
Depth below surface (m)
Bore61218171

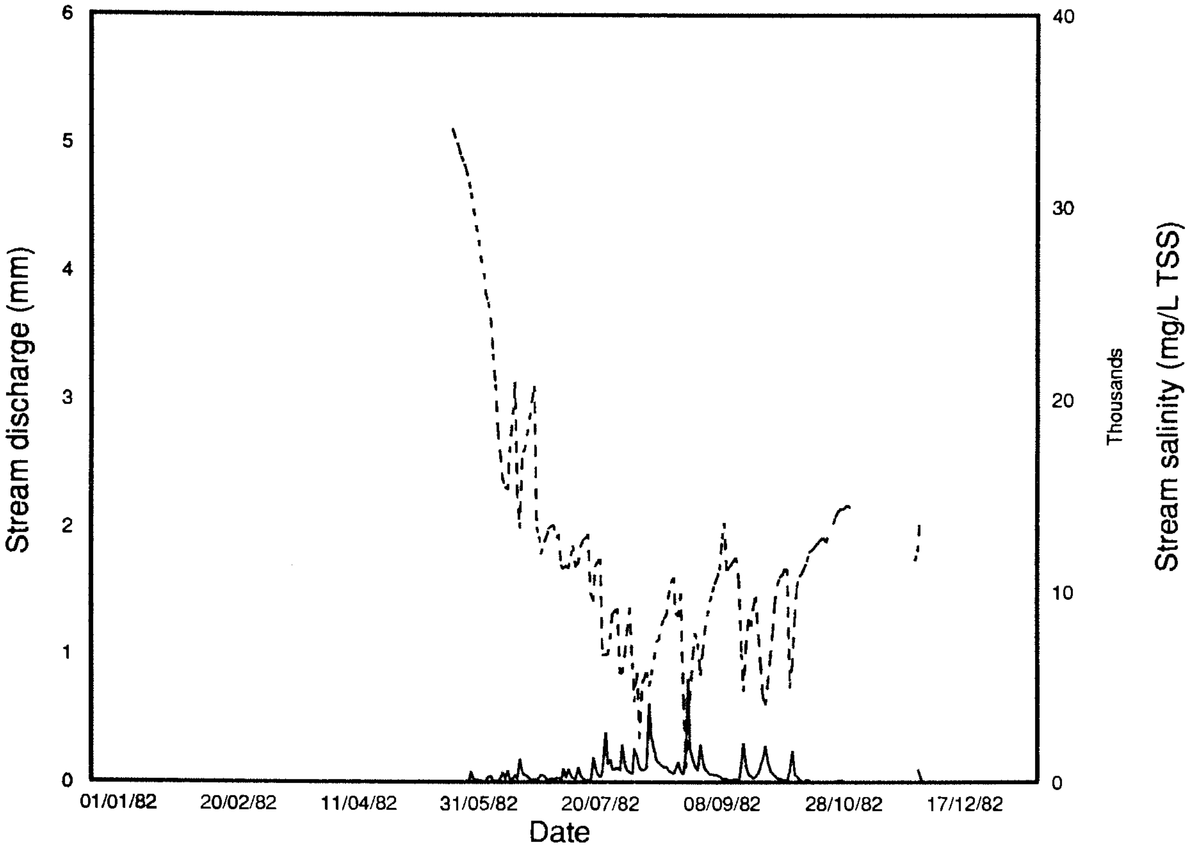
APPENDIX H

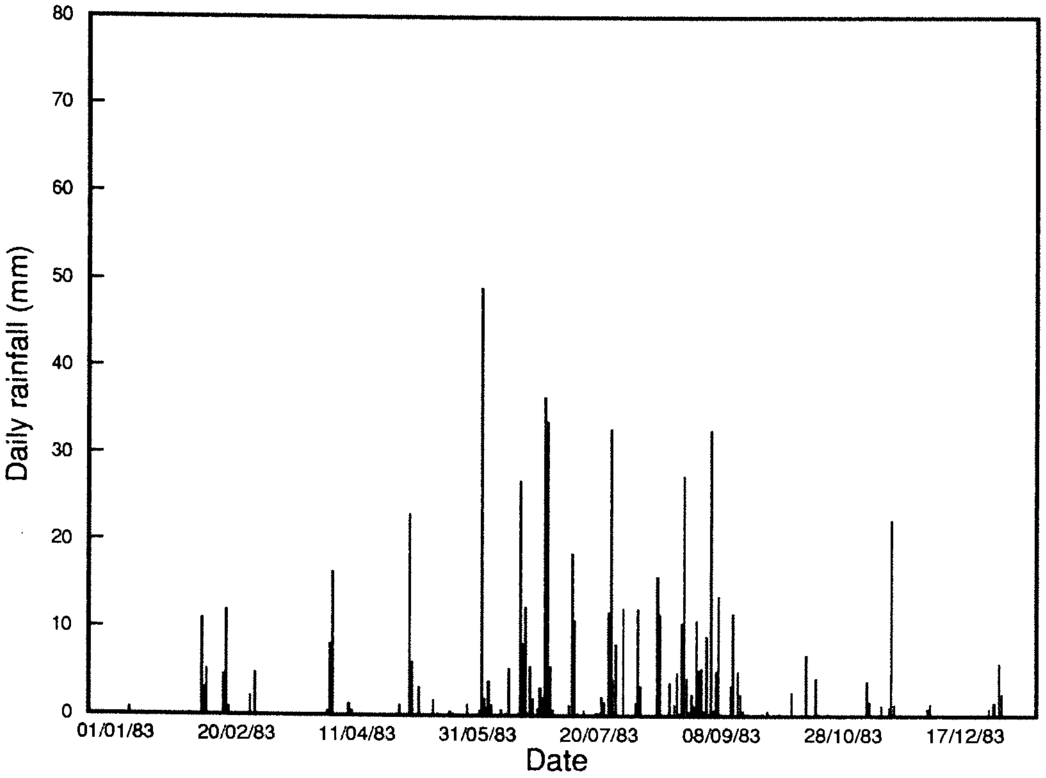
STREAMFLOW HYDROGRAPHS AND CHEMOGRAPHS BETWEEN 1982 AND 1990

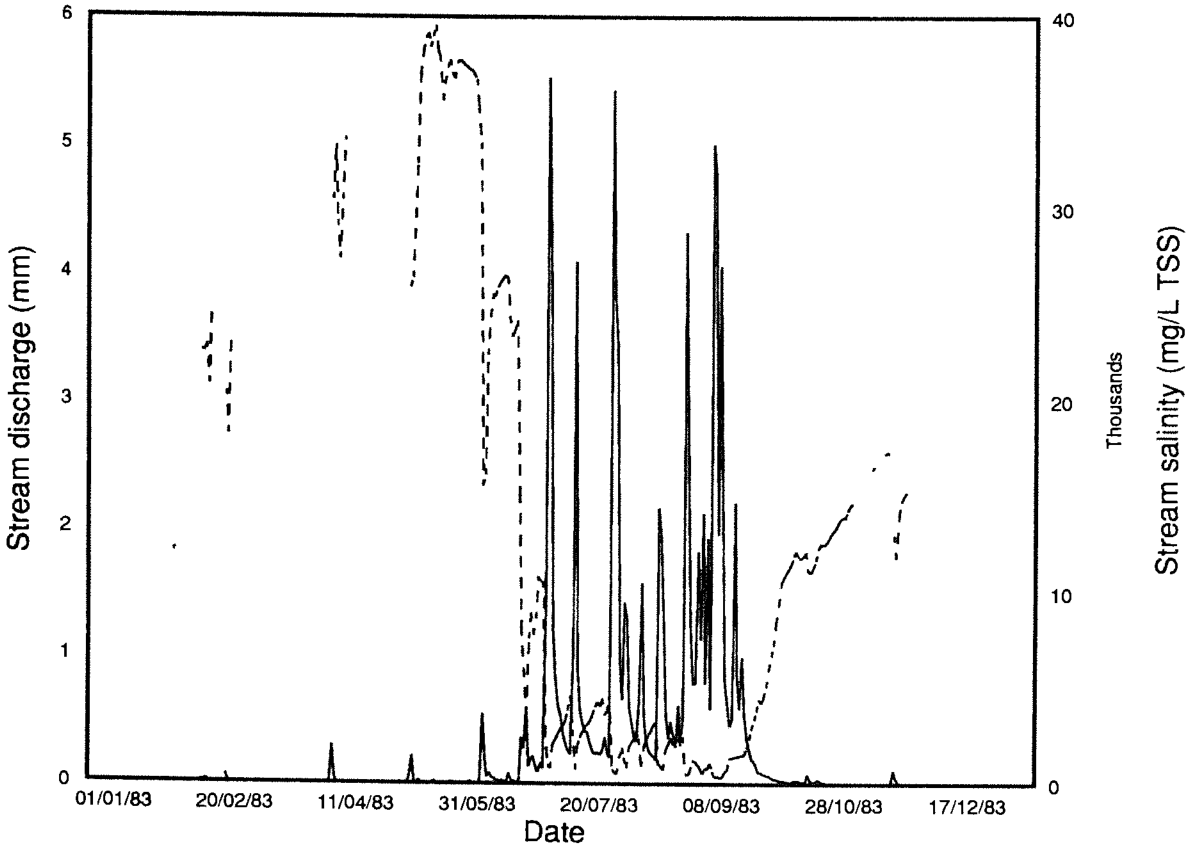

80
70
60
50
40
30
20
10
0
Daily rainfall (mm)
01/01/82
20/02/82
11/04/82
31/05/82
20/07/82
08/09/82
28/10/82
17/12/82
Date

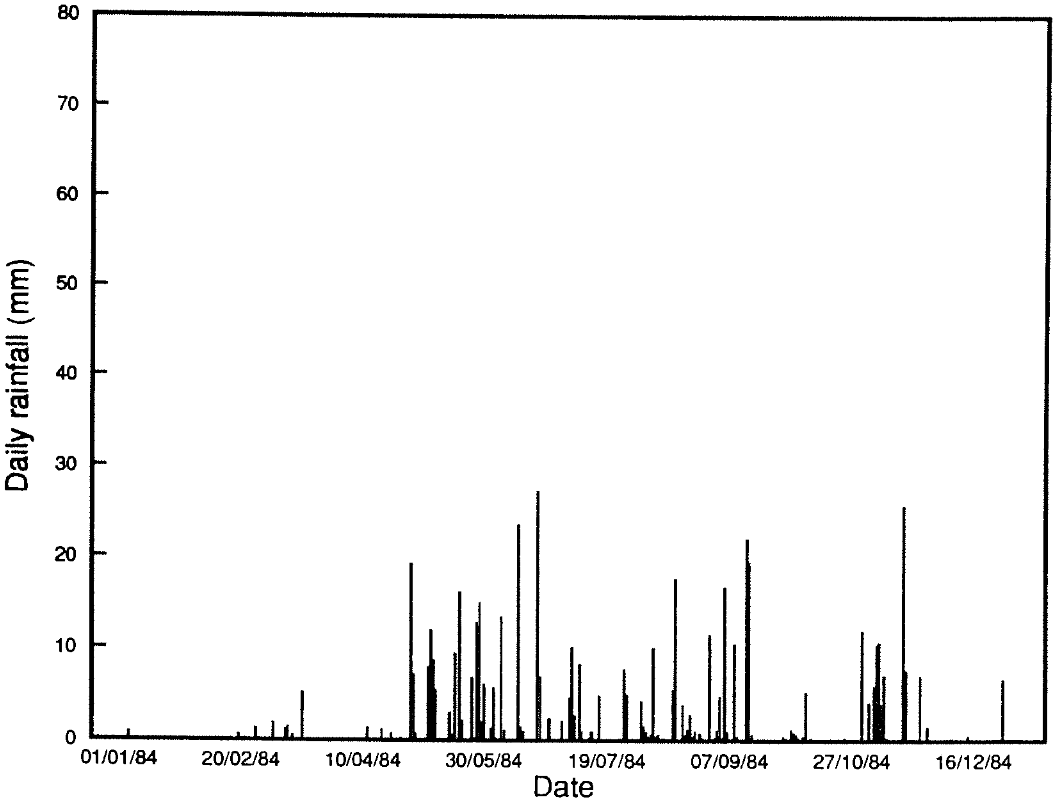

6
5
4
3
2
1
0
Stream discharge (mm)
40
30
20
10
0
Thousands
Stream salinity (mg/L TSS)
01/01/82
20/02/82
11/04/82
31/05/82
20/07/82
08/09/82
28/10/82
17/12/82
Date

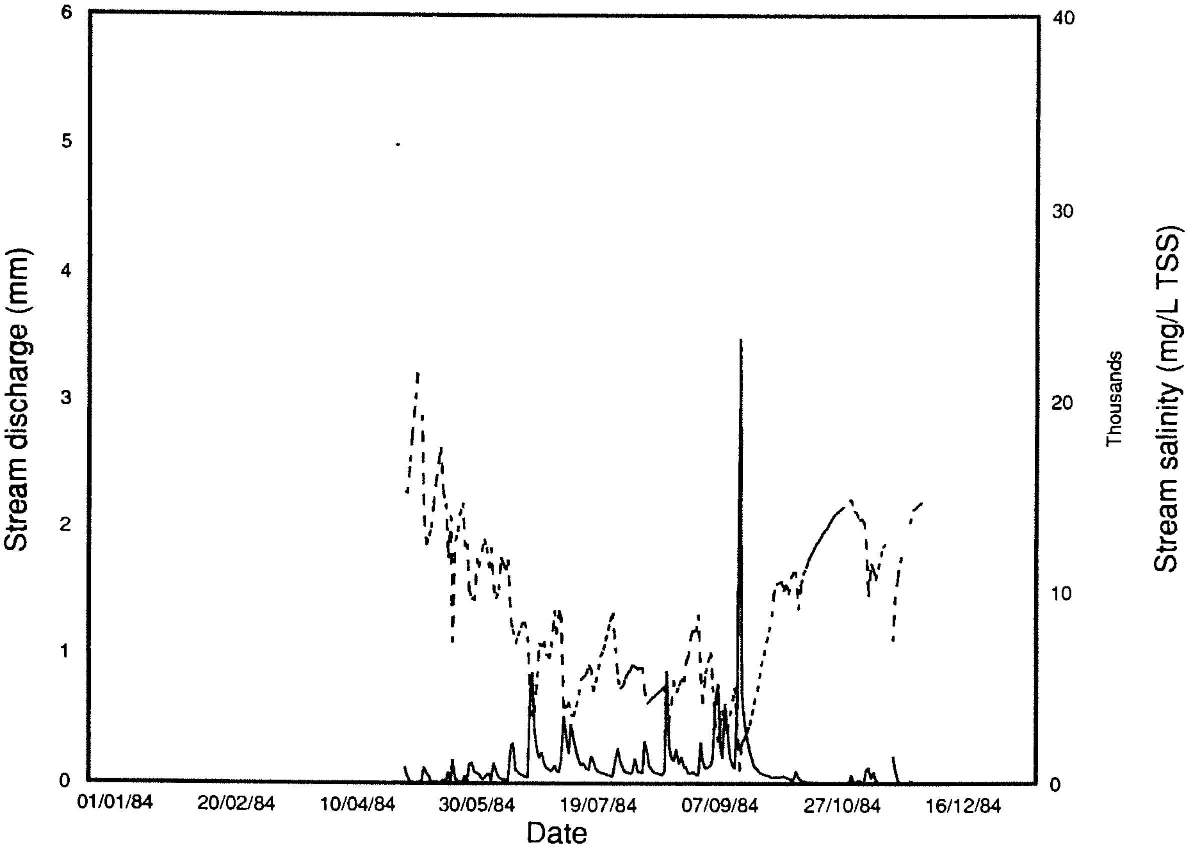

Daily rainfall (mm)
80
70
60
50
40
30
20
10
0
01/01/82
20/02/82
11/04/82
31/05/82
20/07/82
08/09/82
28/10/82
17/12/82
Date

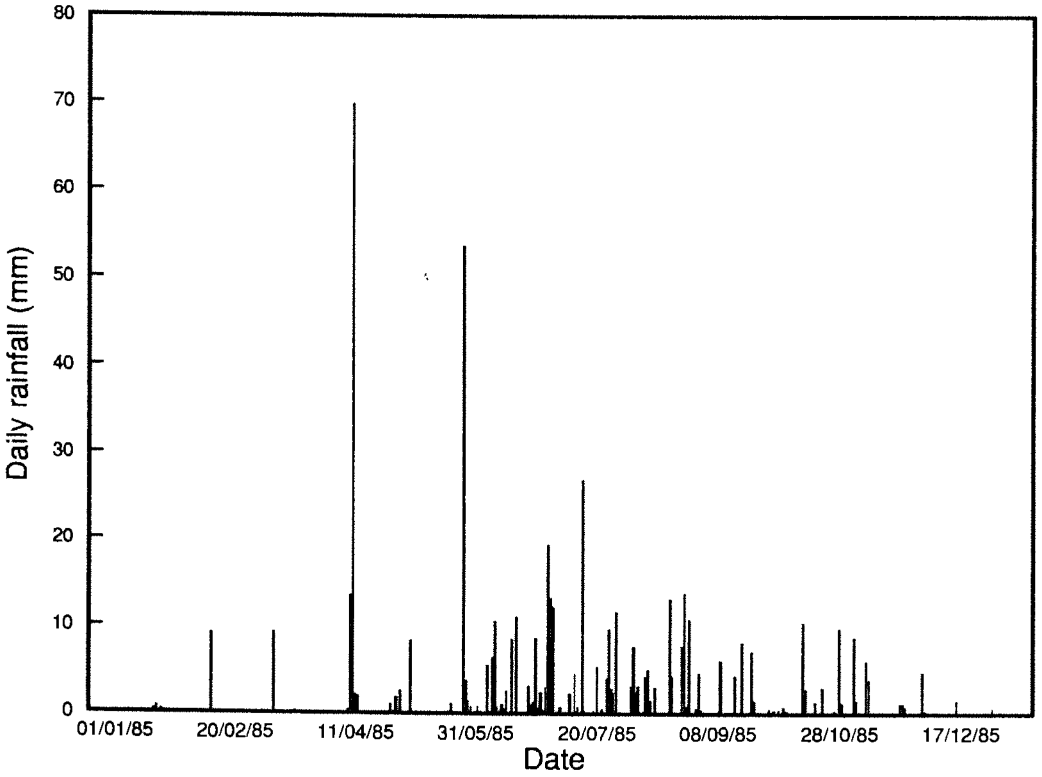

Stream discharge (mm)
6
5
4
3
2
1
0
Stream salinity (mg/L TSS)
Thousands
40
30
20
10
0
01/01/82
20/02/82
11/04/82
31/05/82
20/07/82
08/09/82
28/10/82
17/12/82
Date

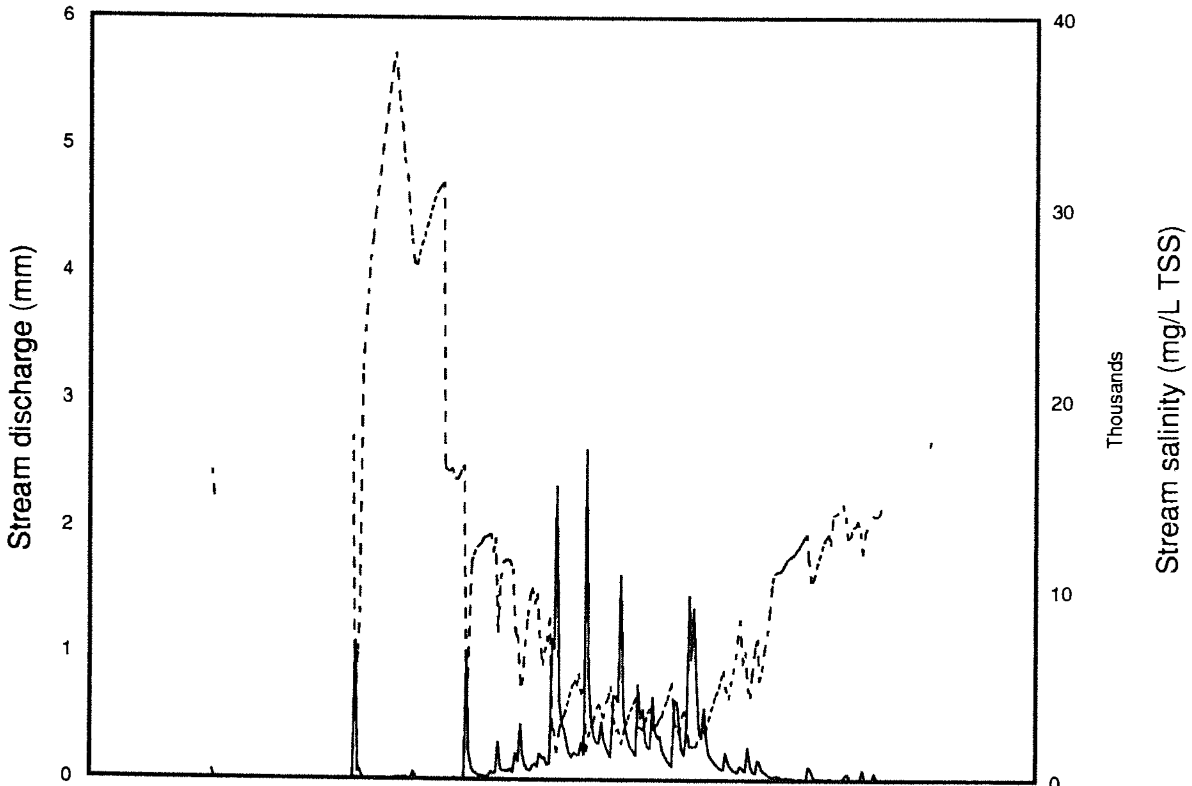

Daily rainfall (mm)
80
70
60
50
40
30
20
10
0
01/01/83
20/02/83
11/04/83
31/05/83
20/07/83
08/09/83
28/10/83
17/12/83
Date

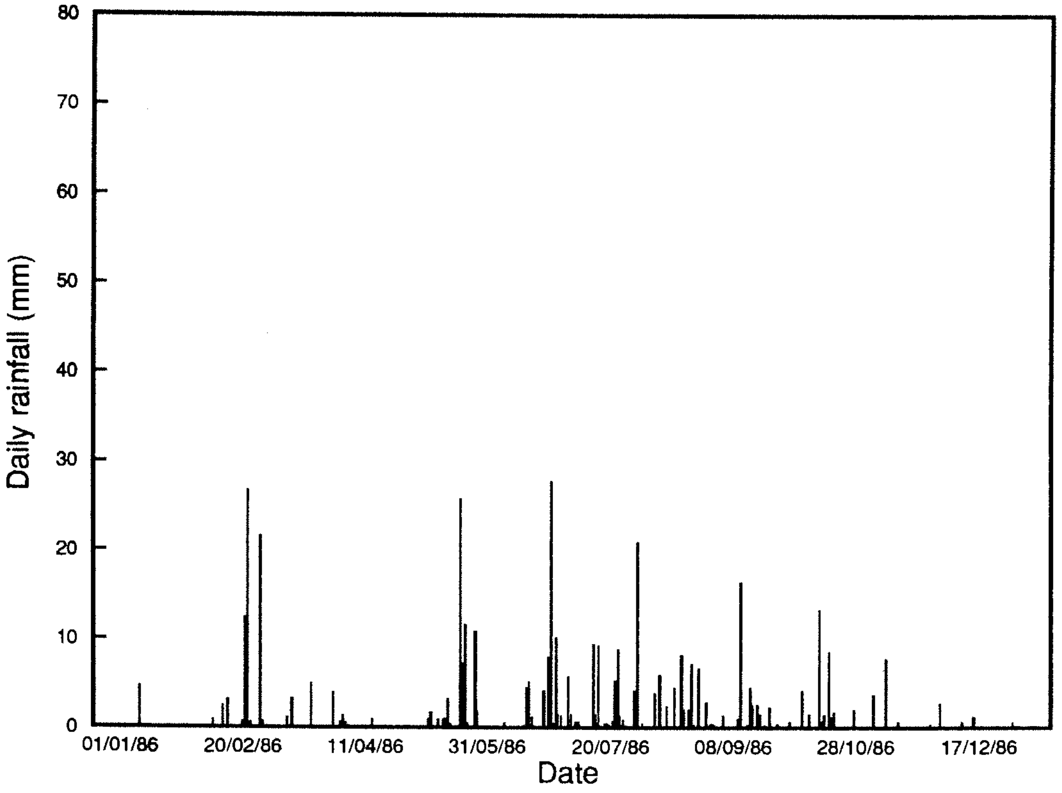

Stream discharge (mm)
6
5
4
3
2
1
0
01/01/83
20/02/83
11/04/83
31/05/83
20/07/83
08/09/83
28/10/83
17/12/83
Date
40
30
20
10
0
Thousands
Stream salinity (mg/L TSS)

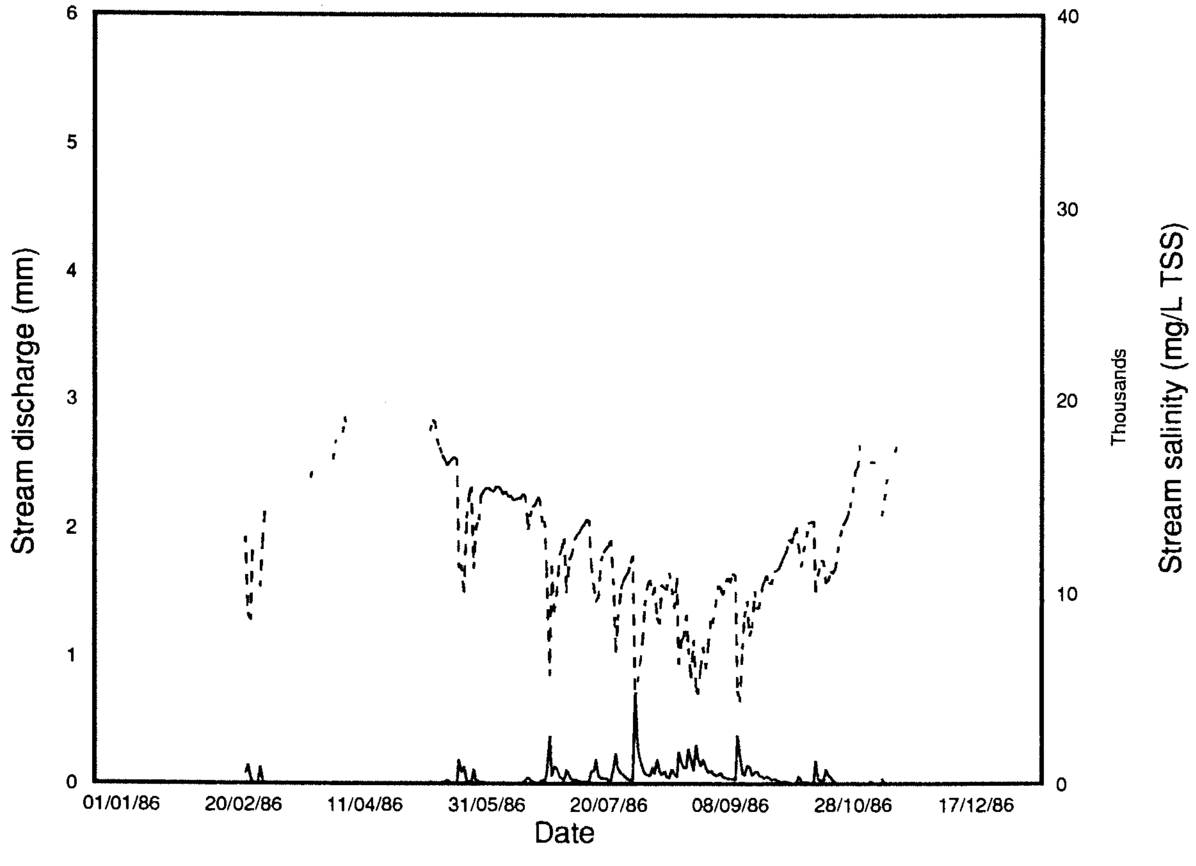

Daily rainfall (mm)
80
70
60
50
40
30
20
10
0
01/01/84
20/02/84
10/04/84
30/05/84
19/07/84
07/09/84
27/10/84
16/12/84
Date

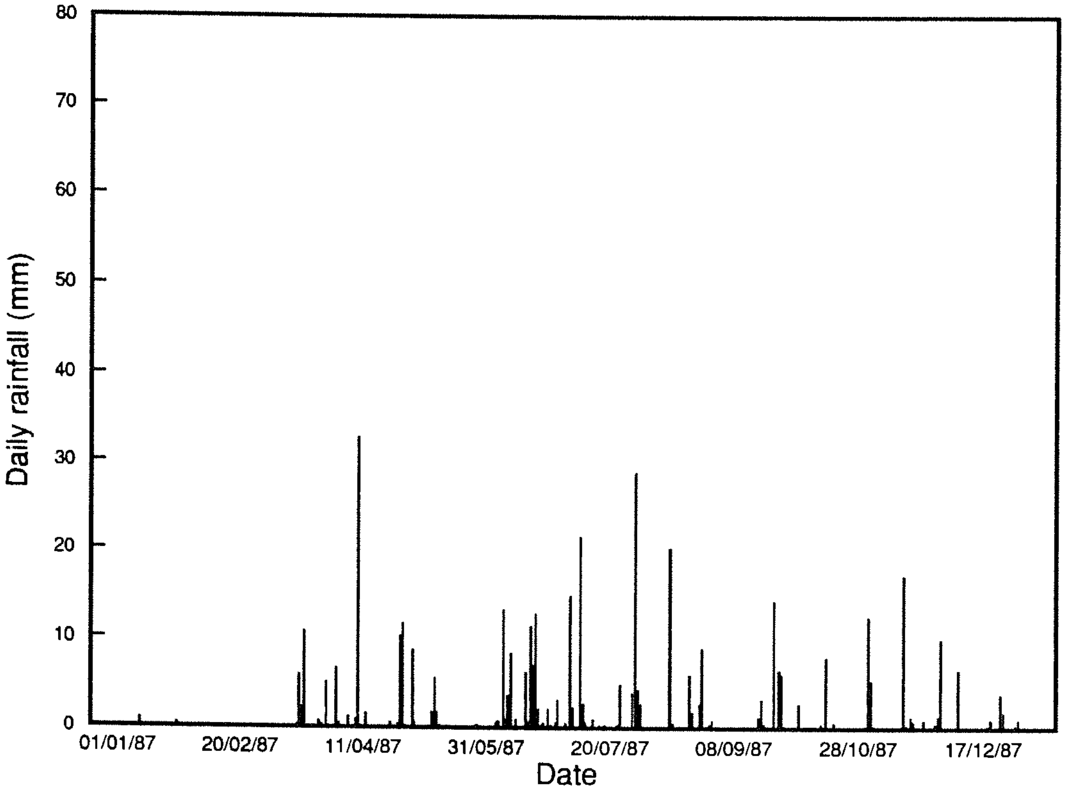

Stream discharge (mm)
6
5
4
3
2
1
0
Stream salinity (mg/L TSS)
Thousands
40
30
20
10
0
01/01/84
20/02/84
10/04/84
30/05/84
19/07/84
07/09/84
27/10/84
16/12/84
Date

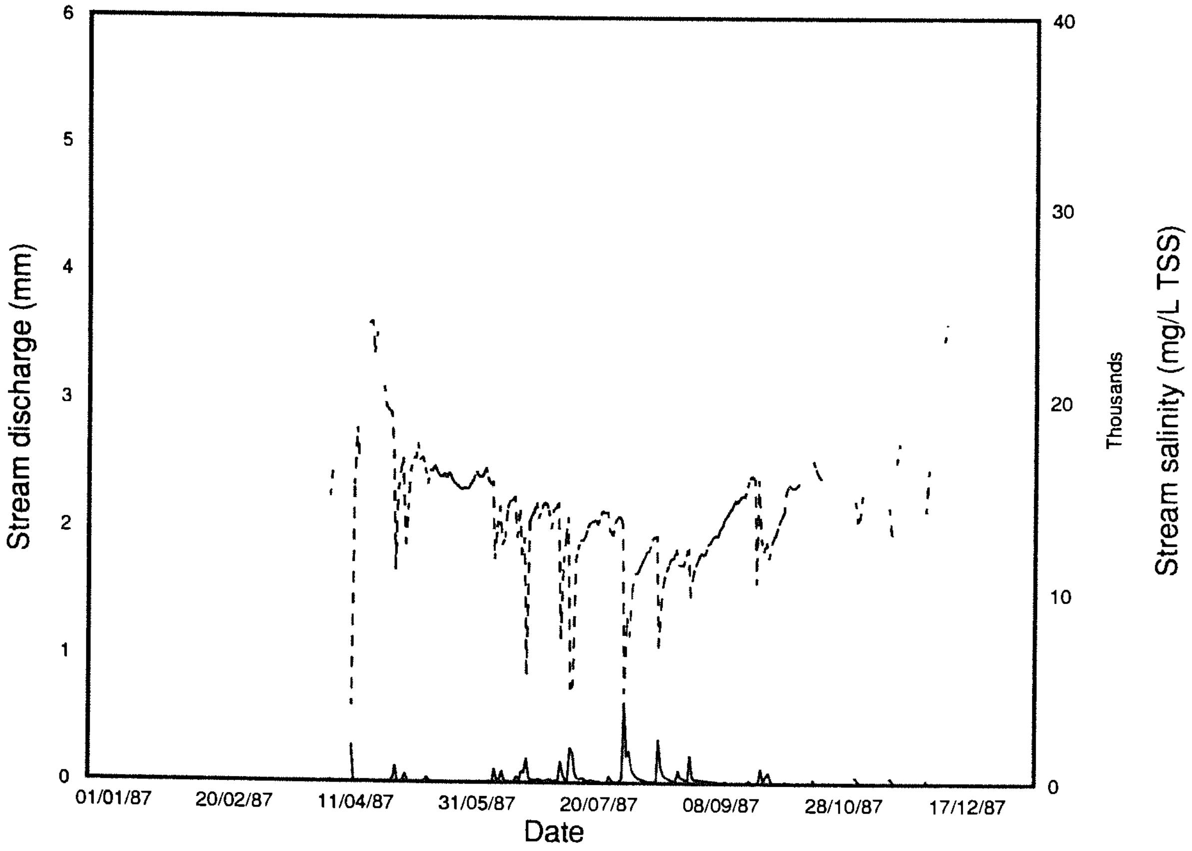

80
70
60
50
40
30
20
10
0
Daily rainfall (mm)
01/01/85
20/02/85
11/04/85
31/05/85
20/07/85
08/09/85
28/10/85
17/12/85
Date

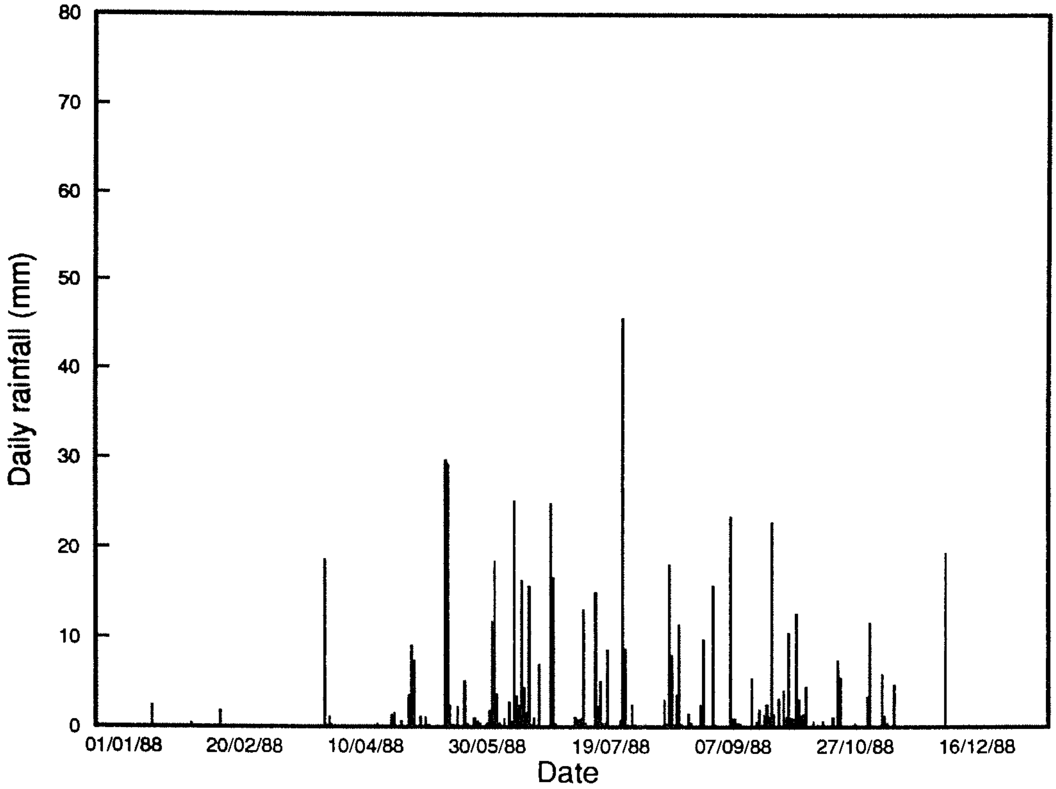

6
5
4
3
2
1
0
Stream discharge (mm)
40
30
20
10
0
Thousands
Stream salinity (mg/L TSS)
01/01/85
20/02/85
11/04/85
31/05/85
20/07/85
08/09/85
28/10/85
17/12/85
Date

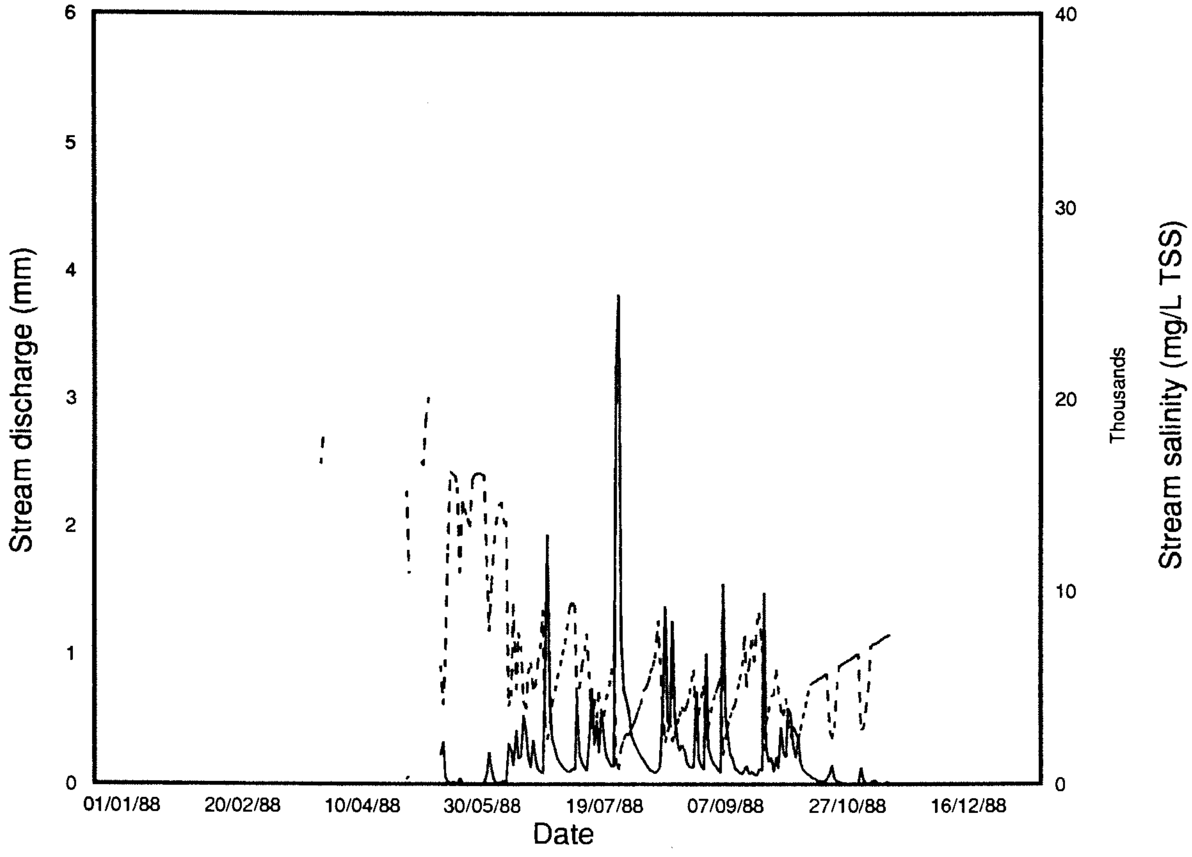

Daily rainfall (mm)
80
70
60
50
40
30
20
10
0
01/01/86
20/02/86
11/04/86
31/05/86
20/07/86
08/09/86
28/10/86
17/12/86
Date

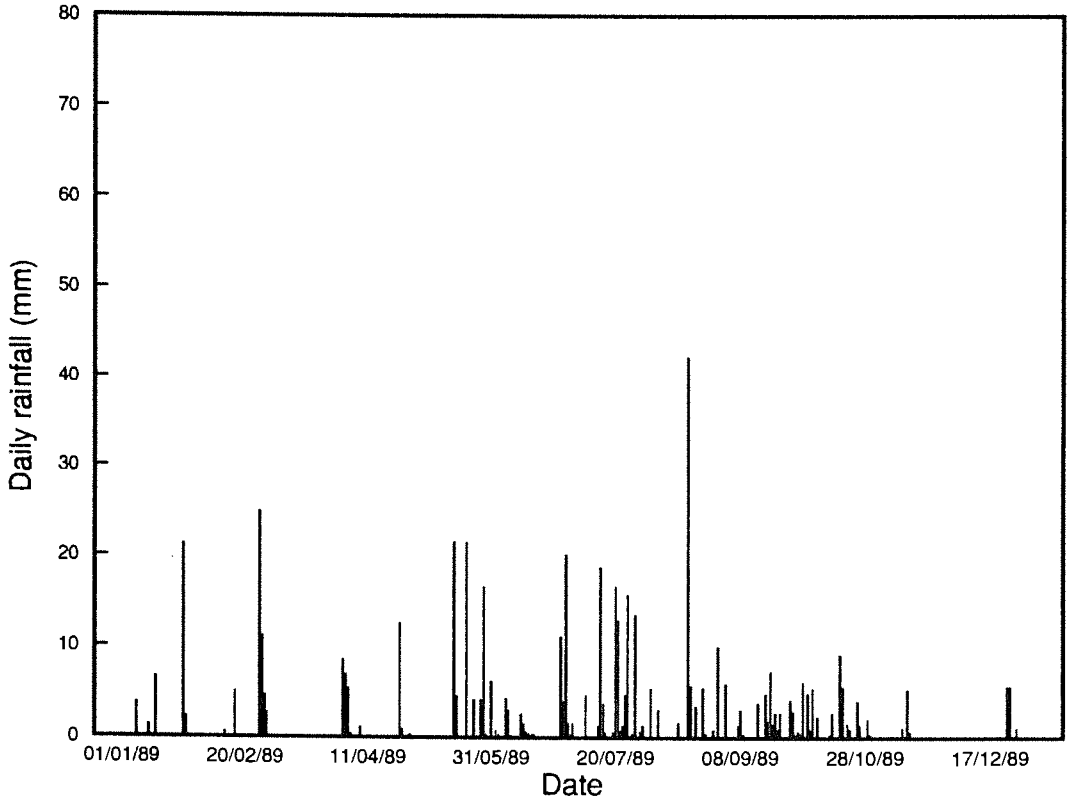

Stream discharge (mm)
6
5
4
3
2
1
0
Thousands
Stream salinity (mg/L TSS)
40
30
20
10
0
01/01/86
20/02/86
11/04/86
31/05/86
20/07/86
08/09/86
28/10/86
17/12/86
Date

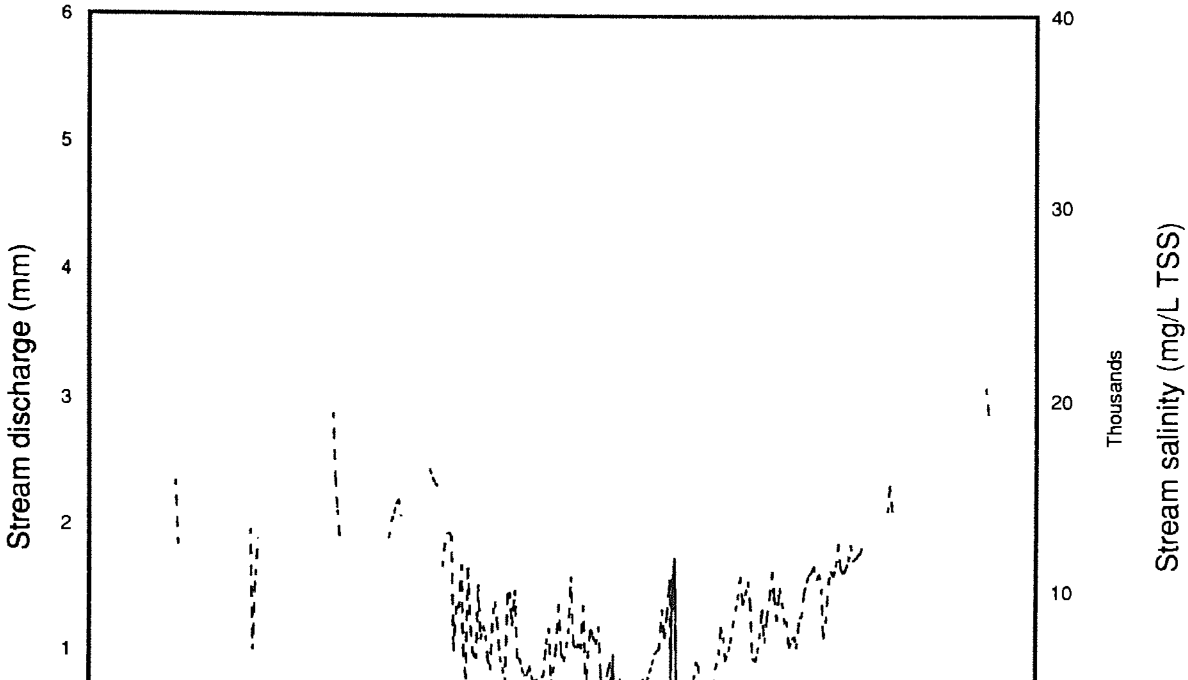

Daily rainfall (mm)
80
70
60
50
40
30
20
10
0
01/01/87
20/02/87
11/04/87
31/05/87
20/07/87
08/09/87
28/10/87
17/12/87
Date

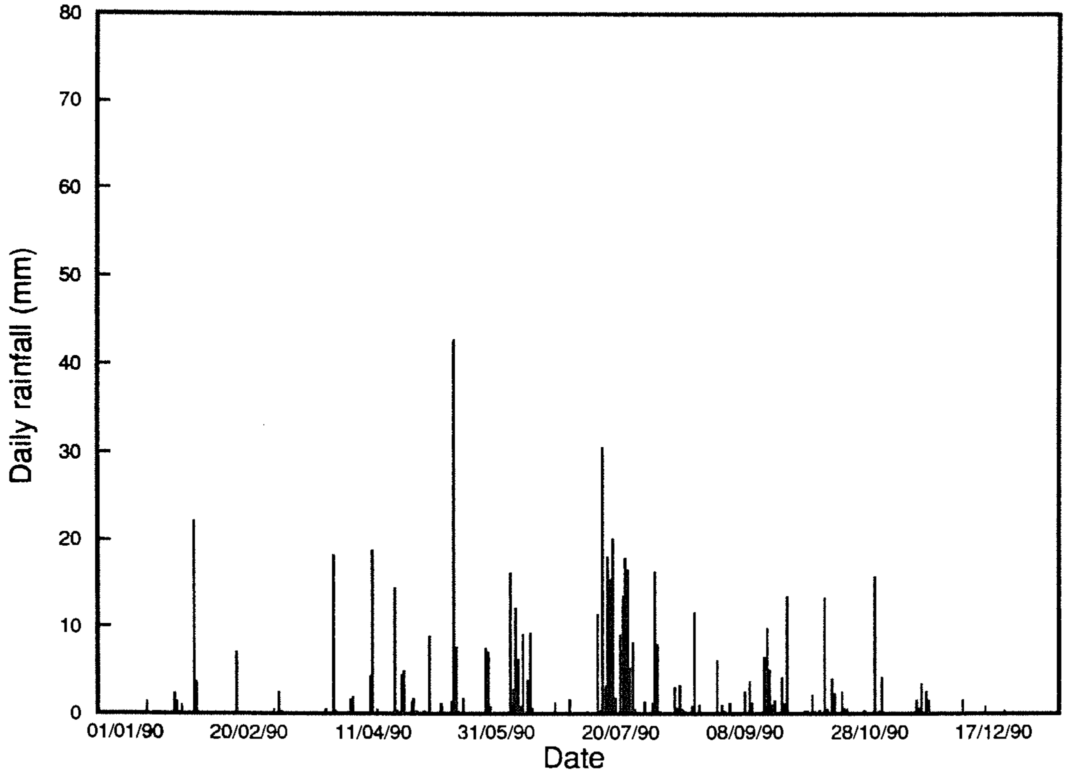

Stream discharge (mm)
6
5
4
3
2
1
0
40
30
20
10
0
Thousands
Stream salinity (mg/L TSS)
01/01/87
20/02/87
11/04/87
31/05/87
20/07/87
08/09/87
28/10/87
17/12/87
Date

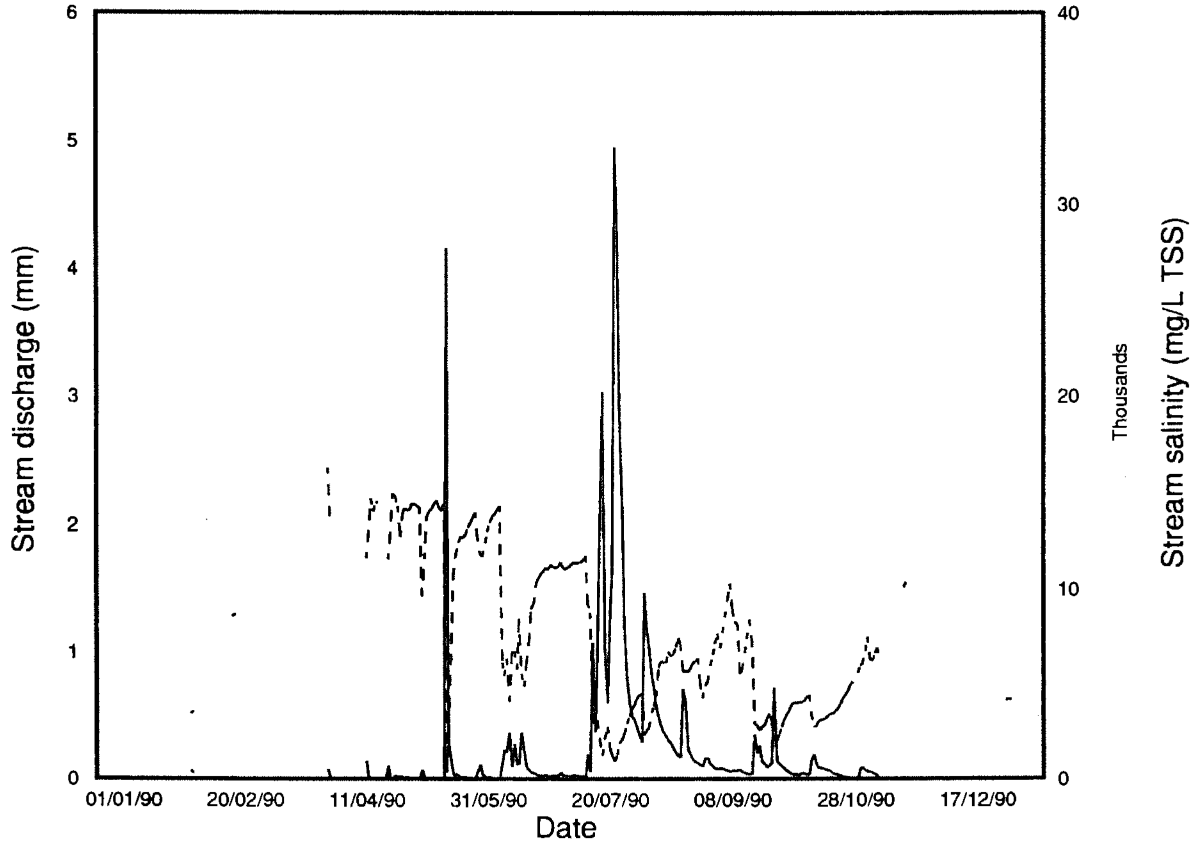

80
70
60
50
40
30
20
10
0
Daily rainfall (mm)
01/01/88
20/02/88
10/04/88
30/05/88
19/07/88
07/09/88
27/10/88
16/12/88
Date


6
5
4
3
2
1
0
Stream discharge (mm)
40
30
20
10
0
Thousands
Stream salinity (mg/L TSS)
01/01/88
20/02/88
10/04/88
30/05/88
19/07/88
07/09/88
27/10/88
16/12/88
Date


80
70
60
50
40
30
20
10
0
Daily rainfall (mm)
01/01/89
20/02/89
11/04/89
31/05/89
20/07/89
08/09/89
28/10/89
17/12/89
Date

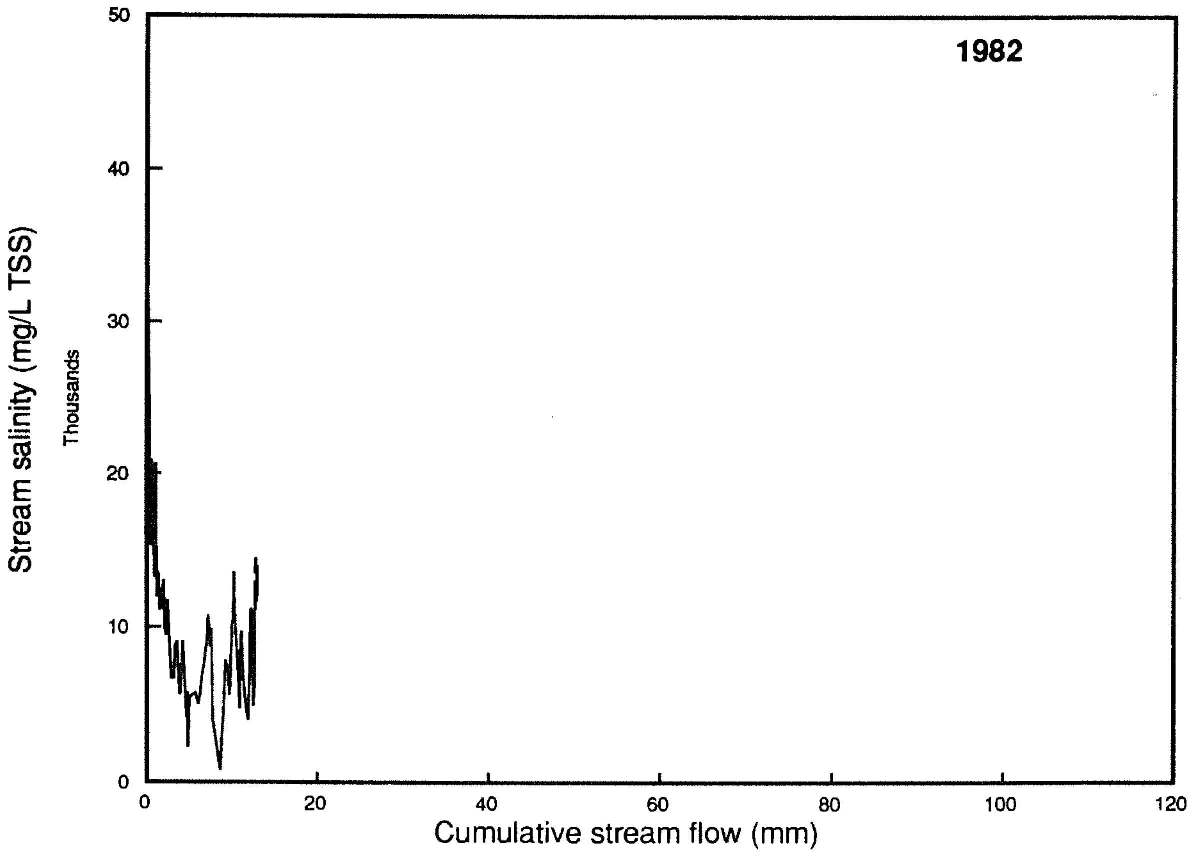

6
5
4
3
2
1
0
Stream discharge (mm)
40
30
20
10
0
Thousands
Stream salinity (mg/L TSS)
01/01/89
20/02/89
11/04/89
31/05/89
20/07/89
08/09/89
28/10/89
17/12/89
Date

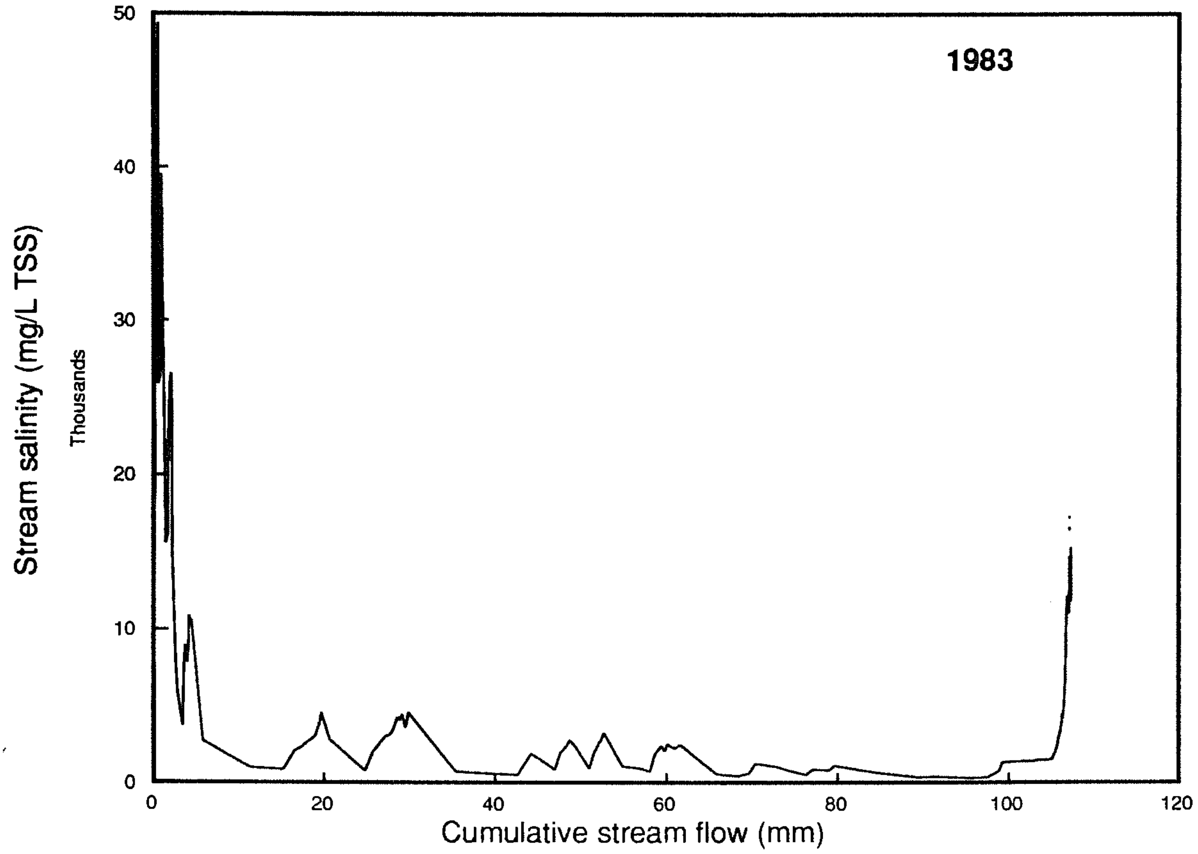

Daily rainfall (mm)
0
10
20
30
40
50
60
70
80
01/01/90
20/02/90
11/04/90
31/05/90
20/07/90
08/09/90
28/10/90
17/12/90
Date

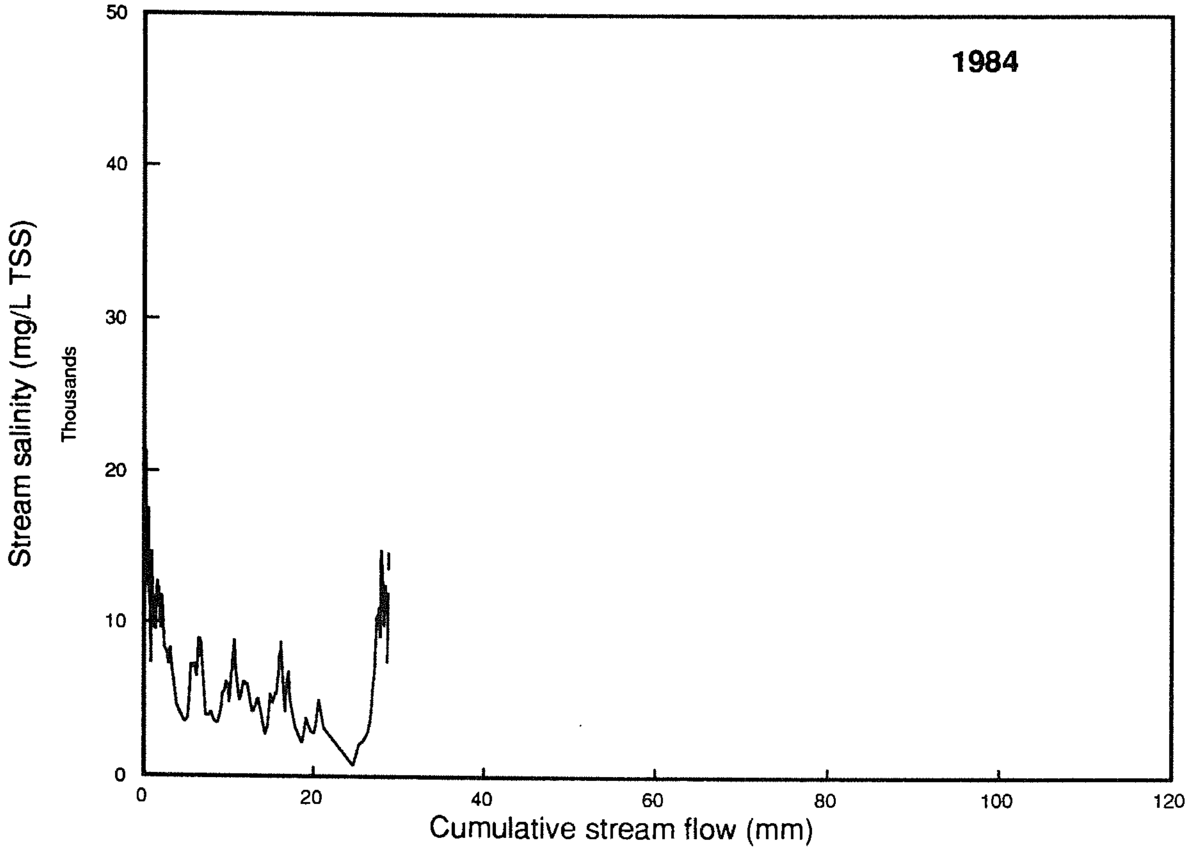

Stream discharge (mm)
0
1
2
3
4
5
6
Stream salinity (mg/L TSS)
Thousands
0
10
20
30
40
01/01/90
20/02/90
11/04/90
31/05/90
20/07/90
08/09/90
28/10/90
17/12/90
Date

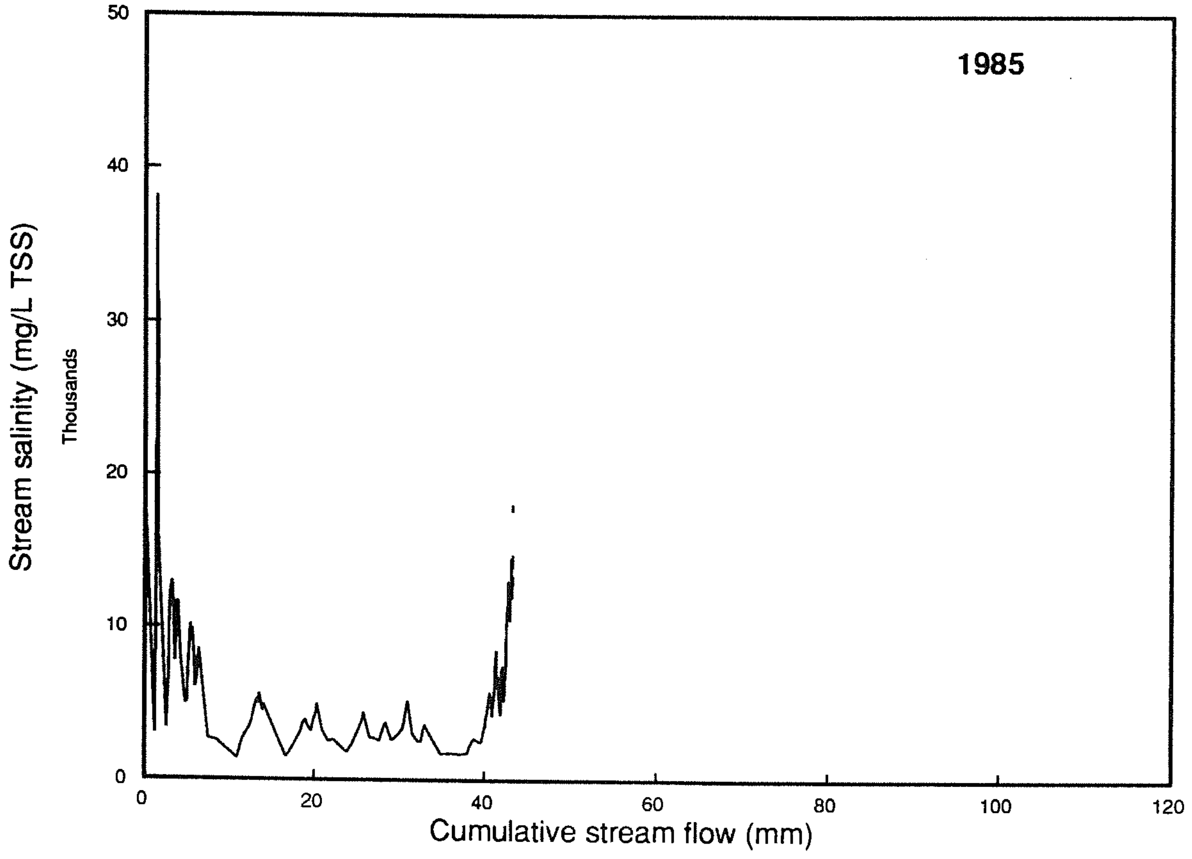
APPENDIX I

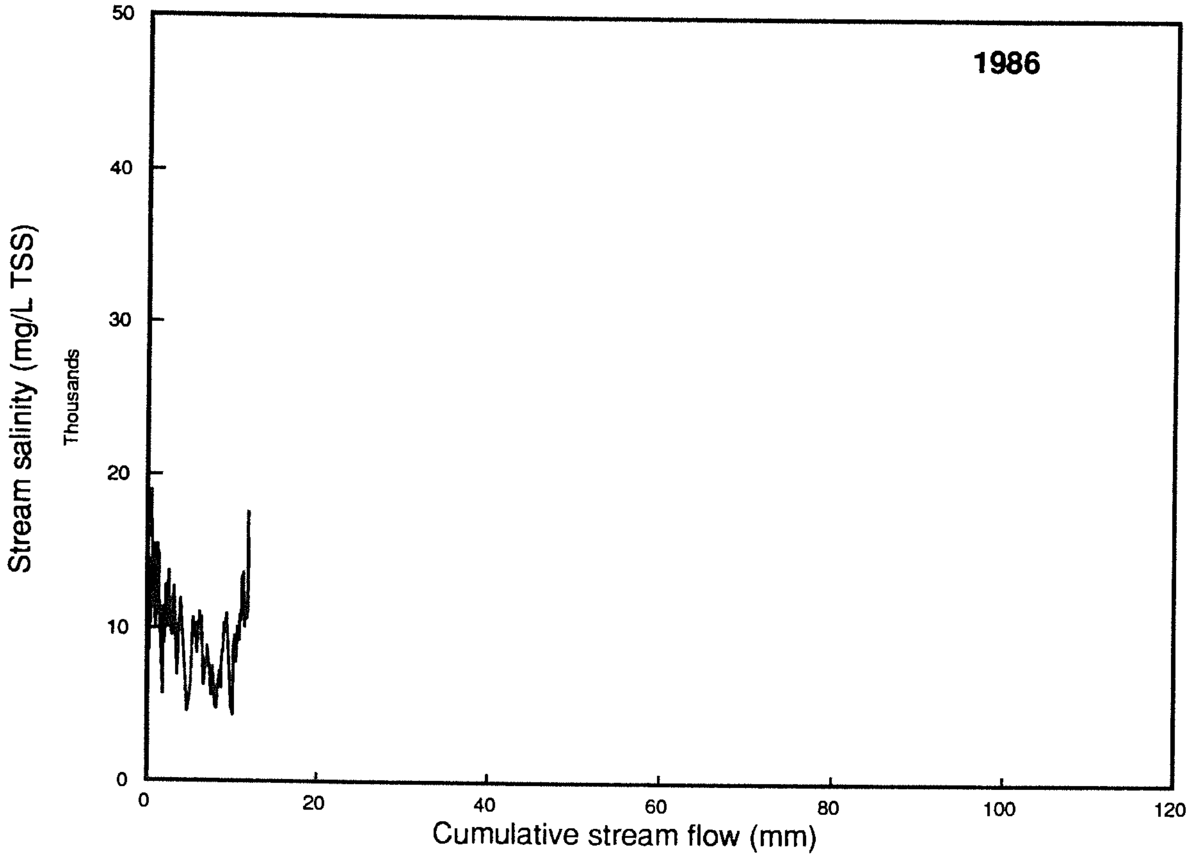
DAILY STREAM SALINITY VERSUS ACCUMULATED STREAMFLOW

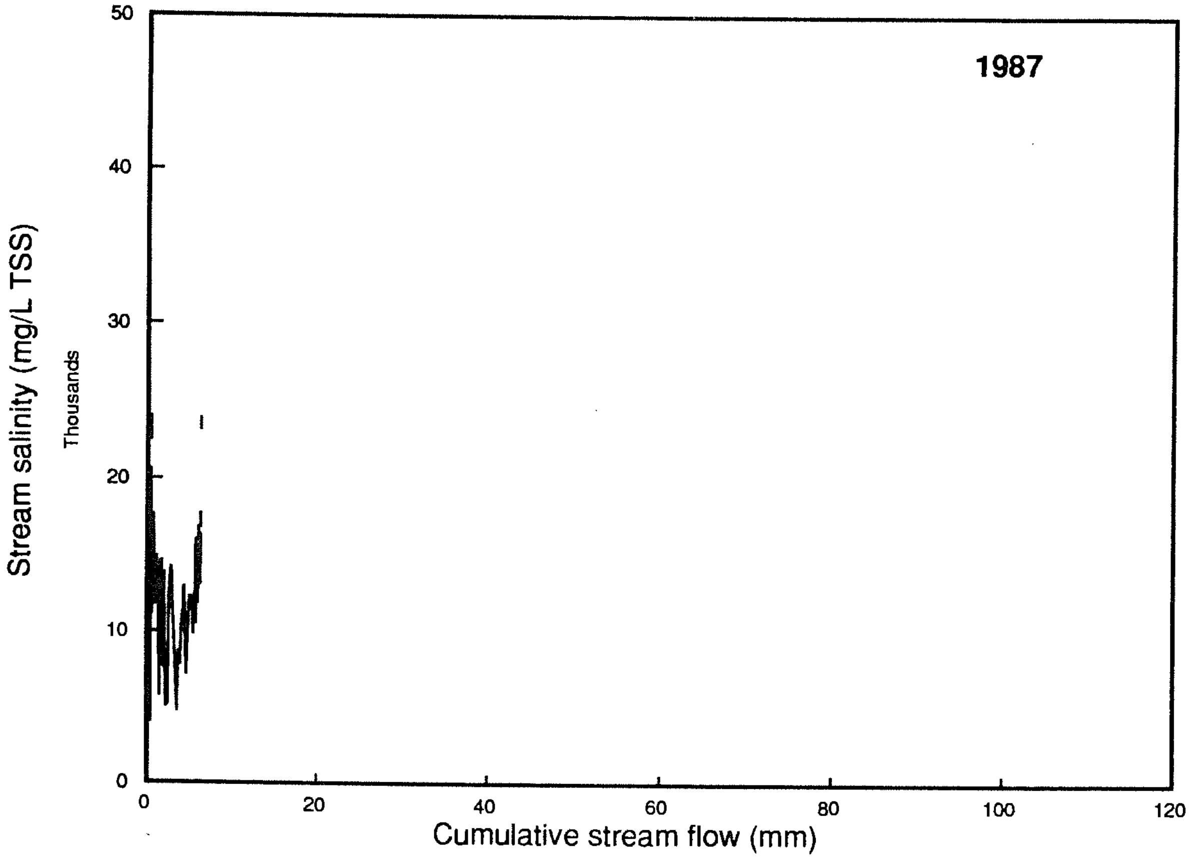

1982
Stream salinity (mg/L TSS)
Thousands
50
40
30
20
10
0
0
20
40
60
80
100
120
Cumulative stream flow (mm)

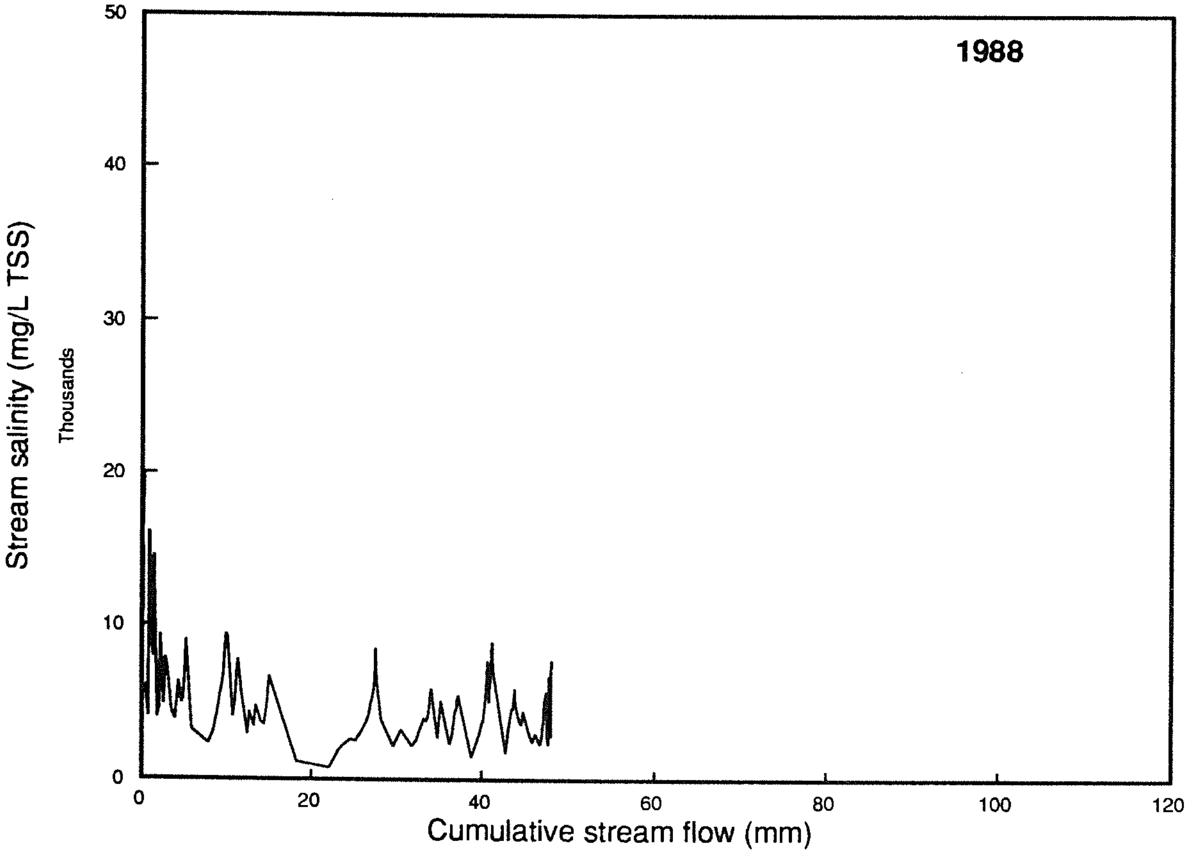

1983
Stream salinity (mg/L TSS)
Thousands
50
40
30
20
10
0
0
20
40
60
80
100
120
Cumulative stream flow (mm)

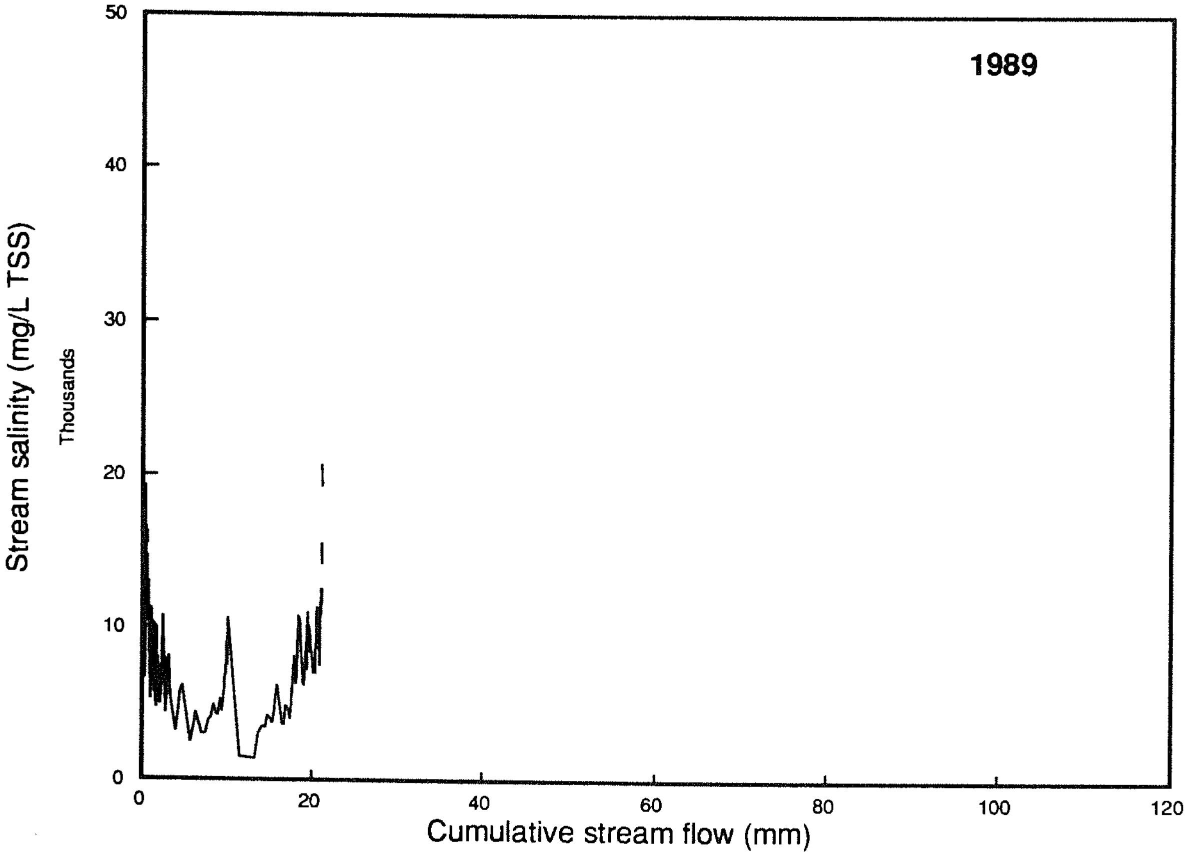

1984
Stream salinity (mg/L TSS)
Thousands
50
40
30
20
10
0
0
20
40
60
80
100
120
Cumulative stream flow (mm)

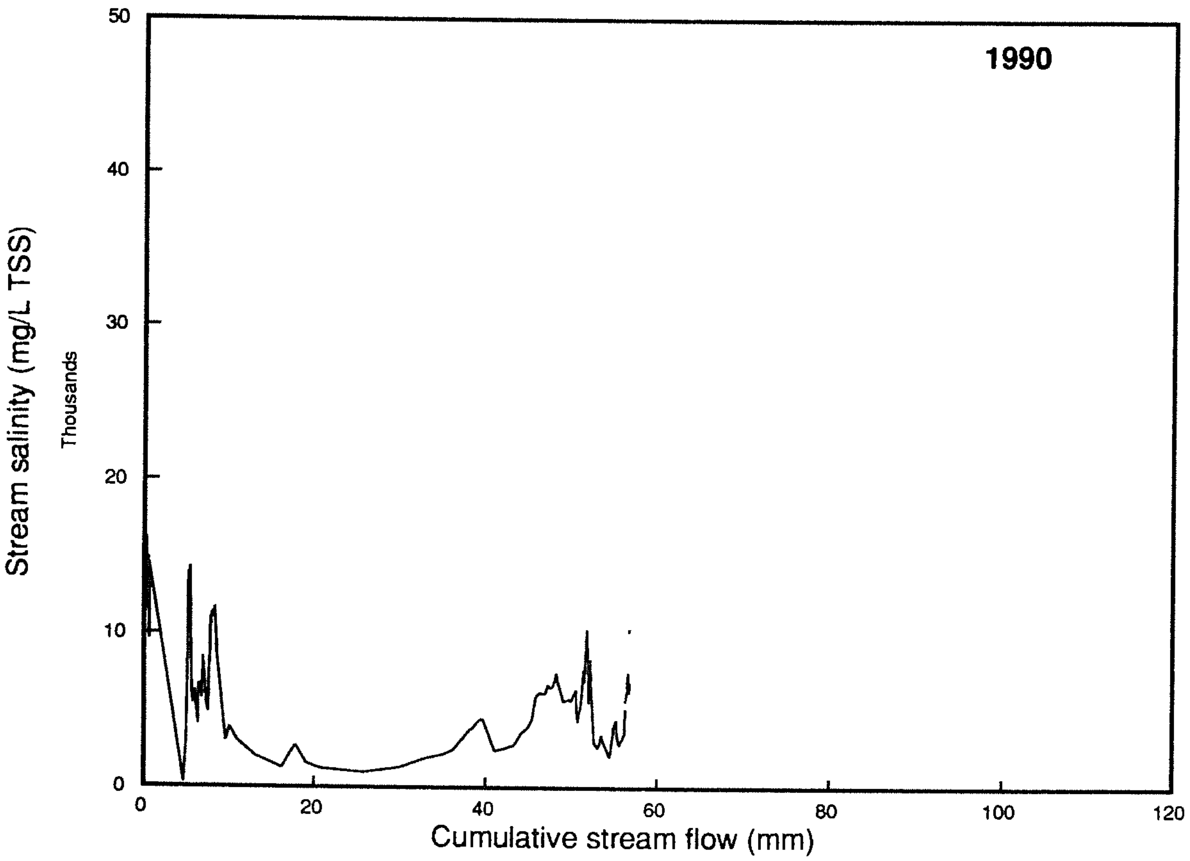

1985
Stream salinity (mg/L TSS)
Thousands
50
40
30
20
10
0
0
20
40
60
80
100
120
Cumulative stream flow (mm)


1986
Stream salinity (mg/L TSS)
Thousands
0
10
20
30
40
50
0
20
40
60
80
100
120
Cumulative stream flow (mm)


1987
Stream salinity (mg/L TSS)
Thousands
0
10
20
30
40
50
0
20
40
60
80
100
120
Cumulative stream flow (mm)

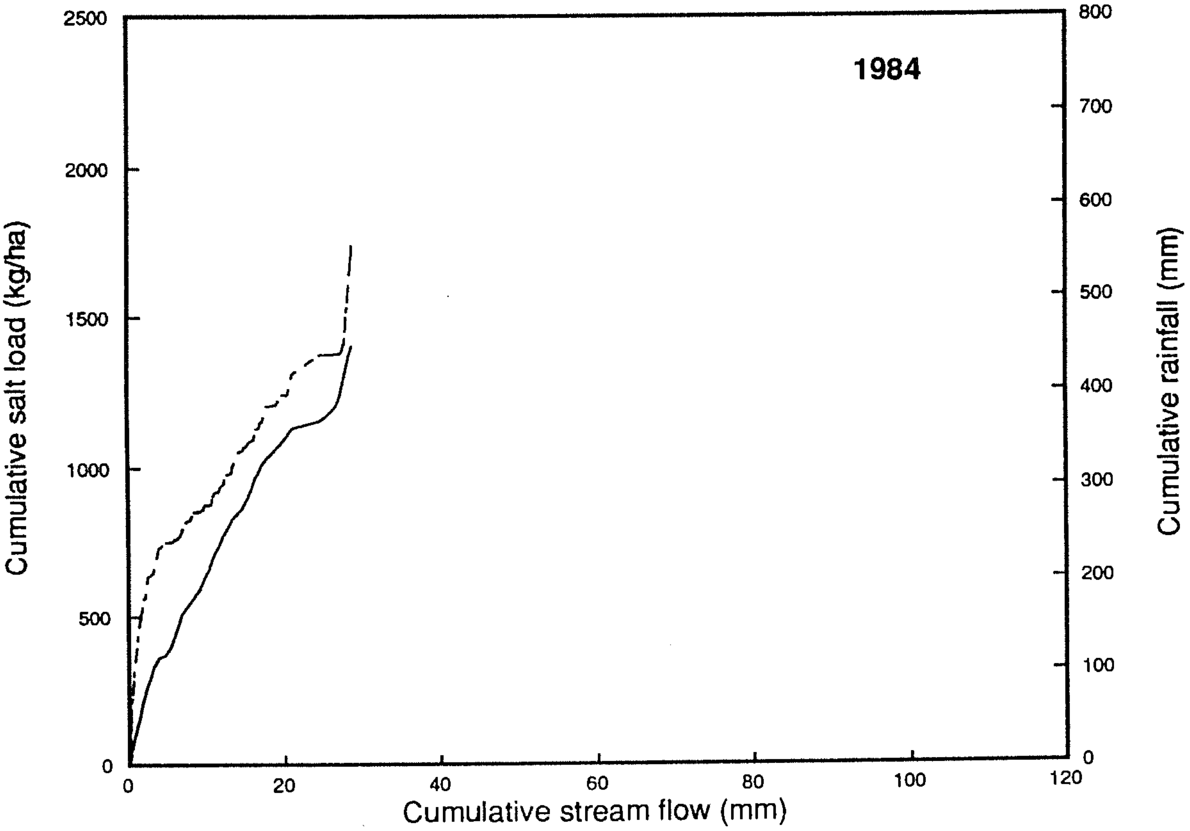

1988
Stream salinity (mg/L TSS)
Thousands
50
40
30
20
10
0
0
20
40
60
80
100
120
Cumulative stream flow (mm)

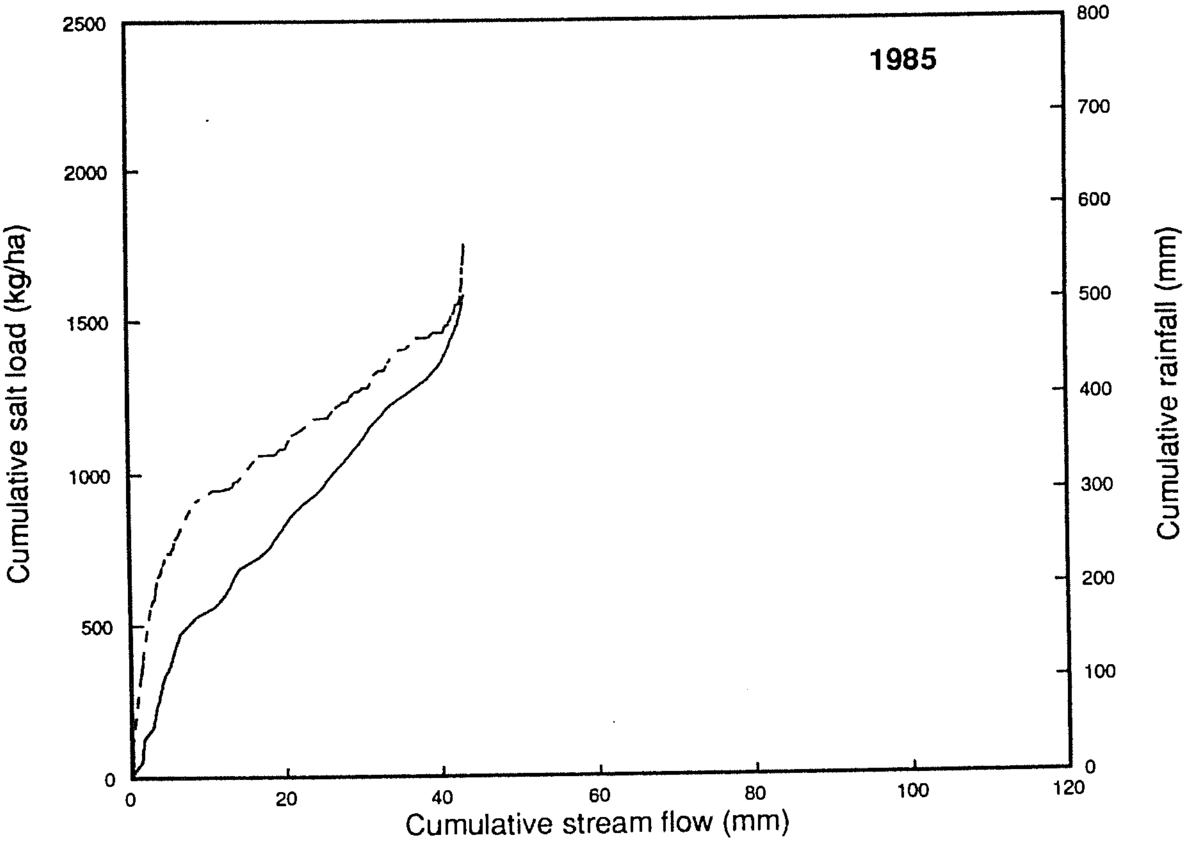

1989
Stream salinity (mg/L TSS)
Thousands
50
40
30
20
10
0
0
20
40
60
80
100
120
Cumulative stream flow (mm)

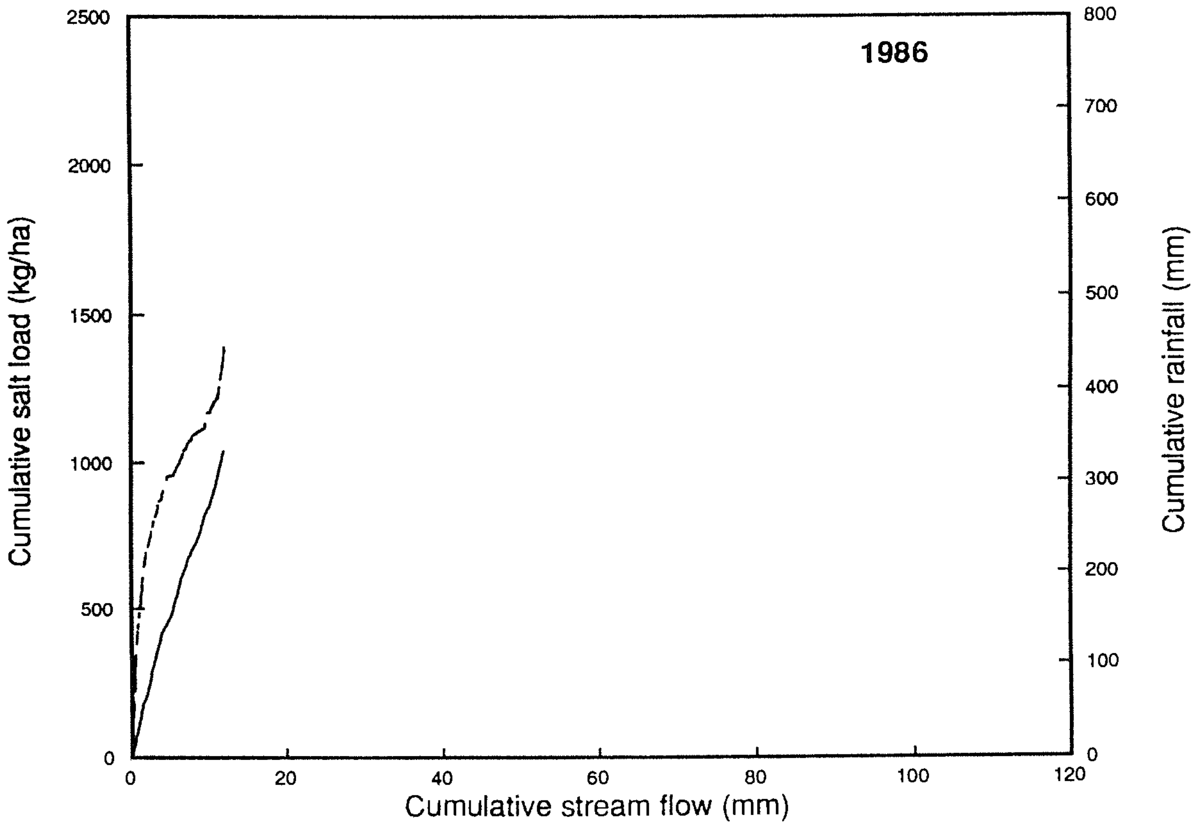

1990
Stream salinity (mg/L TSS)
Thousands
0
10
20
30
40
50
0
20
40
60
80
100
120
Cumulative stream flow (mm)

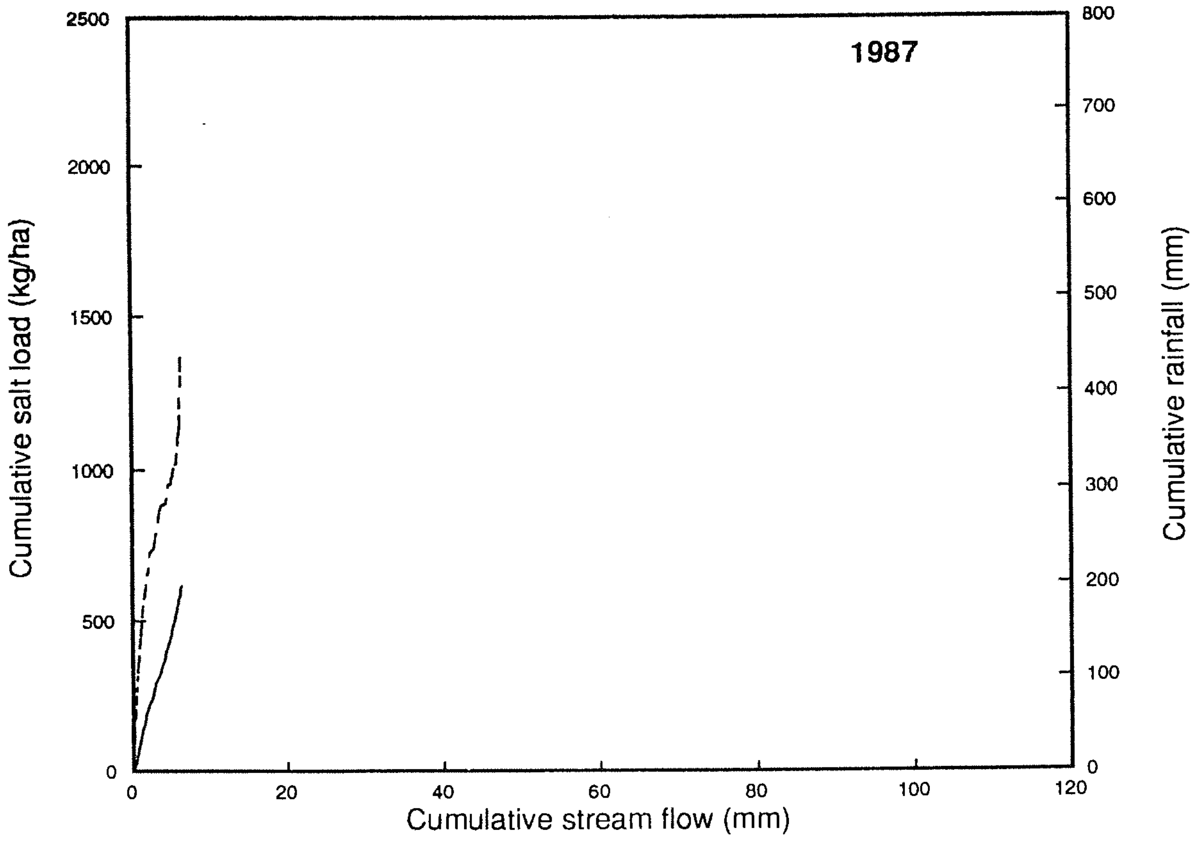
APPENDIX J

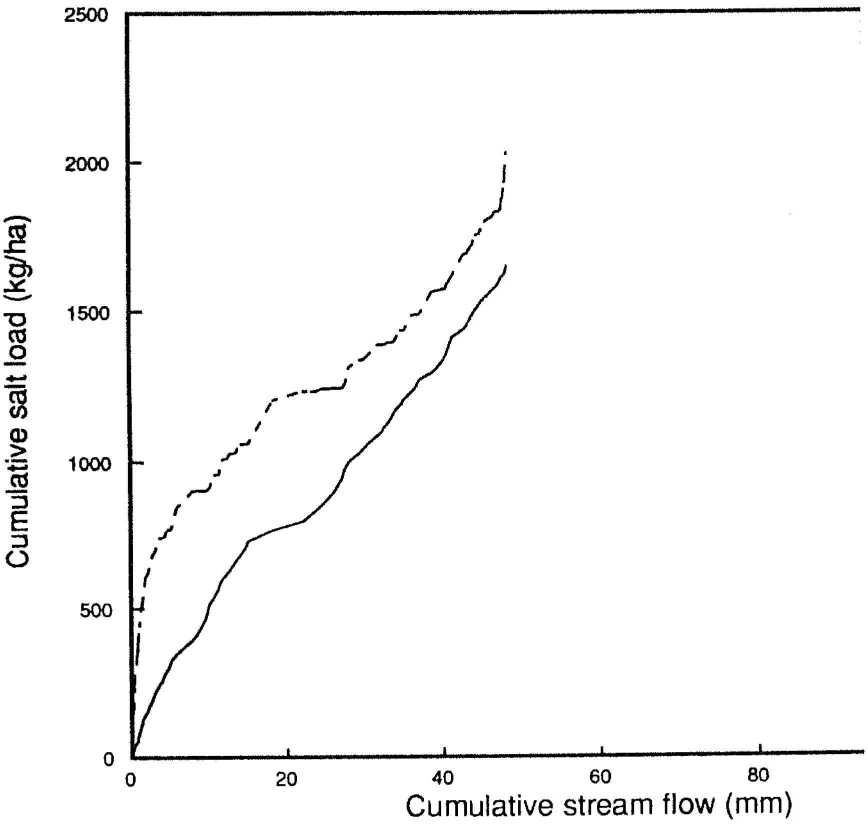
ACCUMULATED STREAM SALT LOAD AND ACCUMULATED STREAMFLOW

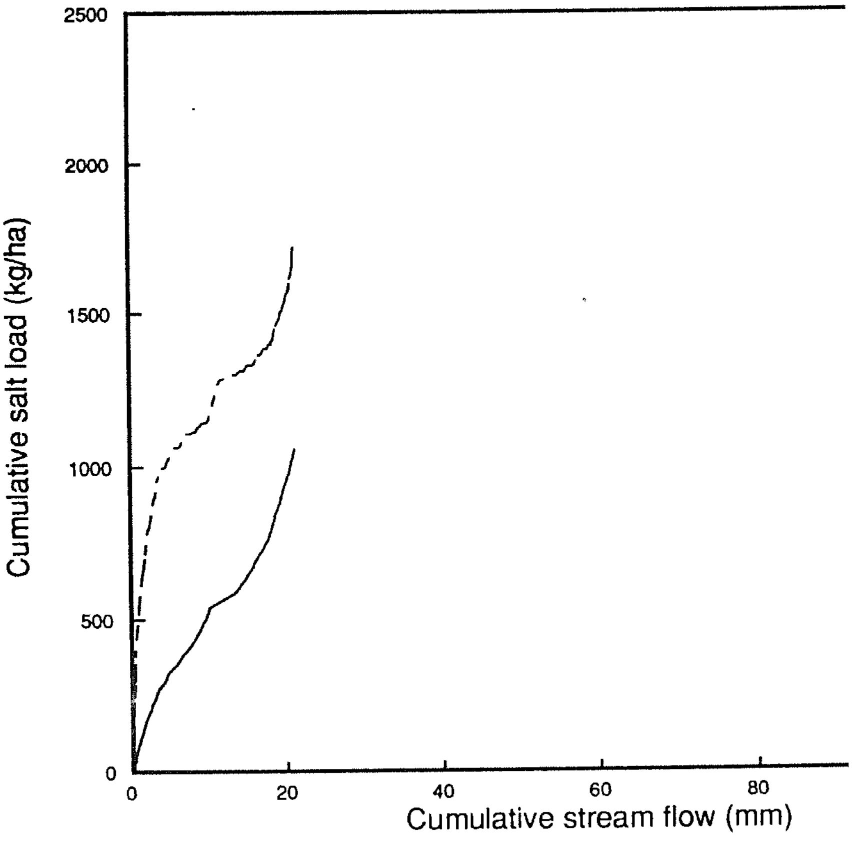

1984
Cumulative salt load (kg/ha)
0
500
1000
1500
2000
2500
Cumulative rainfall (mm)
0
100
200
300
400
500
600
700
800
0
20
40
60
80
100
120
Cumulative stream flow (mm)

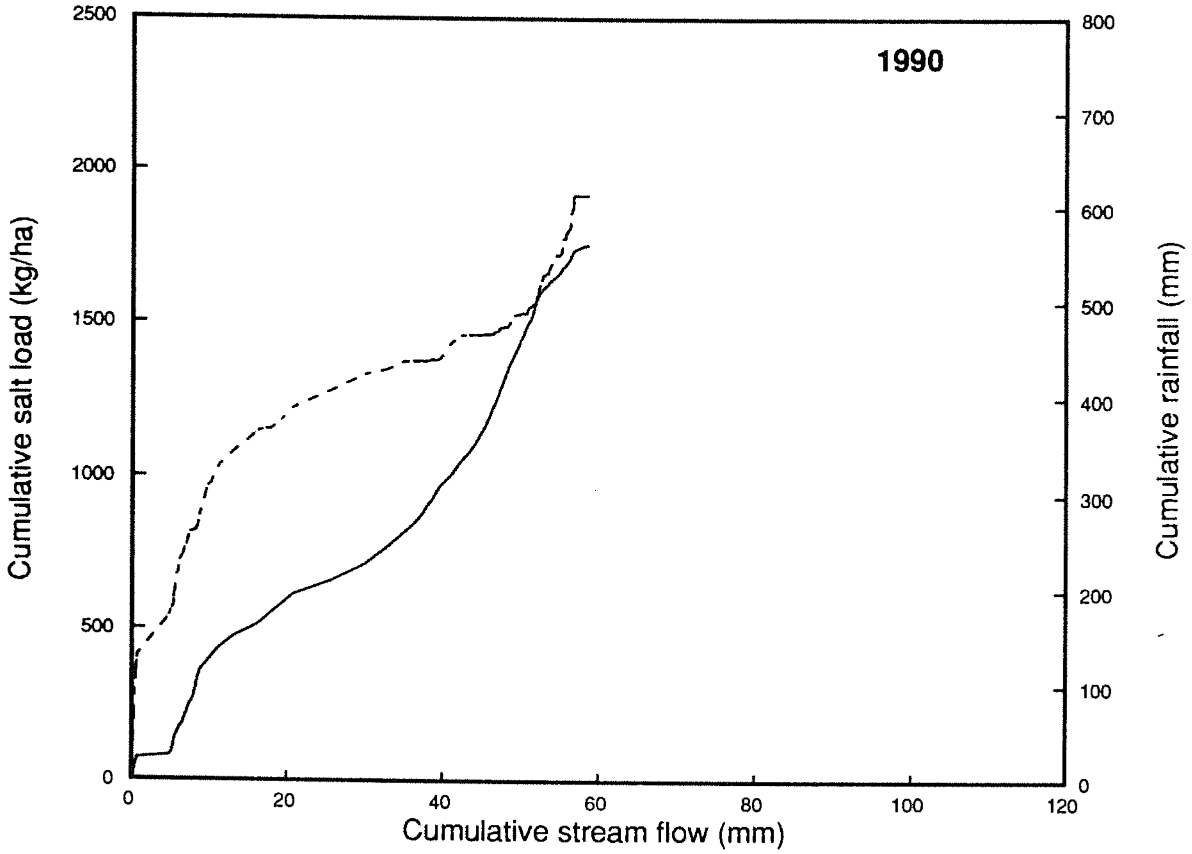

1985
Cumulative salt load (kg/ha)
0
500
1000
1500
2000
2500
Cumulative rainfall (mm)
0
100
200
300
400
500
600
700
800
0
20
40
60
80
100
120
Cumulative stream flow (mm)


1986
Cumulative salt load (kg/ha)
0
500
1000
1500
2000
2500
Cumulative rainfall (mm)
0
100
200
300
400
500
600
700
800
Cumulative stream flow (mm)
0
20
40
60
80
100
120


1987
Cumulative salt load (kg/ha)
0
500
1000
1500
2000
2500
Cumulative rainfall (mm)
0
100
200
300
400
500
600
700
800
Cumulative stream flow (mm)
0
20
40
60
80
100
120


2500
2000
1500
1000
500
0
0
20
40
60
80
Cumulative salt load (kg/ha)
Cumulative stream flow (mm)


2500
2000
1500
1000
500
0
0
20
40
60
80
Cumulative salt load (kg/ha)
Cumulative stream flow (mm)


1990
Cumulative salt load (kg/ha)
0
500
1000
1500
2000
2500
Cumulative rainfall (mm)
0
100
200
300
400
500
600
700
800
Cumulative stream flow (mm)
0
20
40
60
80
100
120

APPENDIX K

COMPUTER PROGRAMME

```
C      THIS PROGRAM IS WRITTEN TO DETERMINE STREAM SALINITY,
C      STREAM SALT LOAD AND STREAM FLOW COMPONENTS
C
       DIMENSION SALTMU(12), SALTMG(12), FLOWMR(12),
     + FLOWMU(12),FLOWMG(12), FLOWMT(12), SALTMT(12),
     + TSSMC(12), RANM(12), RANM1(12), RAIN(5000),
     + TSST(5000), SALTT(5000),FLOWT(5000),FLOWB(5000),
     + FLOWR(5000), TSSCB(5000), IMNTH(5000), IYEAR(5000)
     + , SALTMR(12), FLOWDG(500), FLOWDU(500)
       DATA  TSSCR,TSSCU, TSSCG /10.0,750.0, 18000.0/
       CHARACTER*80 DUMMY


       OPEN(UNIT=11, FILE='B:\MSALTD.DAT', STATUS='OLD')
       OPEN(UNIT=21, FILE='B:\MARSAL.OUT', STATUS='UNKNOWN')

       READ(11,31) DUMMY
       READ(11,31) DUMMY
       READ(11,31) DUMMY
       READ(11,31) DUMMY
       READ(11,31) DUMMY
       READ(11,31) DUMMY
       READ(11,31) DUMMY
31     FORMAT(A80)

C
       KK=0
       DO 10 J=1, 500
       READ(11,41,END=99) IMNTH(J), IYEAR(J), SALTT(J),
     + FLOWT(J),TSST(J), RAIND,RAIND1
41     FORMAT(12X,I2,1X,I2,18X,F10.4,12X,F10.4,10X,F12.4,
     + 4X,F8.1, 4X,F8.1)
       KK= KK+1
       RAIN(J) = RAIND1
10     CONTINUE
99     CONTINUE
C
C      SEPERATION OF BASE FLOW AND DIRECT RUNOFF
C
       NN=1
       M =0
C
       WRITE(*,*) KK
       DO 60 J=1, KK
       IF(FLOWT(J).EQ.0.0) GO TO 70
C       FLDIF=FLOWT(J)-FLOWT(J+1)
       IF(RAIN(J).LT.1.0) GO TO 70
        IF(NN.GT.1) GO TO 90
         NN=1
         DEL=2.0
         M=1
         NM=0
         DO 120 IJ=1,5
          IF(NM.EQ.1) GO TO 120
          IF(RAIN(J+IJ).GT.1.0) THEN
           M=M+1
           DEL= DEL+1.0
C           WRITE(21,*) J, IJ, M, DEL
          ELSE
```

```
             NM=1
C            DEL=2.0
            FLOWDL=(FLOWT(J+M)-FLOWT(J-1))/DEL
            IF(FLOWDL.LT.0.0) FLOWDL=0.0
            TSSDL =(TSST(J+M)-TSST(J-1))/DEL
            IF(TSSDL.GT.0.0) TSSDL=0.0
             DO 80 L=1,M+1
              SDEL = SDEL + 1.0
              FLOWB(J+L-1)= FLOWT(J-1)+FLOWDL*SDEL
              IF(FLOWB(J+L-1).GE.FLOWT(J+L-1))
     +                FLOWB(J+L-1)=FLOWT(J+L-1)
              FLOWR(J+L-1)=FLOWT(J+L-1)-FLOWB(J+L-1)
              IF(FLOWR(J+L-1).LT.0.0) FLOWR(J+L-1)=0.0
              TSSCB(J+L-1)=TSST(J-1)+TSSDL*SDEL
             IF(TSSCB(J+L-1).LE.0.0) TSSCB(J+L-1)=TSST(J+L-1)
C            WRITE(21,111)J, L, M,FLOWT(J), FLOWR(J),
     +       FLOWB(J), RAIN(J)
C            WRITE(21,111) J,FLOWT(J+L-1), FLOWR(J+L-1),
C    +       FLOWB(J+L-1),RAIN(J+L-1), TSSCB(J+L-1),
C    +       TSST(J+L-1)
 80          CONTINUE
111          FORMAT(I5,8F10.2)
             SDEL=0.0
          NN=M+1
          M = 0
          ENDIF
120      CONTINUE
         NM=0
90      CONTINUE
        NN=NN-1
C       WRITE(21,111) J, IJ, NN, FLOWT(J), RAIN(J)
       GO TO 60
 70    CONTINUE
       NN=1
       FLOWR(J)=0.0
       FLOWB(J)=FLOWT(J)
       TSSCB(J)=TSST(J)
C       WRITE(21,111) J,FLOWT(J), FLOWR(J), FLOWB(J),
C    +  RAIN(J),TSSCB(J), TSST(J)
 60    CONTINUE
       DO 130 J=1,500
       WRITE(21,111) J,FLOWT(J), FLOWR(J), FLOWB(J),
     + RAIN(J),TSSCB(J), TSST(J), FLOWT(J)-FLOWR(J)-FLOWB(J)
130    CONTINUE
C
C      CALCULATE EACH COMPONENT
C
       DO 100 I=2, KK
       IDIFY = IYEAR(I)-IYEAR(I-1)
       IDIFF = IMNTH(I) - IMNTH(I-1)
         IF(TSSCB(I).LT.TSSCG) GO TO 40
             FLOWDG(I) = FLOWB(I)
             FLOWDU(I) = 0.0
        GO TO 50
40      CONTINUE
        IF(TSSCB(I).LT.TSSCU) THEN
         FLOWDU(I)= FLOWB(I)
         FLOWDG(I)=0.0
         ELSE
         FLOWDU(I) = FLOWB(I)*(TSSCG-TSSCB(I))/(TSSCG-TSSCU)
```

```
         FLOWDG(I) = FLOWB(I)-FLOWDU(I)
        ENDIF
50      CONTINUE
C       SUM UP MONTHLY VALUES
C
        IF(IDIFF.EQ.0) THEN
        SUMSALTD=SUMSALTD+SALTT(I)
        SUMFLOWD=SUMFLOWD+FLOWT(I)
        SUMFLWDU= SUMFLWDU+ FLOWDU(I)
        SUMFLWDG= SUMFLWDG+ FLOWDG(I)
        SUMFLWDR= SUMFLWDR+ FLOWR(I)
        SUMRAIND=SUMRAIND+RAIN(I)
         IF(TSSCB(I).GE.TSSCG) THEN
              SUMSLTDG=SUMSLTDG+FLOWDG(I)*TSSCB(I)/1000.0
            ELSE
              SUMSLTDG=SUMSLTDG+FLOWDG(I)*TSSCG/1000.0
            ENDIF
       SUMSLTDU=SUMSLTDU+FLOWDU(I)*TSSCU/1000.0
       SUMFLTSS=SUMFLTSS + FLOWT(I)*TSST(I)/1000.0
       ELSE
        SALTMT(IMNTH1)=SUMSALTD
        FLOWMT(IMNTH1)=SUMFLOWD
        FLOWMR(IMNTH1) = SUMFLWDR
        FLOWMU(IMNTH1) = SUMFLWDU
        FLOWMG(IMNTH1) = SUMFLWDG
         SALTMU(IMNTH1) = SUMSLTDU
         SALTMG(IMNTH1) = SUMSLTDG
         SALTMR(IMNTH1) = FLOWMR(IMNTH1)*TSSCR/1000.0
C        SALTMU(IMNTH1) = FLOWMU(IMNTH1)*TSSCU/1000.0
C        SALTMG(IMNTH1) = FLOWMG(IMNTH1)*TSSCG/1000.0
         IF(SUMFLOWD.EQ.0.0) THEN
         TSSMC(IMNTH1) = 0.0
          ELSE
          TSSMC(IMNTH1) =(SUMFLTSS/SUMFLOWD)*1000.0
         ENDIF

        RANM(IMNTH1) =SUMRAIND

61      FORMAT(10X,2I10, 10F10.4//)
        SUMSALTD=SALTT(I)
        SUMFLOWD=FLOWT(I)
        SUMFLWDR=FLOWR(I)
        SUMFLWDU=FLOWDU(I)
        SUMFLWDG=FLOWDG(I)
        SUMRAIND=RAIN(I)
        SUMSLTDU=FLOWDU(I)*TSSCU/1000.0
        SUMSLTDG=FLOWDG(I)*TSSCG/1000.0
        SUMFLTSS=FLOWT(I)*TSST(I)/1000.0
        IMNT   = IMNTH1
        IYER   = IYEAR1
        IMNTH1 = IMNTH(I)
        IYEAR1 = IYEAR(I)
       ENDIF
       IF(IDIFY.EQ.0) GO TO 100

C      SUM UP ALL MONTHLY VALUES
       SFLOWMT=0.0
       SFLOWMR=0.0
       SFLOWMU=0.0
       SFLOWMG=0.0
```

```
       SSALTMU=0.0
       SSALTMG=0.0
       SSALTMT=0.0
       SRANMT =0.0
       DO 30 II=1, 12
       SFLOWMT = SFLOWMT+ FLOWMT(II)
       SFLOWMR = SFLOWMR+ FLOWMR(II)
       SFLOWMU = SFLOWMU+ FLOWMU(II)
       SFLOWMG = SFLOWMG+ FLOWMG(II)
       SSALTMR = SSALTMR+ SALTMR(II)
       SSALTMU = SSALTMU+ SALTMU(II)
       SSALTMG = SSALTMG+ SALTMG(II)
       SSALTMT = SSALTMT+ SALTMT(II)
       SRANMT = SRANMT+ RANM(II)
       WRITE(21,71) II, IYER, FLOWMR(II),FLOWMU(II),
     + FLOWMG(II), FLOWMT(II),SALTMR(II), SALTMU(II),
     + SALTMG(II), SALTMT(II), TSSMC(II), RANM(II)
 71    FORMAT(10X, 2I10, 12F10.4) 30     CONTINUE
        WRITE(21,71) IMNT, IYER, SFLOWMR, SFLOWMU, SFLOWMG,
     +  SFLOWMT,SSALTMR, SSALTMU, SSALTMG, SSALTMT, SRANMT
       IMNTH1=IMNTH(I)
       IYEAR1=IYEAR(I) 100    CONTINUE

       STOP
       END
```