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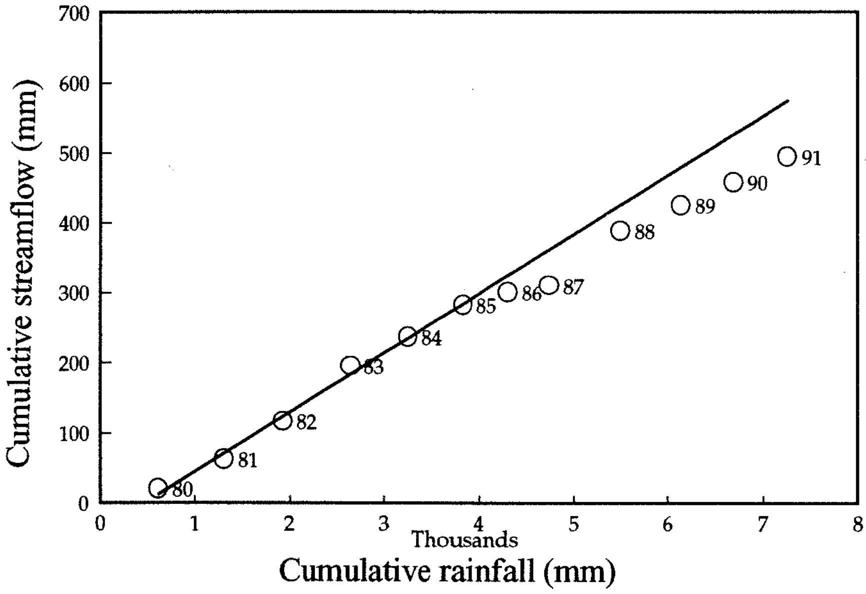

Report No. WS107
August 1992

Water Authority
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Water Resources Directorate
Surface Water Branch

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SUMMARY

In the 1970s, salinity developed in the Wellington reservoir in the south-west of Western Australia as a result of the clearing of native forest for pasture development. Clearing mainly occurred in the lower rainfall zone of the catchment which contributes more than 50% of salt and less than 10% of flow to the reservoir. Initiatives were taken to reverse the process by partial reforestation of the cleared land. A gauging station was established at the Batalling Creek catchment (a subcatchment of Wellington Dam catchment) to monitor the effects of reforestation on streamflow and stream salinity. By 1986, 40% of the cleared land in the Batalling Creek catchment was reforested, mainly on the lower slopes.

The groundwater level beneath reforestation declined by 0.3 m and groundwater salinity declined by 5%. At the valley seep area, the groundwater level increased by 0.3 m but the groundwater salinity remained unchanged. During the study period (1980-91), reforestation lead to a systematic reduction in streamflow due to a reduction in the surface runoff and shallow subsurface flow components. However, the discharge from deep groundwater increased slightly. After reforestation, the streamflow and the flow-weighted stream salinity relationship changed such that the stream salinity increased for a given streamflow volume. In terms of stream salt discharge, the effects of reforestation remained unclear. Since 1985, the annual rainfall has been below the long term average of 640 mm and often below 600 mm. If average rainfall had occurred during this investigation, the reduction in streamflow would have been less.

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1 INTRODUCTION

Land and stream salinisation is a major environmental and economic problem in the arid and semi-arid regions of the world (Dudal and Purnell, 1986). In Western Australia more than 443000 ha of once productive farmland is salt affected (Australian Bureau of Statistics, Personal Communication, 1989) and is increasing at the rate of 18000 ha yr^{-1} (Schofield, 1989). Currently only 48% of the State's total surface water resources remain fresh (<500 mg L^{-1} Total Soluble Salts, TSS).

Extensive investigations in Western Australia and other states shows that land and stream salinisation results from man-induced changes in the water and salt balances in the landscape which existed before European settlement. Land and stream salinity has increased due to the replacement of deep-rooted, perennial vegetation with shallow-rooted agricultural crops and pastures (Ruprecht and Schofield, 1991; Allison, et, al., 1990; Schofield and Ruprecht, 1989; Schofield et,al., 1988; Peck and Williamson, 1987; Wood, 1924). As a result of this landuse change, groundwater recharge has increased and groundwater levels have risen. Research has shown rising groundwater levels mobilise the salt previously 'stored' in the unsaturated zone of the soil profile and discharges to the land surface and streams (Williamson, 1986). This process has also increased the streamflow (Ruprecht and Schofield, 1989); but not enough to balance the increase in stream salinity.

In 1978, the State Government passed legislation to control large scale agricultural development on the Wellington Dam catchment, the largest water supply catchment in the south-west of Western Australia (Fig. 1). At that time it was recognised that stream salinity may increase further due to previous clearing, and active rehabilitation was necessary in the 600-700 mm rainfall zone of the catchment. A significant proportion of the area of this rainfall zone had been cleared and large quantities of salt existed in the landscape. Almost 50% of salt and less than 10% of inflow to the reservoir originates from this region. In the 1980s, trees were planted in this region to control and reverse the current trend of rising groundwater level and salinity. The trees were planted mainly on the lower slopes, adjacent to the streamline to minimise saline groundwater discharge to the stream. The desired result was to have lower salinity in the reservoir without a significant decrease in total flow.

Batalling Creek catchment, a subcatchment of Wellington Dam catchment, was instrumented in 1976 to monitor the effects of reforestation on streamflow and salinity (Fig. 1). Reforestation commenced in 1985. This paper presents the results of 12 years monitoring of groundwater levels, streamflow and salinity within the Batalling Creek catchment.

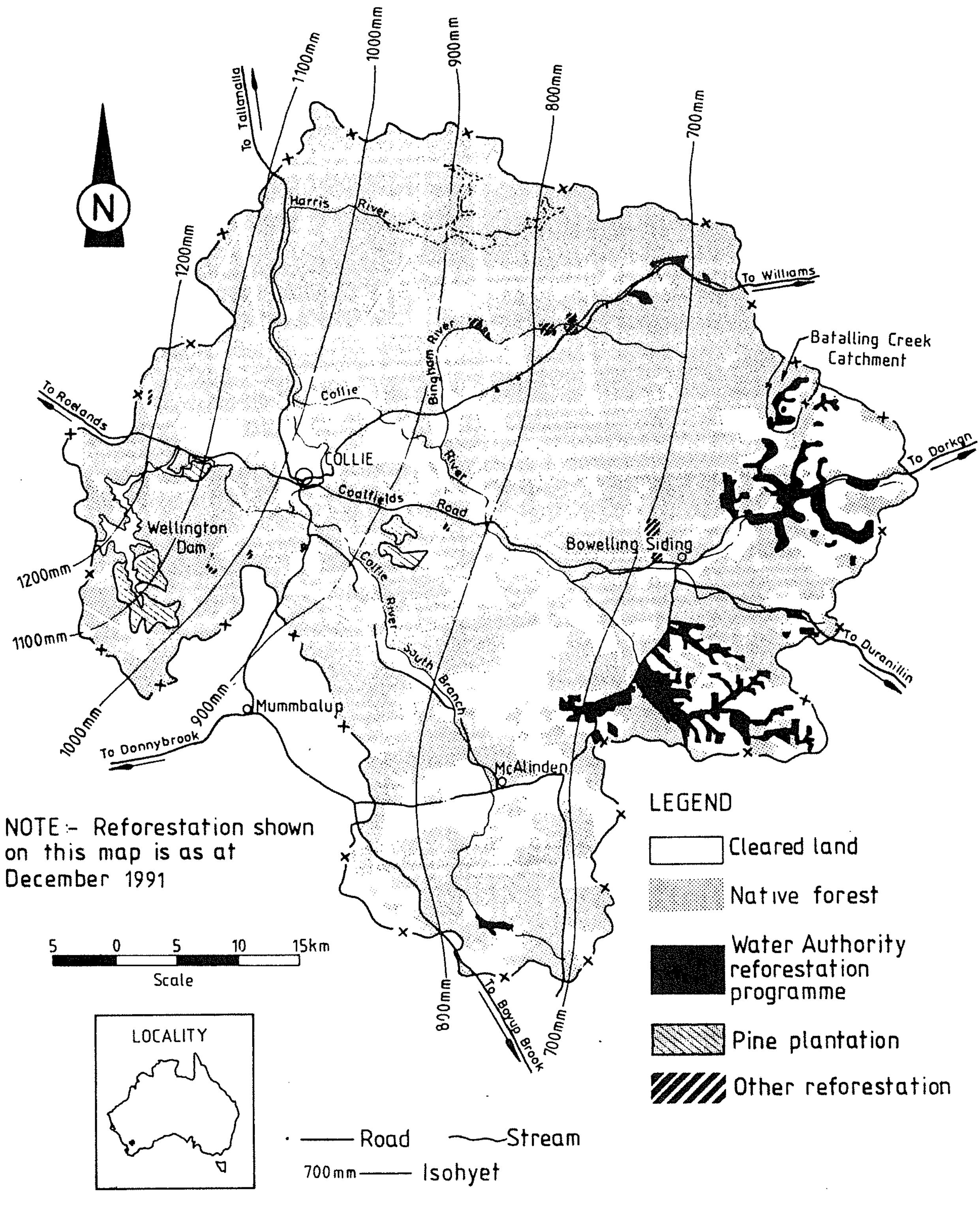


Figure 1 Location of the study area

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 in terms of groundwater level and salinity were to:

(i) determine the groundwater table seasonal variations and longer term trends at valley seep;

(ii) quantify the effect of reforestation on groundwater levels and salinity.

The specific objectives in terms of streamflow and stream salinity were to:

(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 salt load.

3 SITE DESCRIPTION

3.1 Location and Climate

Batalling Creek catchment 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. The catchment has a Mediterranean climate, with cool, humid, wet winters and hot, dry summers. The long term average rainfall of the catchment is estimated to be 640 mm yr^{1} (Hayes and Garnaut, 1981) and the annual average pan evaporation is 1600 mm (Luke et al., 1988).

3.2 Site History

Progressive clearing at Batalling Creek catchment for pasture development commenced in the 1950s (Table 1). By 1977, 51% of the site had been cleared with most of the clearing on the lower slopes. The State Government purchased the farm in 1976 as part of a programme to reforest farmland within Wellington Dam catchment. Clearing and reforestation details at the catchment are given in Appendix A.

3.3 Topography, Soil and Geology

Elevation of Batalling Creek catchment ranges from 270 to 380 m AHD (Fig. 2). The upslope forested portion of the catchment is slightly steeper than the reforested zone. The surface soil is highly permeable and the rainfall intensity rarely exceeds the infiltration capacity of the soil (Sharma, et, et., 1987). The soil types are typical of the eastern Wellington Dam catchment (Bettenay et, al., 1980) and consist of multicoloured clayey silty sand and silty sandy clay. The soil profile varies between a few metres to about 20m thick.

Table 1: Clearing and reforestation history at Batalling Creek catchment

Year	cleared area (ha)	% of total area	reforested area (ha)	%of total area
1945	0	0	-	-
1960	265	16	-	-
1964	286	17.2	-	-
1966	298	18	-	-
1971	821	49.5	-	-
1977	846	51		
1985	-	-	283	17.5
1986			342	20.5
1991	-	-	322	19.4

catchment area = 1660 ha

3.4 Vegetation

Prior to reforestation the cleared area of the Batalling Creek catchment supported a pasture of annual rye grasses (Lolium spp), barley (Hordium marinum) and other grasses and was 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).

In 1985, 15 plots were established in the cleared area along the stream line (Fig. 2). At the hill of the southern boundary of the catchment, 3 more plots were established. Each plot was planted with two eucalypt species at an initial stem density of 830 stems per hectare (sph). In 1987, 6 additional plots were planted (Fig. 2). Tree survival was poor in the salt affected and waterlogged plots. By 1990 average tree survival was more than 70% of the initial stem density. Trees were not thinned or pruned at the study site.

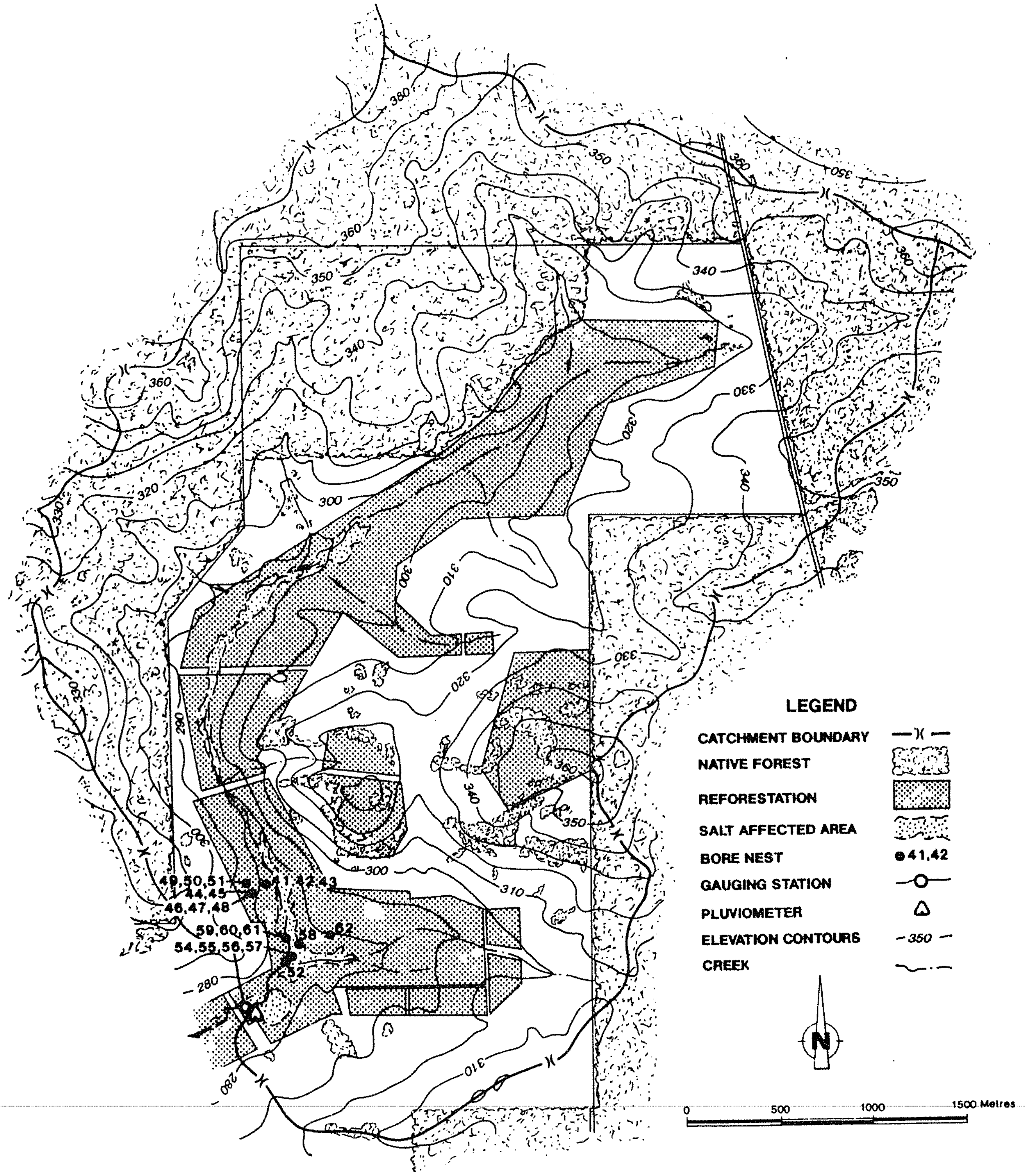


Figure 2 Reforestation layout and hydrometric network

3.5 Hydrology

The area of Batalling Creek catchment is 16.6 km^2 (Fig. 2). The gauging station was established in 1976. In 1980, the depth to groundwater level across the cleared area varied from 0.0 m (i.e. at ground surface) to 5.0 m. The average groundwater salinity was 12000 mg L^{-1} Total Soluble Salts (TSS). The average stream salinity was 5700 mg L^{-1} TSS. Saline seeps were evident along the stream line.

4 HYDROLOGICAL DATA COLLECTION

4.1 Rainfall

Daily rainfalls were recorded with a pluviometer located within the catchment (Fig. 2). For the periods of missing records, rainfall data were interpolated from the nearest pluviometer using a correlation between two the stations.

4.2 Groundwater

A network of 21 monitoring bores were installed at Batalling creek catchment in 1978 (Fig. 2). A group of 2 to 3 bores were drilled at each monitoring point, to provide shallow (<2 m depth), intermediate (<10 m) and deep (>10 m) groundwater information. The groundwater observation bore details are given in Appendix B.

Most of the bores were monitored for water level and salinity once a month except for the period 1982-87 when no records were taken (Appendix C). Salinity was measured from the samples collected within the screen area of the bores. The groundwater salinity (Total Soluble Salts, TSS) was determined using the derived relationship between TSS (mg L^{-1}) and electrical conductivity (m Sm^{-1}).

4.3 Streamflow

A calibrated, sharp-crested V notch weir was installed at the outlet of the catchment in 1976. The water level over the weir (stage) was continuously recorded by a float operated graphical recorder and converted to discharge using a rating curve. Stream water quality 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 D). Electrical conductivity of stream water has been recorded continuously since the installation of the weir.

5 GROUNDWATER LEVEL AND SALINITY RESPONSE

5.1 Groundwater Level

Groundwater levels beneath the reforestation areas declined by an average of 0.3 m over the 1978-91 period. Since 1988 groundwater levels were in steady decline in response to a continuous crown growth of the plantations. In contrast, at the valley seep area groundwater level increased by an average of 0.3 m (Fig. 3).

5.2 Groundwater salinity

When comparing groundwater salinity data collected in 1980 and 1991, a considerable variability in groundwater salinity changes among individual bores is evident. Beneath reforestation the average groundwater salinity reduction was 5% while at the valley seep area the reduction was practically negligible (Table 2).

Table 2: Comparison of groundwater salinity at Batalling Creek catchment

Location	Bore	Groundwater Salinity 1980	Groundwater Salinity 1991	% change
	52	19702	20516	4
Valley seep	55	12600	15067	19.6
	60	13381	10013	-25.2
(mean)		(15228)	(15199)	(-0.2)
	45	9830	11823	20.3
	48	11257	13185	17.1
Reforestation	50	262	217	-17.2
	51	17692	12018	-32.1
(mean)		(9760)	(9311)	(-4.6)

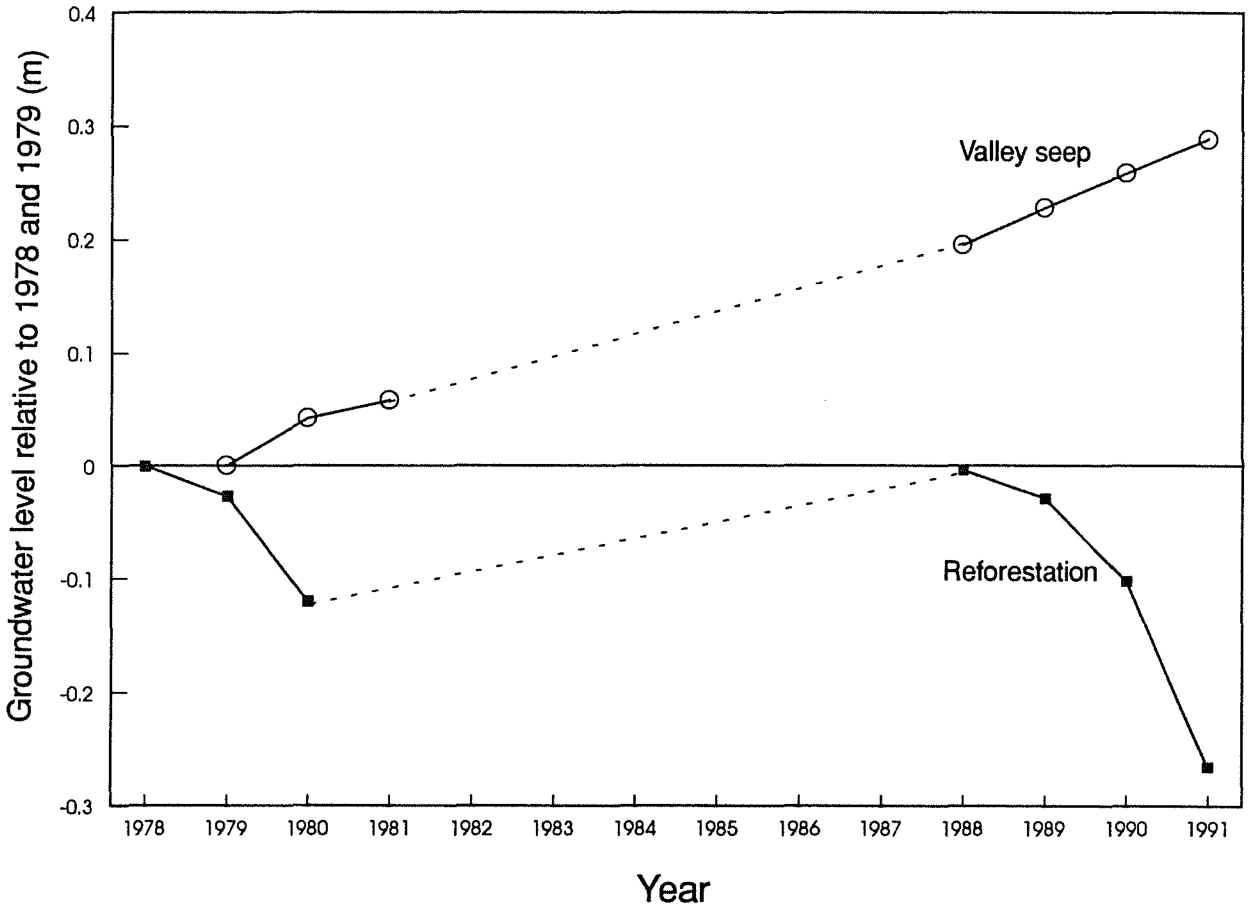


Figure 3 Groundwater level changes relative to 1978 and 1979

6 STREAMFLOW AND STREAM SALINITY RESPONSE

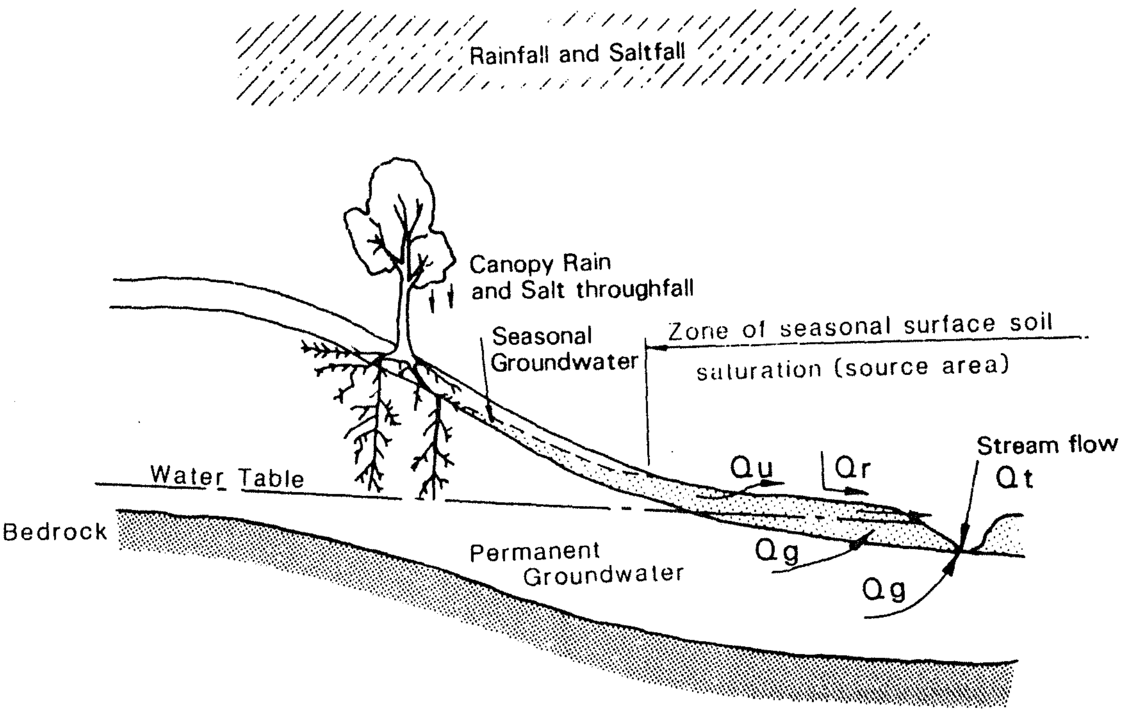
6.1 Seasonal Variations

Generally, streamflow commenced in April/May, following a significant rainfall event, and ceased in November or early December. Most of the streamflow occurred in July/August after considerable rainfall and catchment saturation. Average daily stream salinity (Total Soluble Salts, TSS) 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 high flows are much lower in salinity at around 700 $mg\ L^{-1}$ TSS. Flows in spring have higher salinity but not as high as autumn. Stream salt discharge was highest during the mid-winter high flows and lowest during low flows in autumn and summer. Daily streamflow and salinity graphs during the study period are given in Appendix E.

6.2 Components of Streamflow and Salt Load

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 (Fig. 4). The relative proportions of these stream flow components were quantified by applying the model of source proportions (Sharma, et al., 1980; Stokes and Loh, 1982; Stokes, 1985) given in Appendix F. The computer programme for deriving these values is included in Appendix G.

Annual surface runoff (Q_r) ranged from 28% to 52% of streamflow and averaged 36% (15 mm). The shallow subsurface flow component, Q_u, was highly variable with time. As a proportion of total streamflow, it ranged from 14% to 57% with an average of 49% (20 mm) over the study period. The deep groundwater flow component, Q_g, was relatively stable compared to the other two components. During 1980-91, Q_g ranged from 6% to 50% of streamflow and averaged 14% (Table 3).



Legend

Qr : Surface Runoff
Qu : Discharge from Seasonal Groundwater
Qg : Discharge from Permanent Groundwater

Figure 4 Schematic representation of the hydrological process in a partially cleared catchment

Table 3: Annual streamflow components

Year	Rainfall (mm)	Q_t (mm)	Q_r (mm)	Q_u (mm)	Q_g (mm)	Q_r/Q_t (%)	Q_u/Q_t (%)	Q_g/Q_t (%)
1980	619.6	19.7	7.6	8.3	3.8	38.6	41.9	19.5
1981	688.6	43.1	15.6	22.2	5.3	36.3	51.5	12.3
1982	623.6	53.0	27.7	21.2	4.1	52.2	40.1	7.8
1983	711.6	79.2	29.0	45.1	5.1	36.6	56.9	6.5
1984	610.0	40.8	14.2	19.9	6.7	34.8	48.9	16.3
1985	575.3	46.1	17.3	23.4	5.4	37.5	50.8	11.7
1986	479.1	18.4	6.0	5.7	6.7	32.5	31.2	36.4
1987	441.2	9.9	3.6	1.3	5.0	36.1	13.7	50.2
1988	749.3	78.0	26.7	43.4	7.9	34.2	55.7	10.1
1989	638.0	36.4	12.7	17.0	6.7	34.9	46.8	18.3
1990	554.1	33.0	10.1	15.1	7.9	30.5	45.6	23.9
1991	570.7	36.5	10.1	20.3	6.0	27.7	55.8	16.6
Mean	605.1	41.3	15.1	20.3	5.9	36.6	49.2	14.3
CV	0.15	0.52	0.57	0.69	0.24			

CV = Coefficient of variation

Table 4: Annual salt discharge for the three streamflow components

Year	L_t (kg/ha)	L_r^a (kg/ha)	L_u (kg/ha)	L_g (kg/ha)	L_r/L_t (%)	L_u/L_t (%)	L_g/L_t (%)
1980	1002	46.5	31.4	924	4.6	3.1	92.2
1981	1362	51.6	84.6	1225	3.8	6.2	90.0
1982	1145	46.8	58.9	1038	4.1	5.1	90.7
1983	1339	53.4	163.1	1115	4.0	12.2	83.3
1984	1590	45.8	71.7	1469	2.9	4.5	92.4
1985	1237	43.1	81.0	1113	3.5	6.5	90.0
1986	1616	35.9	20.7	1558	2.2	1.3	96.4
1987	1249	33.1	4.8	1206	2.6	0.4	96.6
1988	1857	56.2	151.2	1649	3.0	8.1	88.8
1989	1491	47.8	58.4	1383	3.2	3.9	92.7
1990	1637	41.6	47.6	1546	2.5	2.9	94.5
1991	1316	42.8	67.9	1205	3.3	5.2	91.6
Mean	1412	45.4	70.1	1297	3.2	5.0	91.8
CV	0.17						

CV =Coefficient of variation

a Chloride ion concentration of rainfall (4.2 mg L^{-1}) was assumed to be 56% of Total Soluble Salts (Hingston and Gailitis, 1977).

The annual stream salt load (L_t) ranged from 1002 kgha^{-1} TSS to 1857 kgha^{-1} TSS. The annual average salt discharge from shallow subsurface system (L_u) was 70 kgha^{-1} TSS, which was 5% of the total salt load. There was more salt discharge from the deep groundwater system (L_g) than from other streamflow components (Table 4). During the study period, it ranged from 924 kgha^{-1} TSS to 1649 kgha^{-1} TSS and averaged 1297 kgha^{-1} TSS.

6.3 Streamflow Components and Rainfall

Figure 5 compares the three components of streamflow with rainfall. Shallow subsurface flow (Q_u) is most sensitive to annual rainfall. The surface runoff (Q_r) is less variable and less sensitive to rainfall than the shallow subsurface flow (Q_u). Flow from the deep groundwater system (Q_g) is practically independent of rainfall and discharges at an almost steady rate to the stream.

6.4 Streamflow and Reforestation

Figure 6 presents the double mass curve of annual rainfall and streamflow. During 1985-91, streamflow declined at an average rate of 12 mm yr^{-1} due to the higher evapotranspiration of the plantations. The reduction of streamflow was about 30% of what would have occurred without reforestation. However, the response of the three streamflow components were not similar (Fig. 7). The surface runoff and shallow subsurface flow components declined at the rate of 7 mm yr^{-1}. The flow from deep, permanent groundwater table increased in the order of 2 mm yr^{-1} (Fig. 7c).

6.5 Reforestation and Stream Salinity

Since reforestation in 1985, the stream salinity and streamflow relationship has changed such that there has been an increase in flow-weighted stream salinity for a given streamflow volume (Fig. 8). In terms of salt discharge, the effects of reforestation remained unclear (Fig. 9).

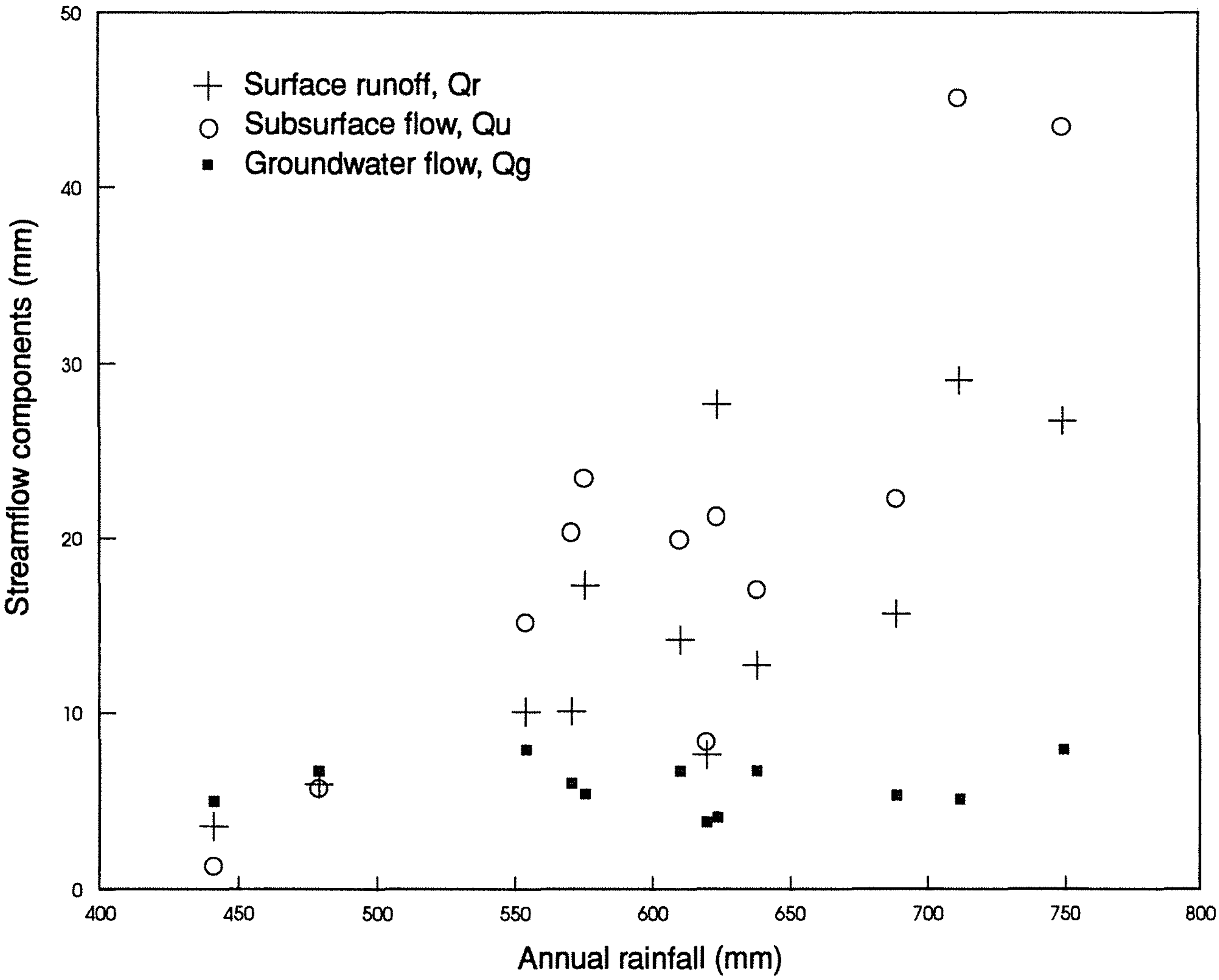


Figure 5 Annual rainfall and streamflow components

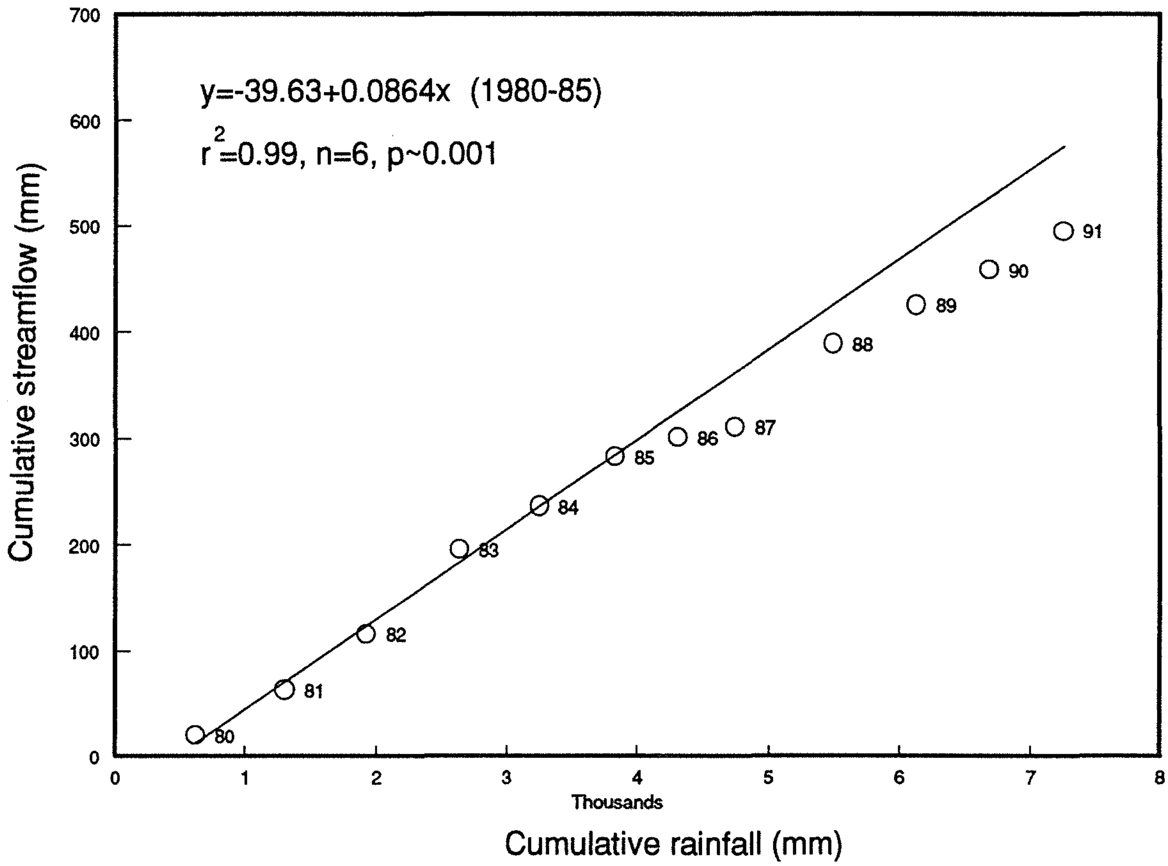


Figure 6 Double mass curve of annual streamflow and rainfall

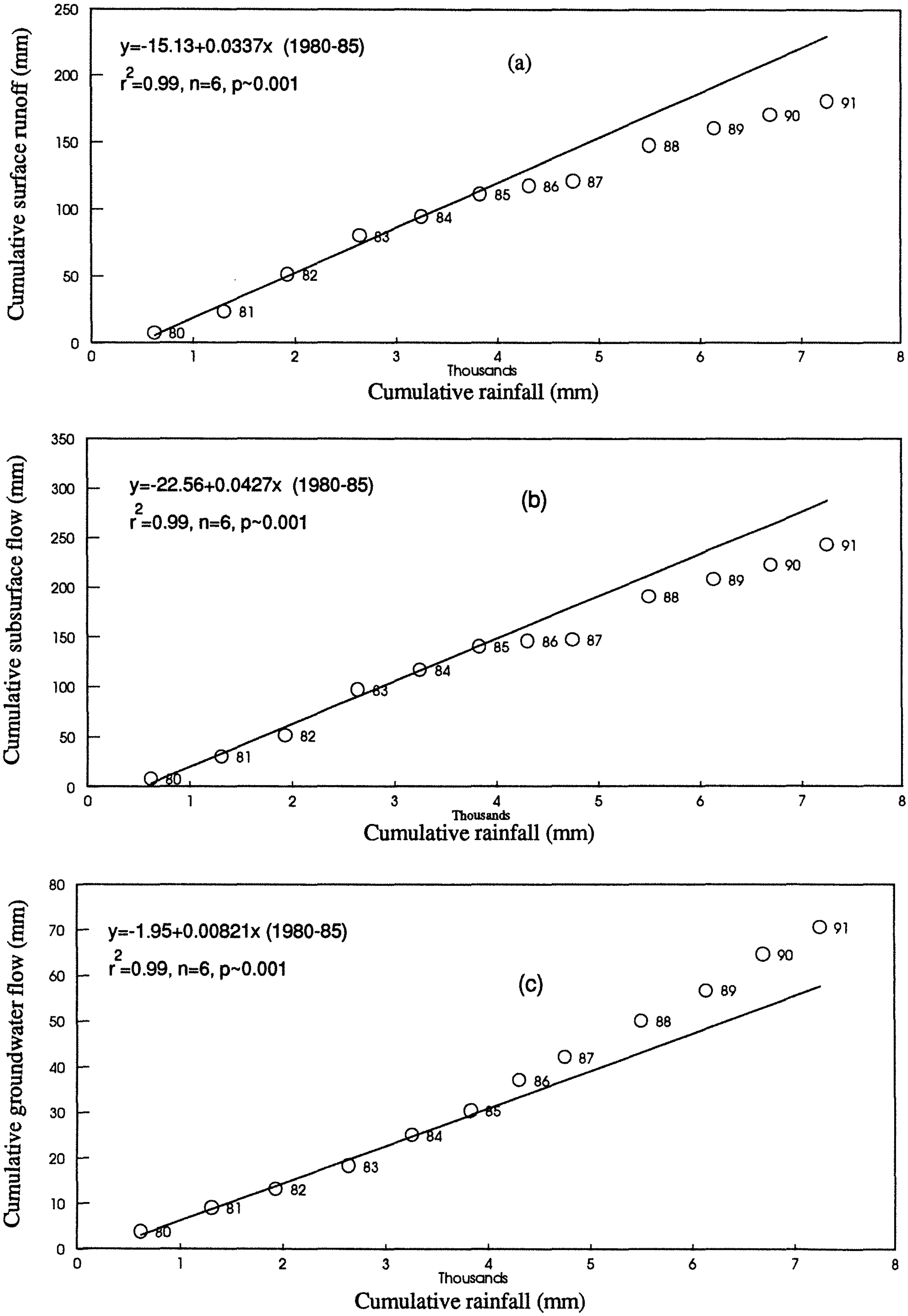


Figure 7 Double mass curve of annual streamflow components and rainfall

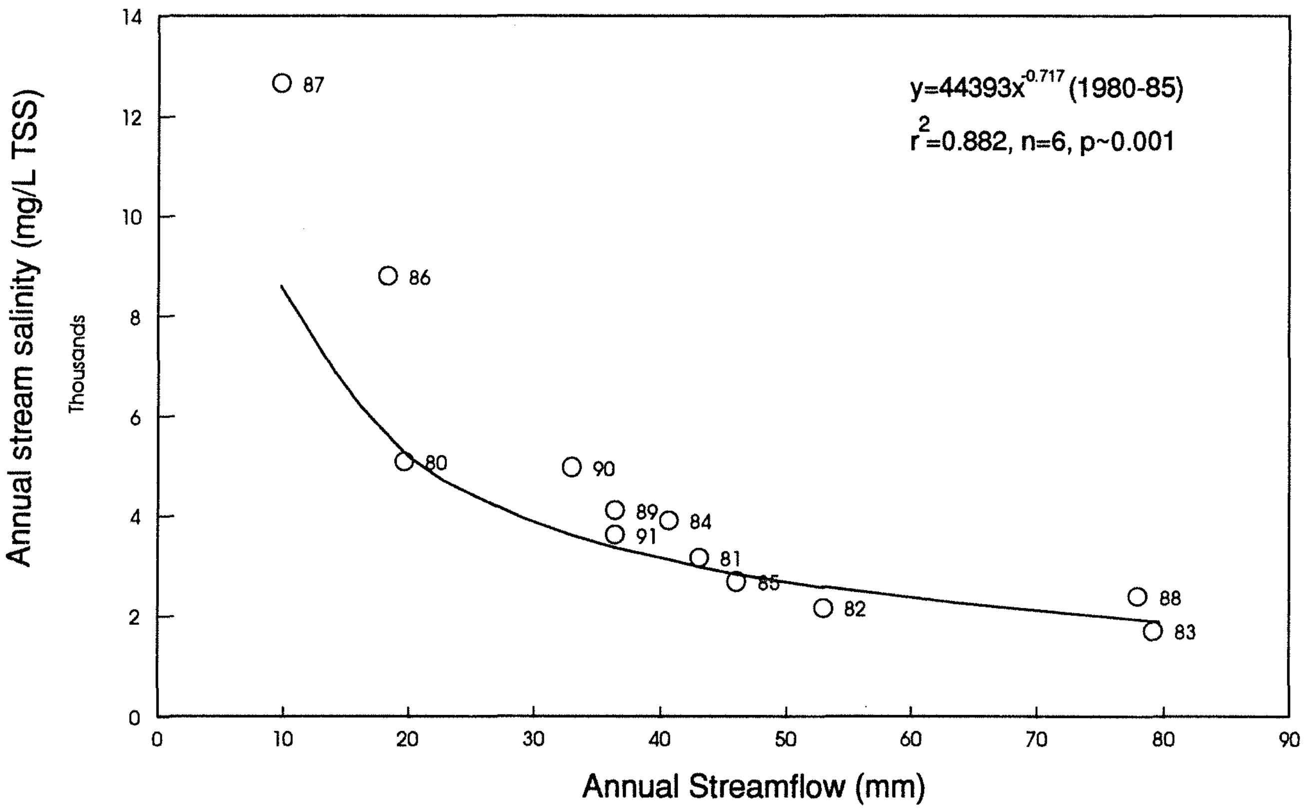


Figure 8 Relationship between streamflow and flow-weighted stream salinity

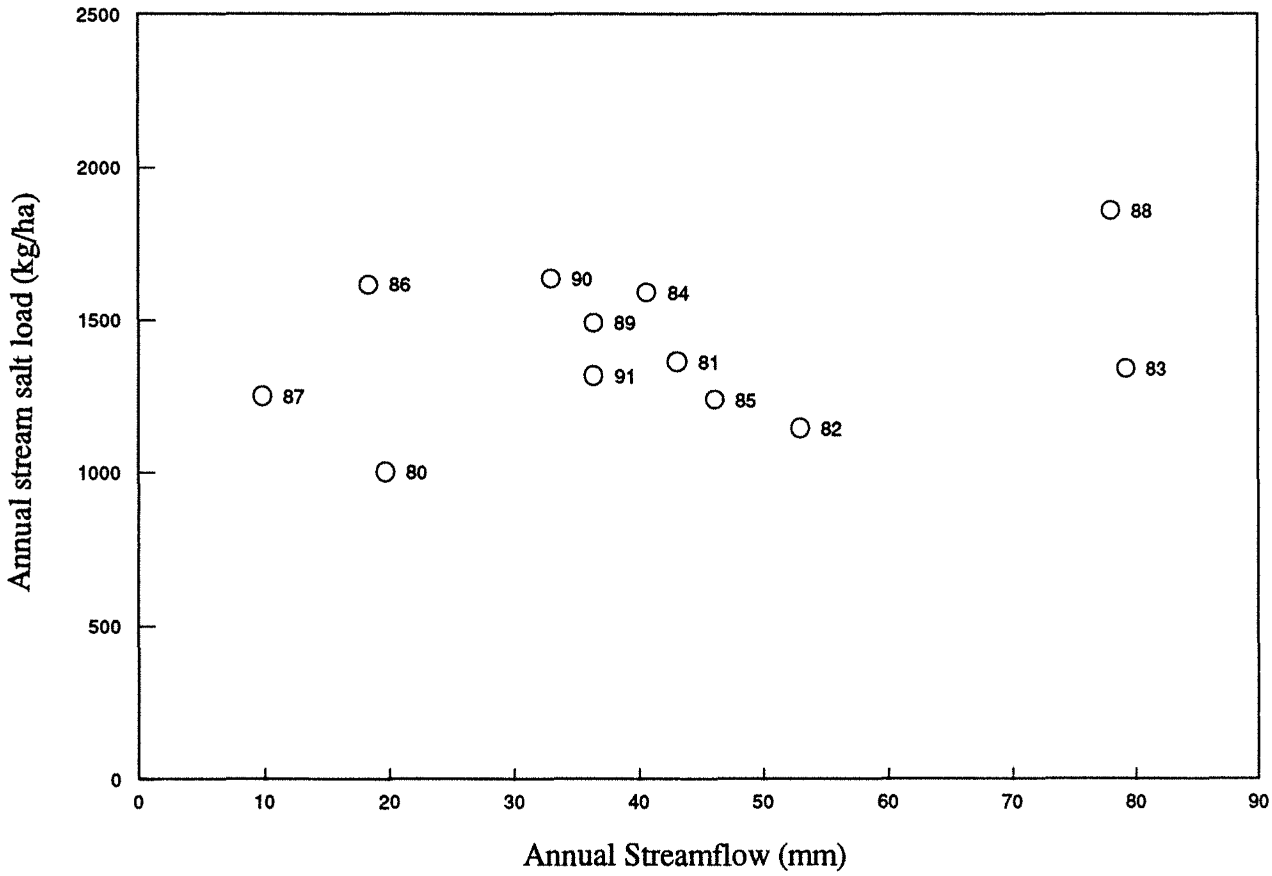


Figure 9 Annual streamflow and salt load

6.6 Reforestation and the Permanent Seep Area

The permanent seep area was measured from aerial photographs taken in 1985 and 1991. The area in 1985 was 19 ha and in 1991 it was 20 ha. It appears reforestation may have halted the increase of the permanent seep area.

6.7 Catchment Salt Balance

The salt balance equation for a catchment is:

$$\Delta L_s = L_r - L_t \qquad (1)$$

where ΔL_s=change in the salt storage in the catchment. Using the average salt input from rainfall (L_r) and salt output from the catchment (L_t) for the period 1980-91 (Table 4), ΔL_s becomes -1370 kgha^{-1} TSS. That means, the catchment is exporting salt (TSS) at a rate of 1370 kgha^{-1}yr^{-1}. The average salt storage in the regolith was 120 kg m^{-2} (Public Works Dept. of W.A., 1981). Assuming a piston type salt discharge at this rate, total salt leaching from the catchment would require 900 years.

7 DISCUSSION

7.1 Rainfall

The average annual rainfall during the study period (1980-91) was 5% lower than the long term average (1926-81) of 640 mm. If long term average rainfall conditions had prevailed, it is likely that the reduction of streamflow would have been less. On the other hand, should drier climate conditions prevail for south-west Western Australia (Pittock, 1988) due to climatic change, then the lower rainfall would assist in lowering streamflow and groundwater levels.

7.2 Groundwater Level and Salinity

Beneath reforestation at mid slopes, the groundwater level decreased slightly between 1988 and 1991. The rate of decline of groundwater level was slow but fairly uniform and is probably attributable to the continuous crown growth of the plantations. In the valley seep area groundwater level increased by 0.3 m (Fig. 3). In the south-west of Western Australia, groundwater level increases dramatically below the lower slopes and valley floors of the cleared catchment. 20 years after catchment clearing, a rise of 15 to 20 m has been observed (Ruprecht and Schofield, 1991). By 1977, 51% of Batalling Creek catchment was cleared (Table 1). The groundwater level at the valley seep area may still be rising due to previous clearing.

Groundwater salinity beneath reforestation decreased 5% over the study period. The significance of this result is that salinities have not increased as a result of evaporative concentration as assumed 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 groundwater system 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.

Analyses of groundwater level and salinity data were limited to 21 bores located at the southern portion of the catchment (Fig. 2). If monitoring bores were installed all over the catchment, beneath reforestation, native forest, pasture and valley seep area, then the interpretations of groundwater data would be more reliable.

7.3 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 an overland flow system (Sharma, et al., 1980; Stokes and Loh, 1982; Stokes, 1985). 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 37% of the total streamflow over the study period. On Batalling Creek catchment, surface runoff was generated from the seep area, close to the stream and gullies. 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 (49% of flow and 5% of salt). Similar results were found in the lower rainfall area of Darling Range (Bari and Boyd, 1992; Stokes and Loh, 1982). Wood (1924) argued that the primary source of stream salts was deep groundwater. The results from this catchment (14% of flow and 92% 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.

Also there is no surface runoff or shallow subsurface flow during the dry months.

Sometimes the observed stream salinity was higher than the groundwater salinity (15000 mg L^{-1} TSS), particularly at the onset of winter (Fig. 4). This is attributed to the concentration of salts at or near the seep area, which occurs as a result of evapotranspiration of groundwater discharge during 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 dependent 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 250 mgL^{-1} TSS and 15000 mgL^{-1} TSS for C_u and C_g are considered reasonably accurate.

7.4 Effects of Reforestation on Streamflow and Salt Load

The decrease in streamflow indicates that there has been an increase in evapotranspiration since reforestation. Most of the decrease occurred in the surface runoff and shallow subsurface flow components (Fig. 7) which generate up to 86% of streamflow and only 8% of salt (Table 4). Transpiration appears to be limited to the extraction of water by shallow roots of young plantations from the seasonal groundwater. Increased evapotranspiration resulted in a decline in the groundwater table. A decline of 2 to 7 m has been observed in the south-west of Western Australia (Bari, 1992; Bari and Schofield, 1992; Bari and Schofield, 1991; Schofield and Bari, 1991; Schofield et, al., 1991; Schofield, 1990a; Bell et., al., 1990; Schofield et., al., 1989). In Batalling Creek catchment, groundwater level declined by 0.3 m since reforestation in 1985. Groundwater discharged 92% of stream salt load. There is also evidence that salt is transported from the groundwater table to the upper soil layer by capillary rise. The transported salt is then discharged to the stream through shallow subsurface flow (Williamson et, al., 1987). Therefore a decline in groundwater level should be accompanied by a decline in stream salt load. In this study, streamflow decreased (Fig. 6) but the stream salinity increased for a particular flow volume (Fig.8). In terms of salt discharge from the catchment, the effects of reforestation is still uncertain. This may be attributable to the transpiration of water by young trees mainly from seasonal groundwater and very little from deep groundwater. This may also be possible due to the position of planted trees in the landscape, species planted and higher salinities and water logging. In future it is likely that rooting depth of trees will increase and trees will transpire more water from deep groundwater. This process may lead to a decrease of saline groundwater discharge to the stream and stream salt load.

Hookey (1985), using a two-dimensional finite difference groundwater model, predicted that if there had been no reforestation, the permanent seep area would double by 1990. After reforestation, the permanent seep area remained stable at around 20 ha. This implies that reforestation may have stopped the expansion of saline seep area.

7.5 The Use of the Reforestation as Salinity Control

The results demonstrate that reforestation is partially successful in lowering streamflow and the saline groundwater table beneath reforestation. It is likely that, with time, the replanted trees may 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 farmland planted, retaining higher stem densities, and by using faster growing trees with higher transpiration rates. The reforestation design should consider the water balance of the site, particularly the annual rainfall (Schofield, 1990b). This would have direct relevance the large scale reforestation programme in the Wellington Dam catchment (Loh, 1988).

8 CONCLUSIONS

8.1 Groundwater Level and Salinity

(i) Reforestation covering 40% of the farmland has lowered the groundwater level by 0.3 m. During the study period, rainfall was 7% lower than the long term average. Under long term rainfall conditions, the rate of decline of groundwater level beneath reforestation could have been less.

(ii) During the study period the groundwater salinity beneath reforestation decreased by about 5%. This decrease was contrary to early expectations.

8.2 Streamflow and Stream Salt Load

(i) Reforestation has resulted in a decrease in streamflow at the rate of 12 mm yr^{-1}. Both the surface runoff and shallow subsurface flow components declined by about 7 mm yr^{-1}; while the flow from deep groundwater increased in the order of 2 mm yr^{-1}. The decrease in streamflow may partially be attributable to the lower rainfall during the study period.

(ii) Since reforestation, the streamflow and stream salinity relationship has changed such that there has been an increase in stream salinity for a given streamflow volume.

9 RECOMMENDATIONS

- As reforestation appears to reduce streamflow, further study is recommended to assess its impact on stream salinity and salt load.

- Measurement of streamflow and stream salinity should be continued to determine the longer term effects of trees on streamflow and salt load.

- Additional monitoring bores should be installed over the catchment; beneath reforestation, pasture, and native forest. Bore monitoring should be continued to determine future groundwater level and salinity behaviour under reforestation, native forest and valley seep area.

10 ACKNOWLEDGMENTS

The authors are grateful to the Water Resources staff of the Water Authority of Western Australia for measuring and supplying groundwater and rainfall data. Thanks also go to Mr J. Ruprecht, Mr P. Goodman, Dr R. Froend and Dr N. J. Schofield for comments on an earlier draft of this report.

We would also like to thank Mr M. Bozikovic and Mr I. Logan for preparing the figures.

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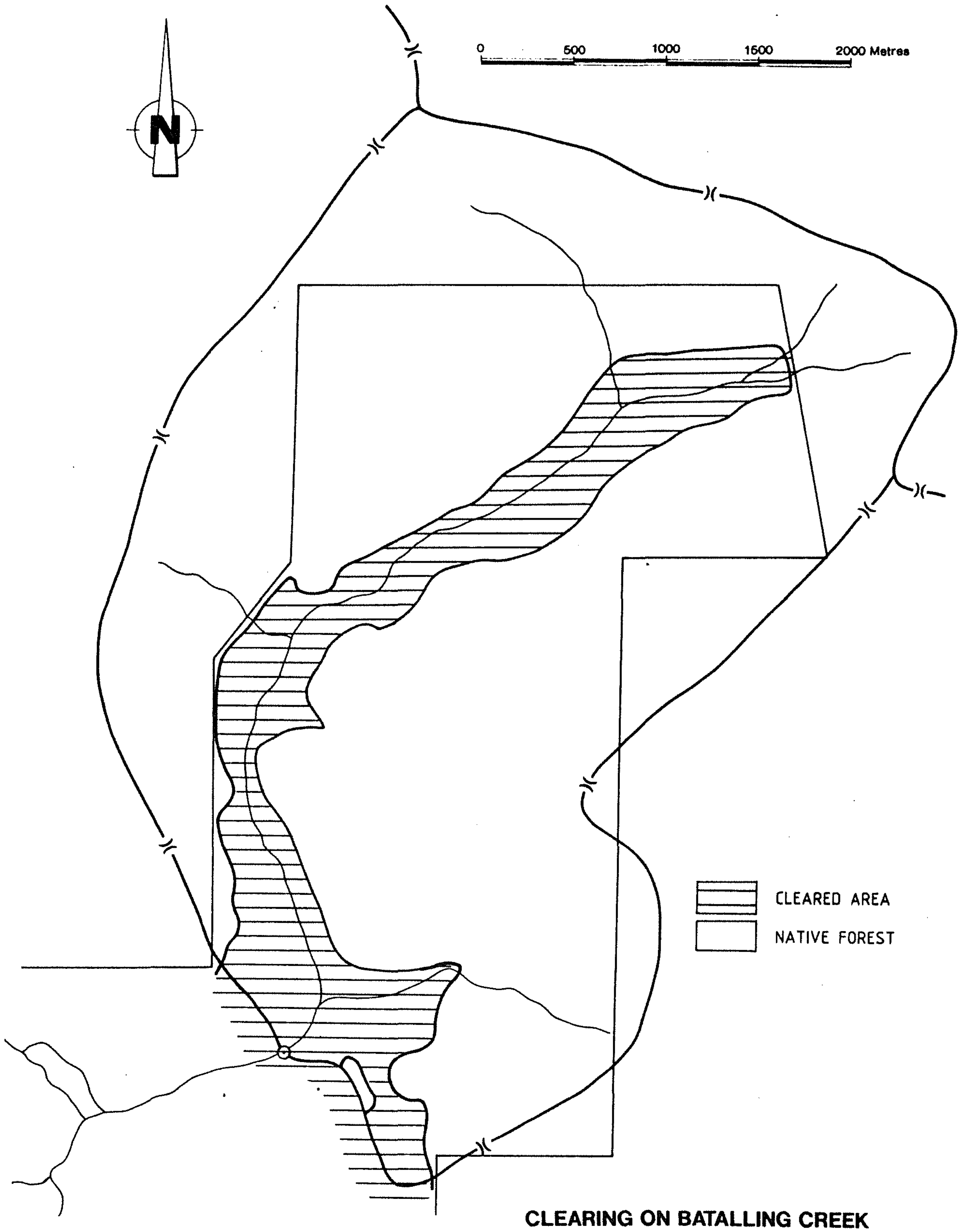
APPENDIX A

Clearing and reforestation details of Batalling Creek catchment



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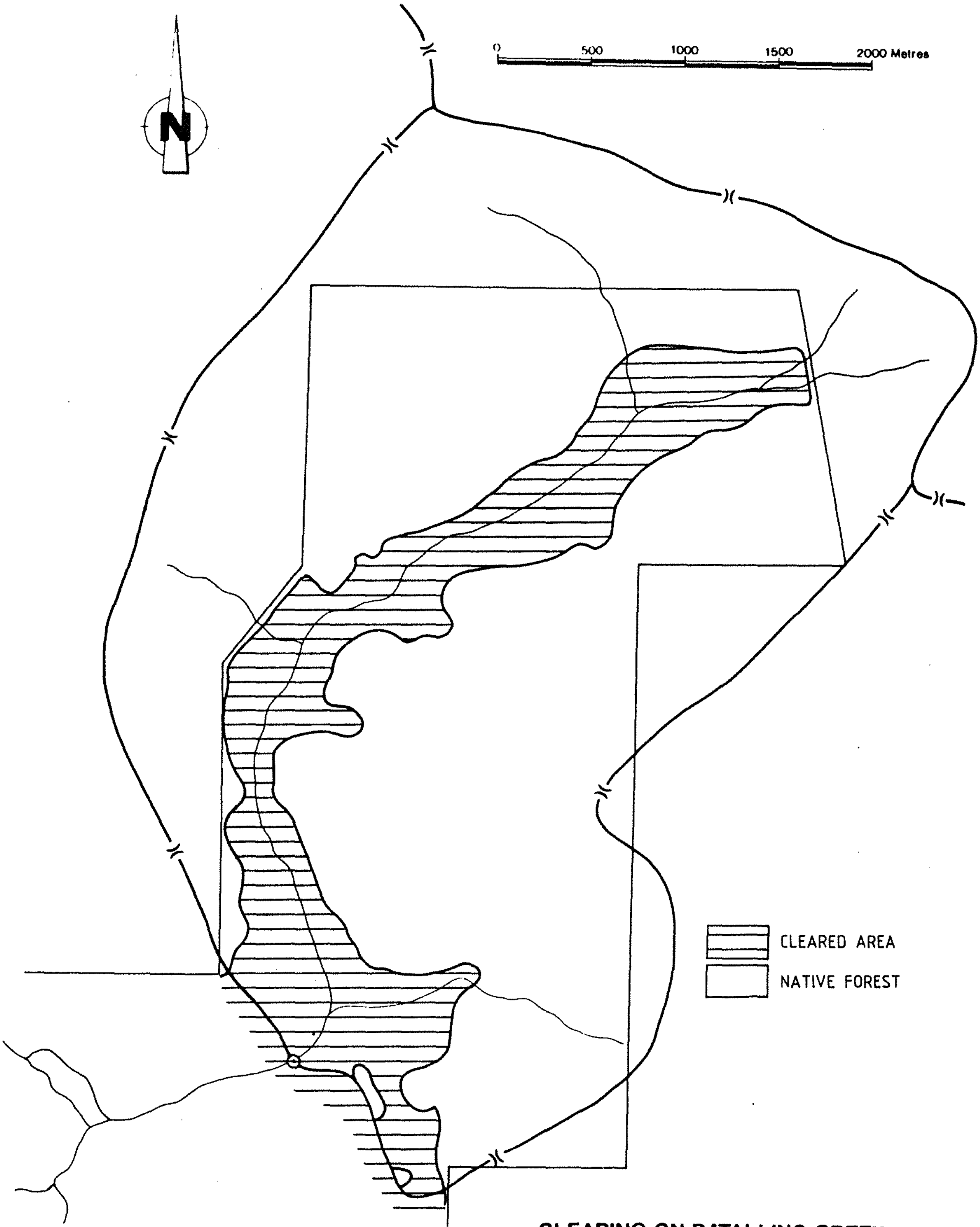

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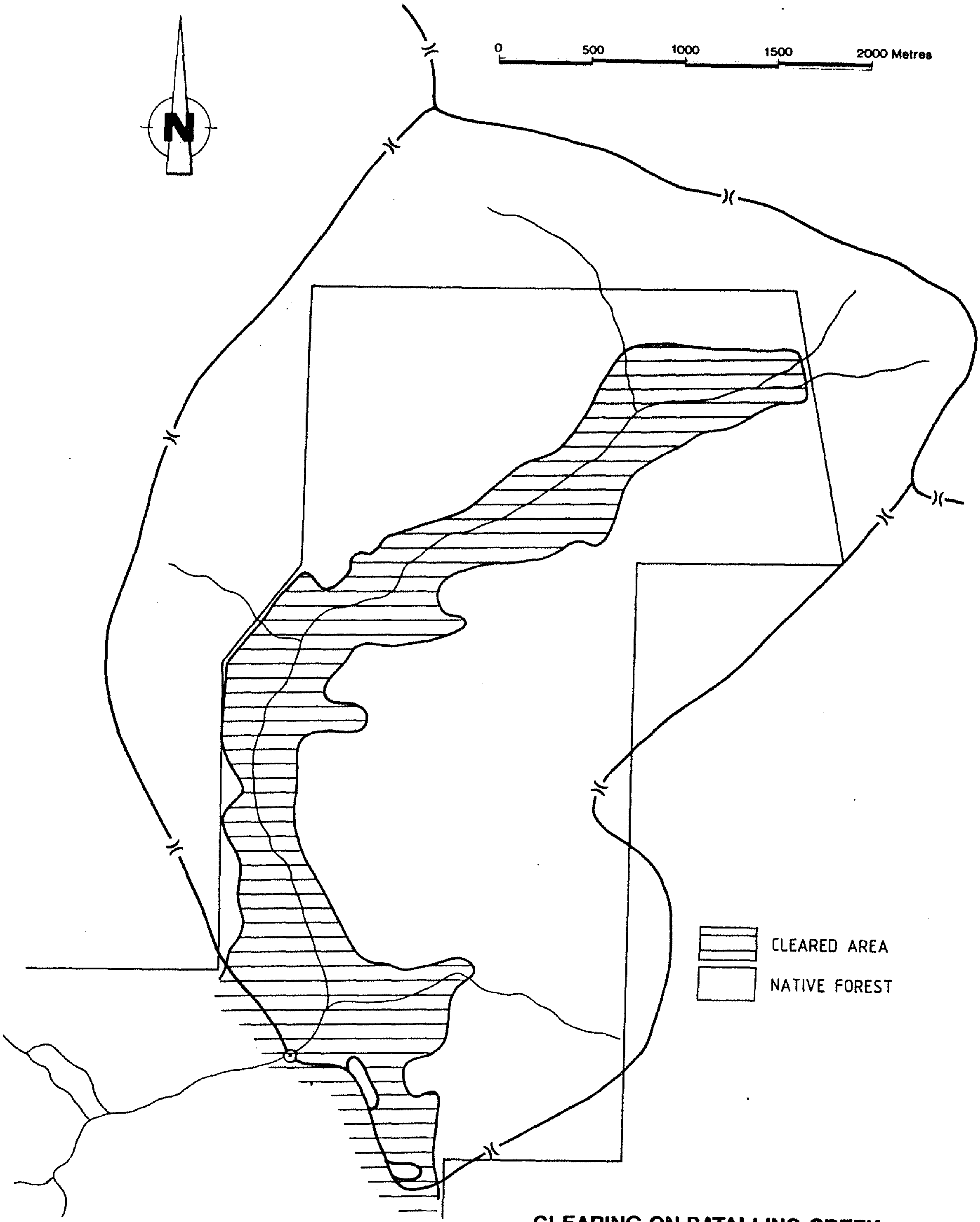
DEC. 1964



CLEARING ON BATALLING CREEK
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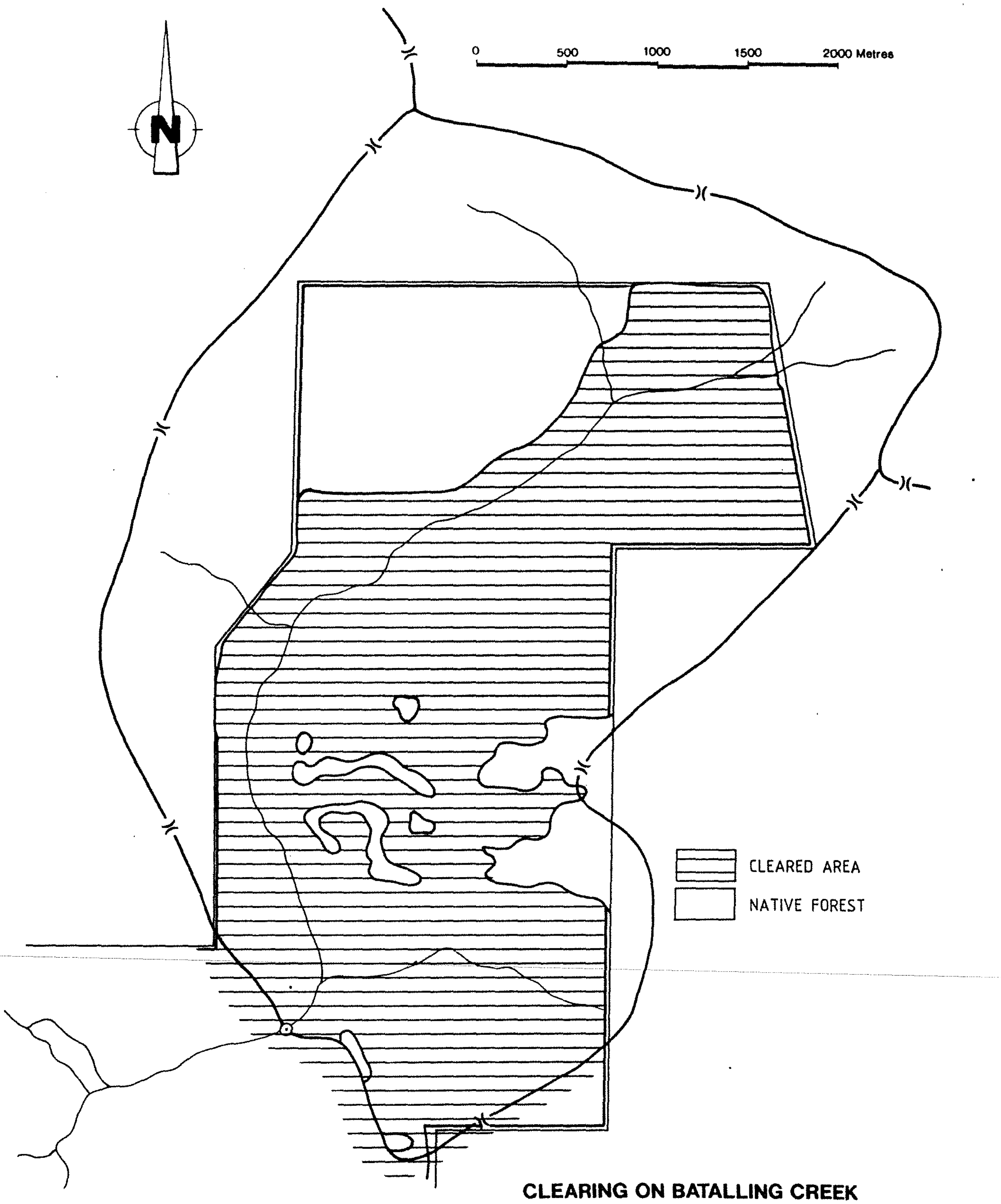
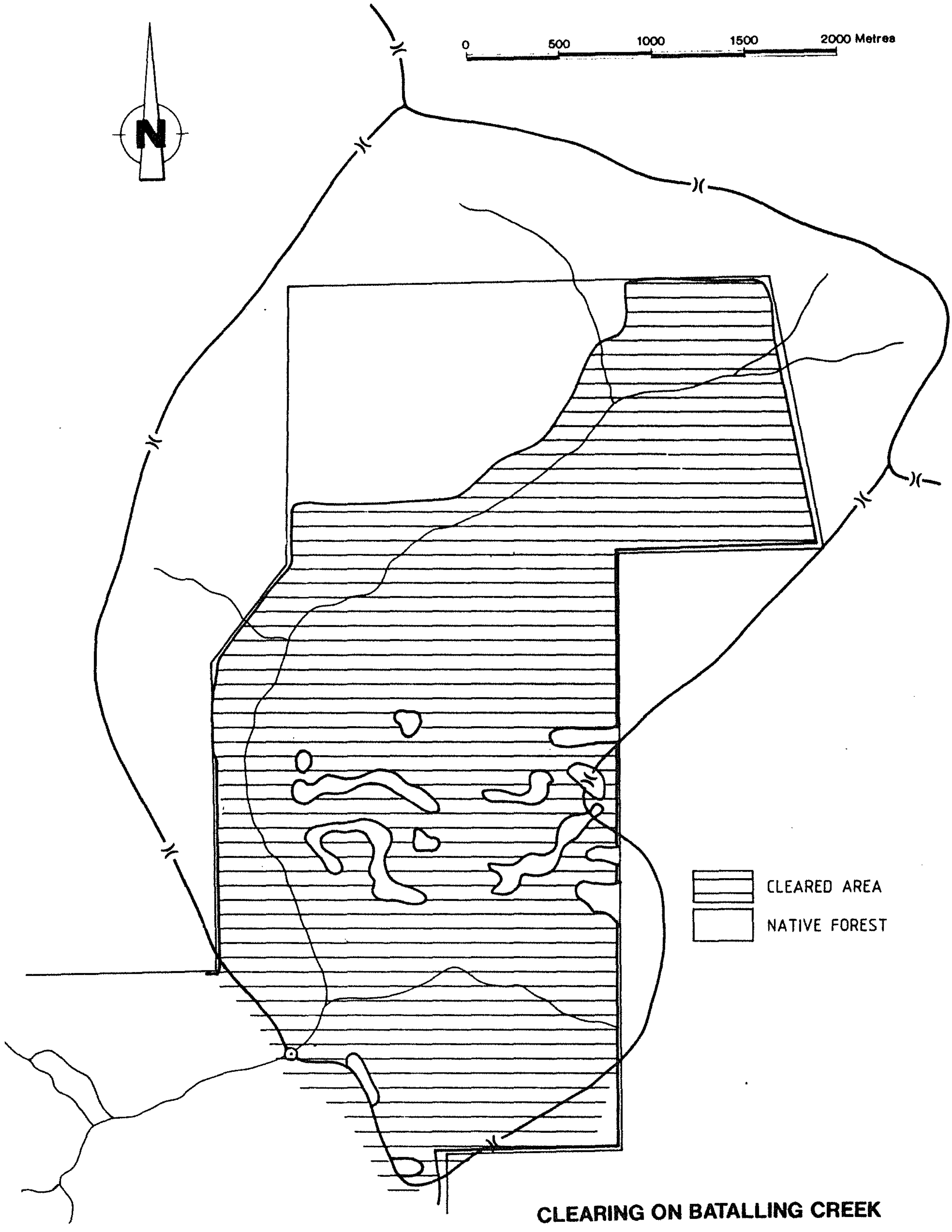
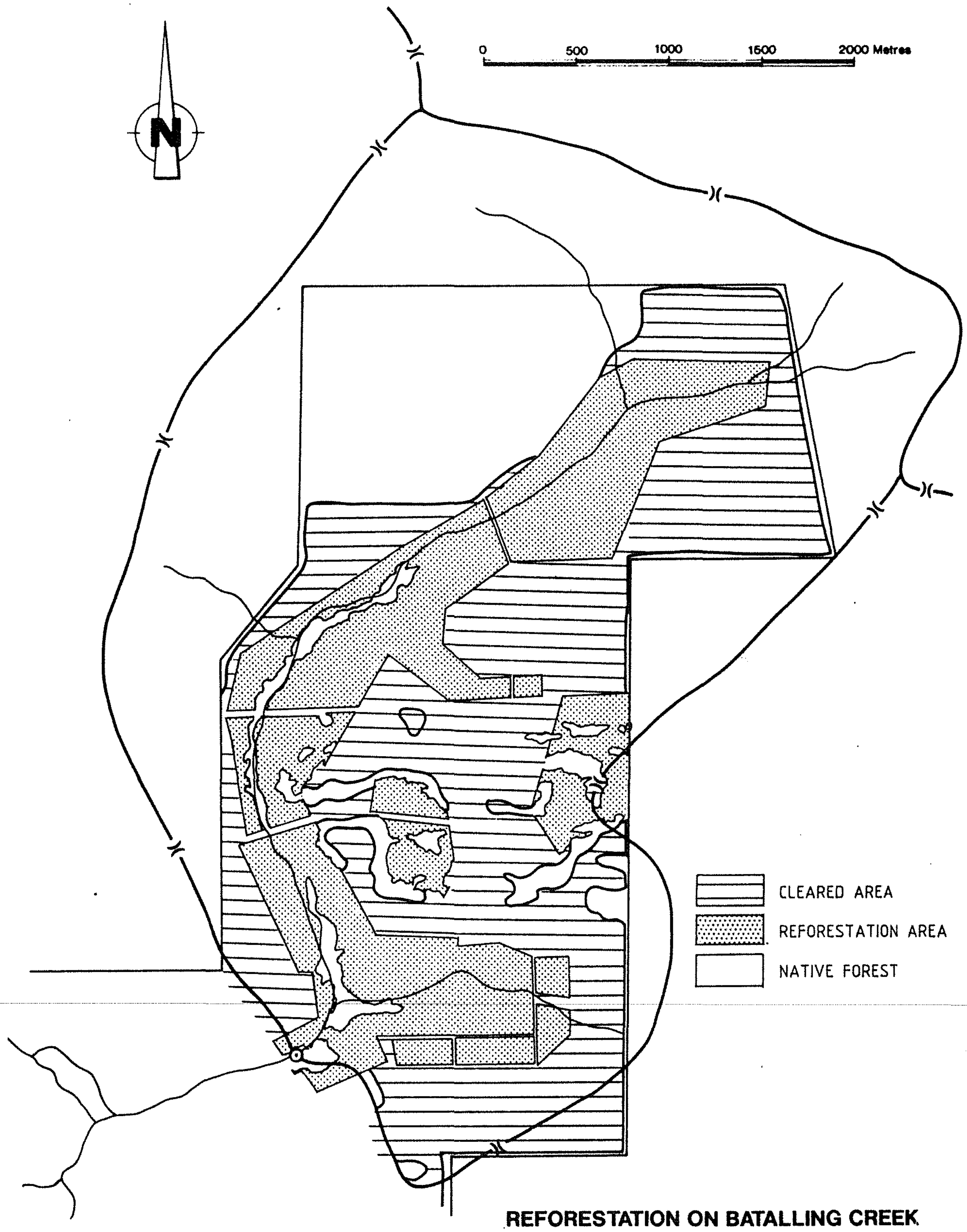


CLEARING ON BATALLING CREEK
FEB. 1971



CLEARING ON BATALLING CREEK
JAN. 1977



REFORESTATION ON BATALLING CREEK
JAN. 1990

APPENDIX B

Details of observation bores

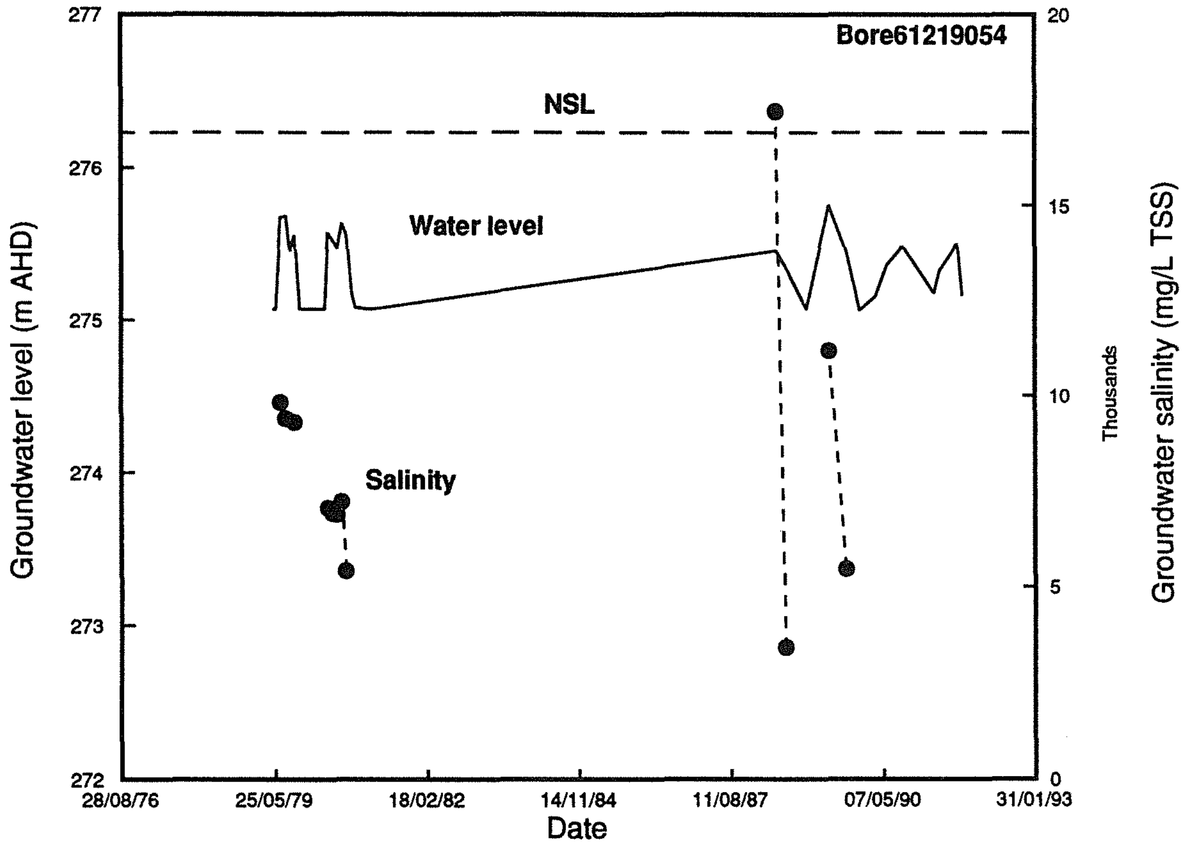
Details of observation bores - Batalling Creek catchment

SWRIS Bore No.	Drillers Bore No.	Commencement of Operation	Bore Classification	Top of Inner Tube (m AHD)	Natural Surface Level (m AHD)	Bottom of Inner Tube (m AHD)	Length of Slotting (m)	Length of Inner Tube (m)	Height of TOIT above NSL (m)	Depth of BOT under NSL (m)
G61219041	1A/78	05/05/78	Valley seep	277.548	277.11	275.846	1.0	1.70	0.50	1.20
G61219042	1B/78	05/05/78	Valley seep	277.548	277.10	272.048	1.0	5.50	0.50	5.00
G61219043	1C/78	05/05/78	Valley seep	277.694	277.16	267.194	2.0	10.50	0.50	10.00
G61219044	2A/78	05/05/78	Reforest	278.881	278.47	277.181	1.0	1.70	0.50	1.20
G61219045	2B/78	05/05/78	Reforest	278.944	278.376	273.444	1.0	5.50	0.50	5.00
G61219046	3A/78	05/05/78	Reforest	280.046	279.55	278.346	1.0	1.70	0.50	1.20
G61219047	3B/78	05/05/78	Reforest	280.047	279.55	274.547	1.0	5.50	0.50	5.00
G61219048	3C/78	05/05/78	Reforest	280.026	279.48	269.526	2.0	10.50	0.50	10.00
G61219049	4A/78	05/05/78	Reforest	285.705	285.18	284.005	1.0	1.70	0.50	1.20
G61219050	4B/78	05/05/78	Reforest	285.689	285.14	280.189	1.0	5.50	0.50	5.00
G61219051	4C/78	05/05/78	Reforest	285.646	285.15	275.546	2.0	10.10	0.30	9.60
G61219052	1/79	09/04/79	Valley seep	276.131	275.34	274.141	1.0	1.99	0.78	1.21
G61219054	2-6A/79	09/04/79	Valley seep	276.753	276.253	275.053	1.0	1.70	0.50	1.20
G61219055	2-6/79	09/04/79	Valley seep	276.445	275.945	273.465	1.0	2.98	0.50	2.48
G61219056	2-7/79	09/04/79	Valley seep	276.883	275.383	168.993	3.0	7.89	0.50	7.49
G61219057	3/79	09/04/79	Valley seep	276.957	276.24	275.057	1.0	1.90	0.68	1.22
G61219058	4/79	09/04/79	Valley seep	277.280	276.568	275.380	1.0	1.90	0.66	1.24
G61219059	6-2/79	09/04/79	Valley seep	276.401	275.901	274.651	1.0	1.75	0.50	1.25
G61219060	6-1/79	09/04/79	Valley seep	276.521	276.021	272.271	1.0	4.25	0.50	3.75
G61219061	6-8/79	09/04/79	Valley seep	276.444	275.944	256.584	3.0	19.86	0.50	19.36
G61219062	5/79	01/08/79	Reforest	279.818	279.19	278.008	1.0	1.81	0.68	1.13

NSL = Natural surface level
TOIT = Top of inner tube
BOT = Bottom of tube

APPENDIX C

Groundwater level and salinity graphs between 1980 and 1991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Salinity
Groundwater level (m AHD)
Groundwater salinity (mg/L TSS)
Thousands
Date
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276
275
274
273
272
20
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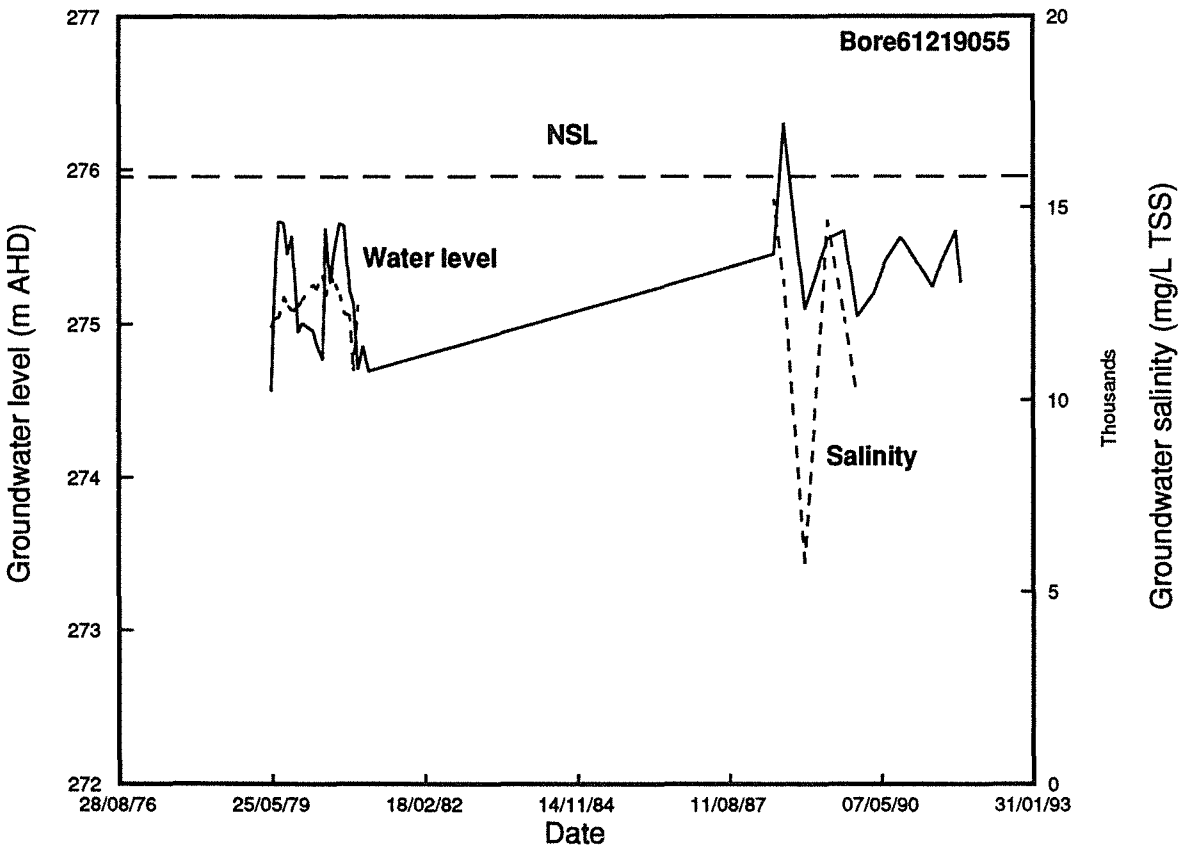
28/08/76
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93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Water level
Salinity
Groundwater level (m AHD)
Groundwater salinity (mg/L TSS)
Thousands
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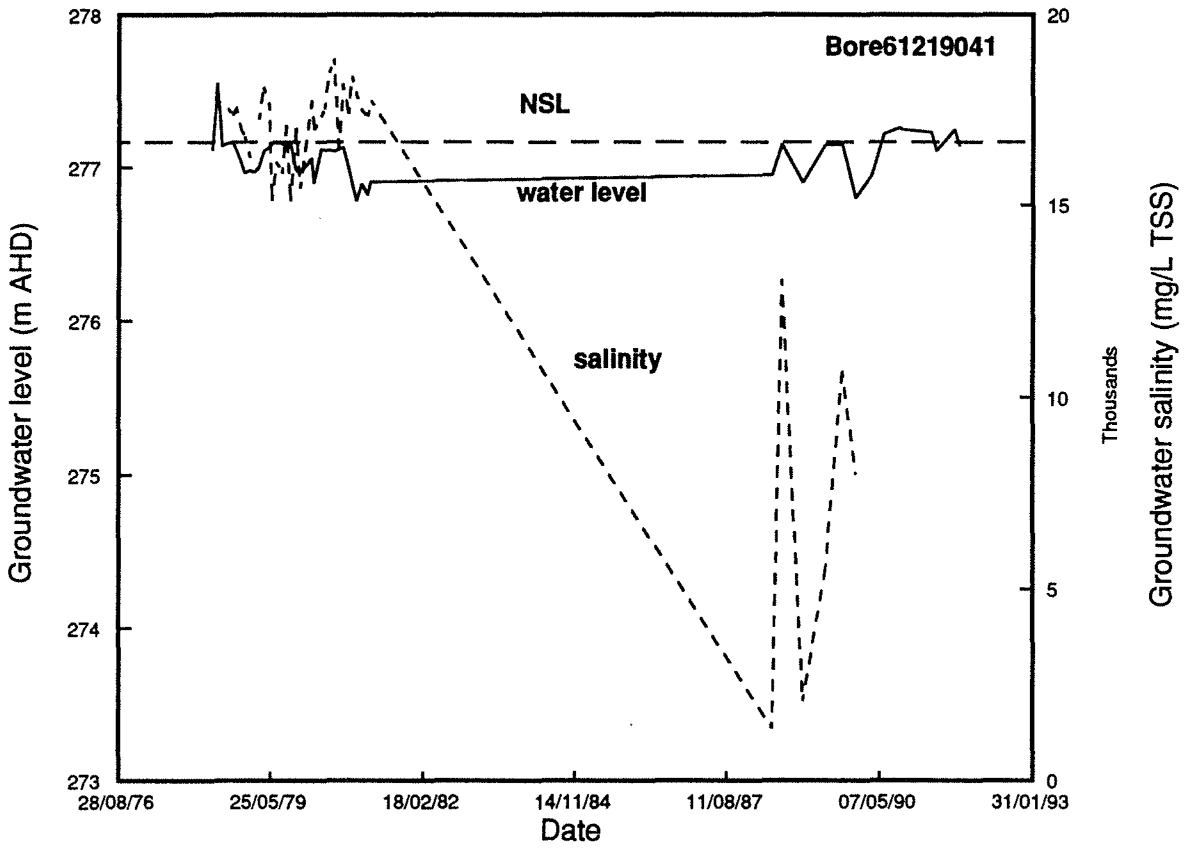
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Groundwater salinity (mg/L TSS)
Thousands
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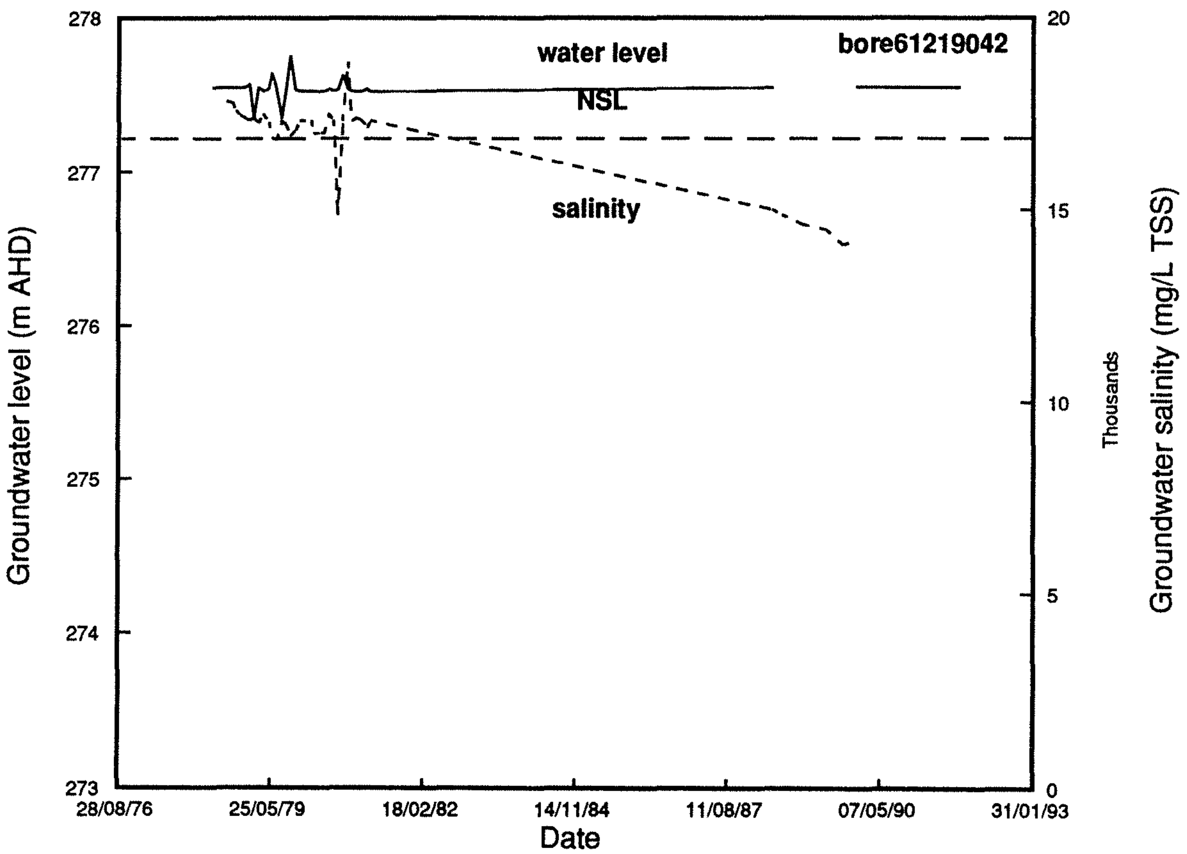
Date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salinity
Groundwater level (m AHD)
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Groundwater salinity (mg/L TSS)
Thousands
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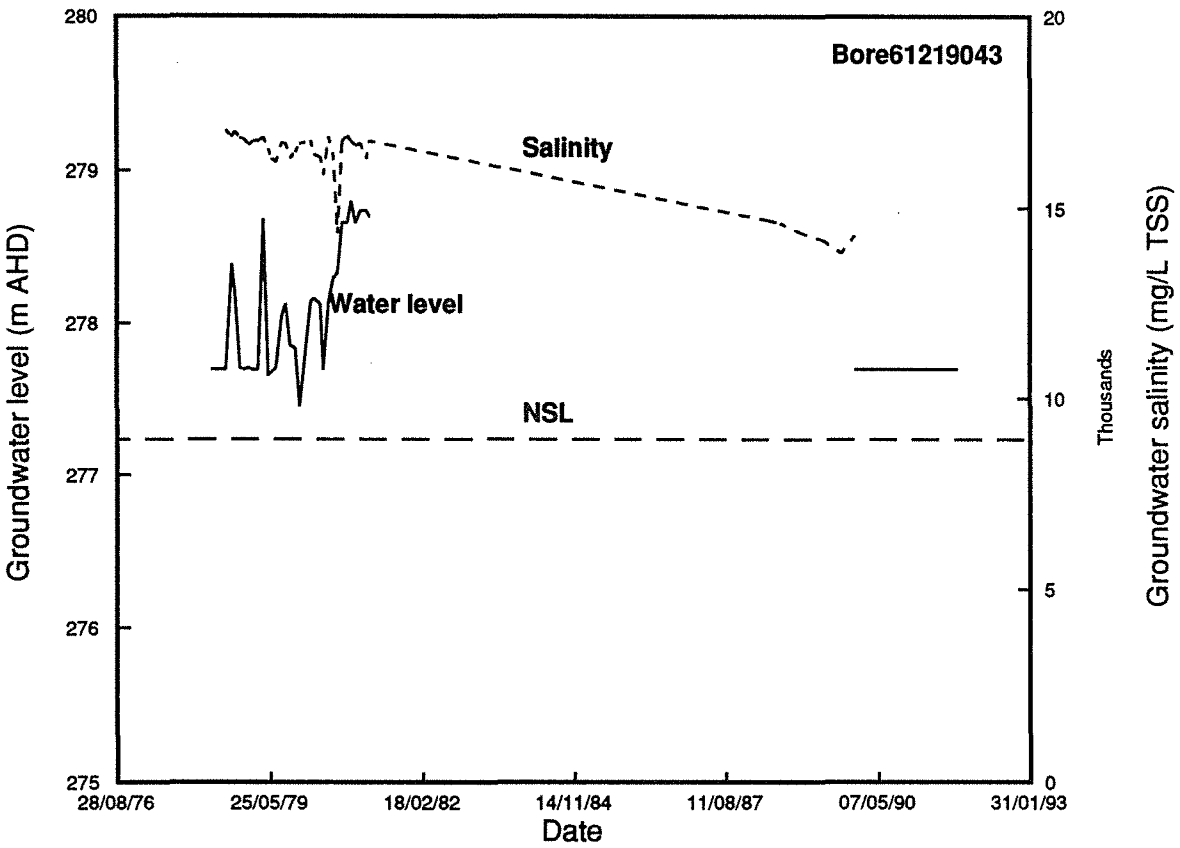
Date



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Groundwater level (m AHD)
Groundwater salinity (mg/L TSS)
Thousands
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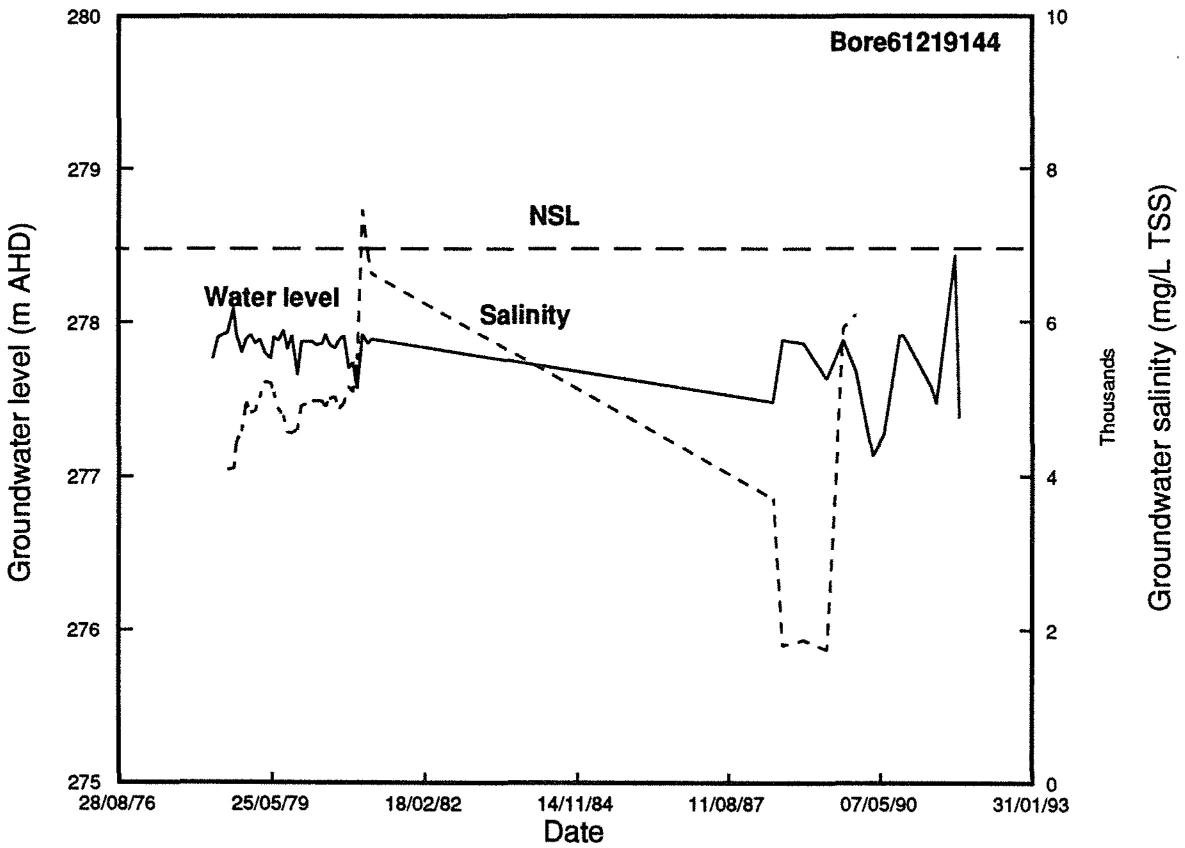

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Groundwater level (m AHD)
Groundwater salinity (mg/L TSS)
Thousands
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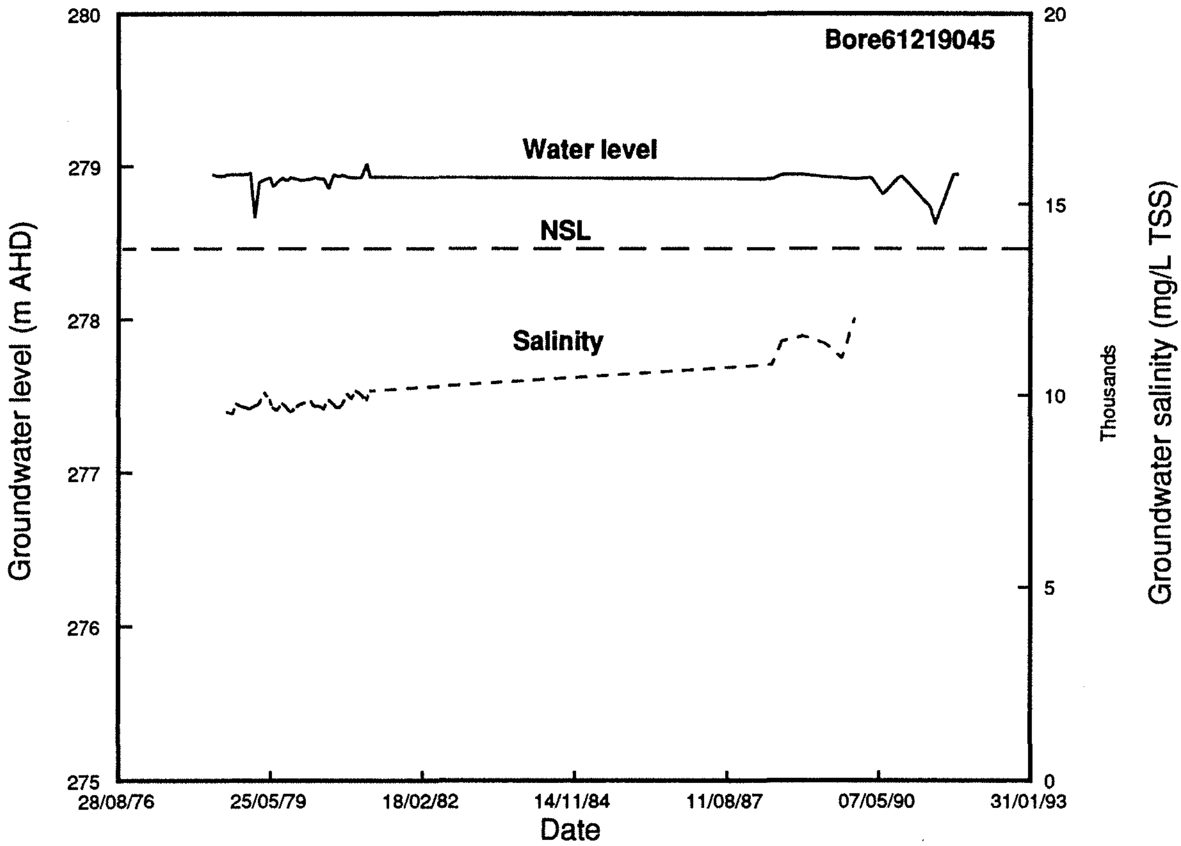

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Groundwater salinity (mg/L TSS)
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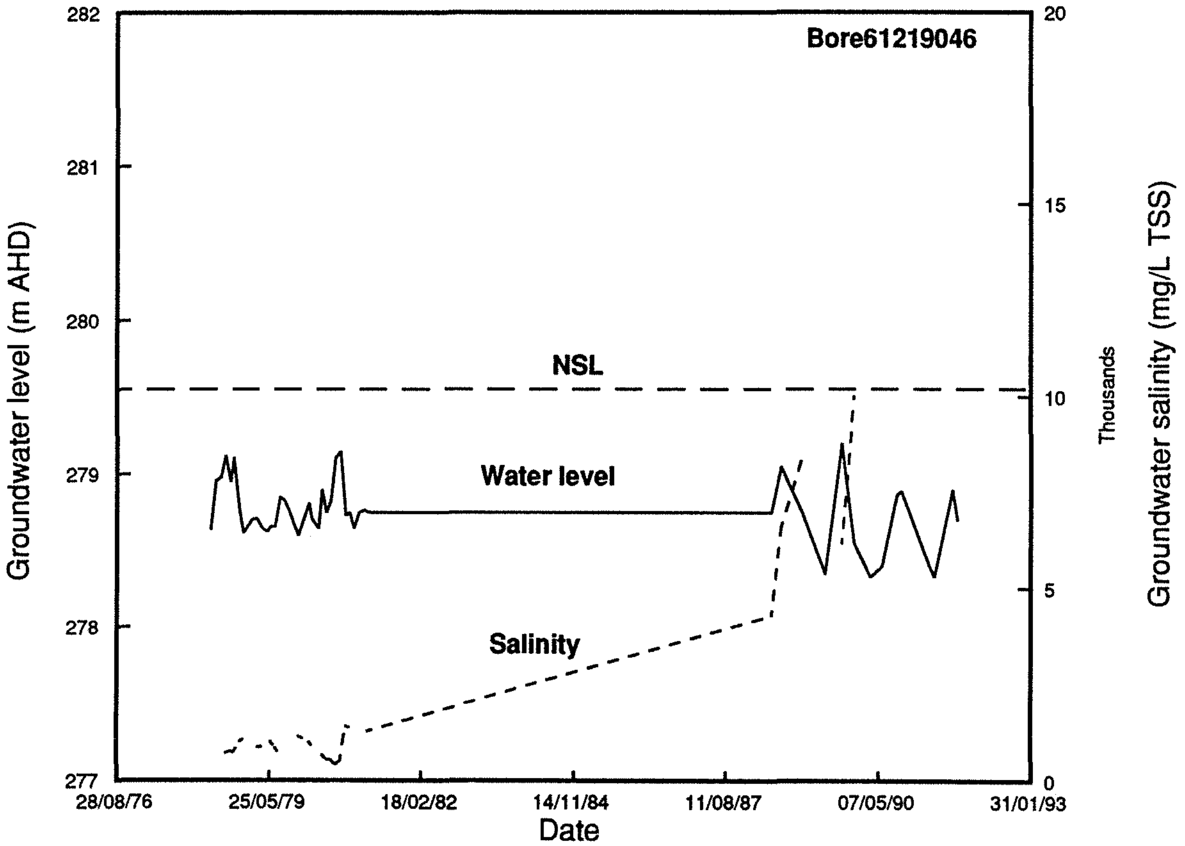

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Thousands
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Groundwater salinity (mg/L TSS)
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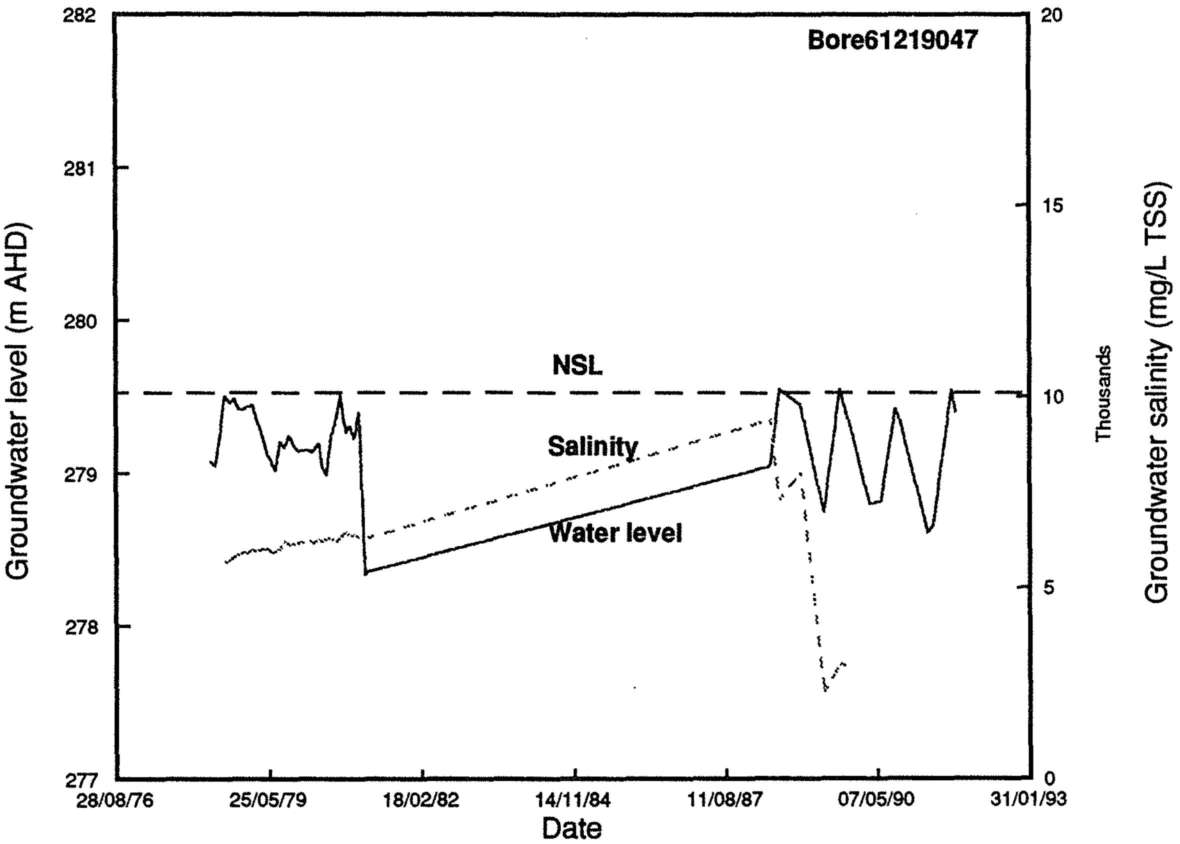
Date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Groundwater level (m AHD)
Thousands
Groundwater salinity (mg/L TSS)
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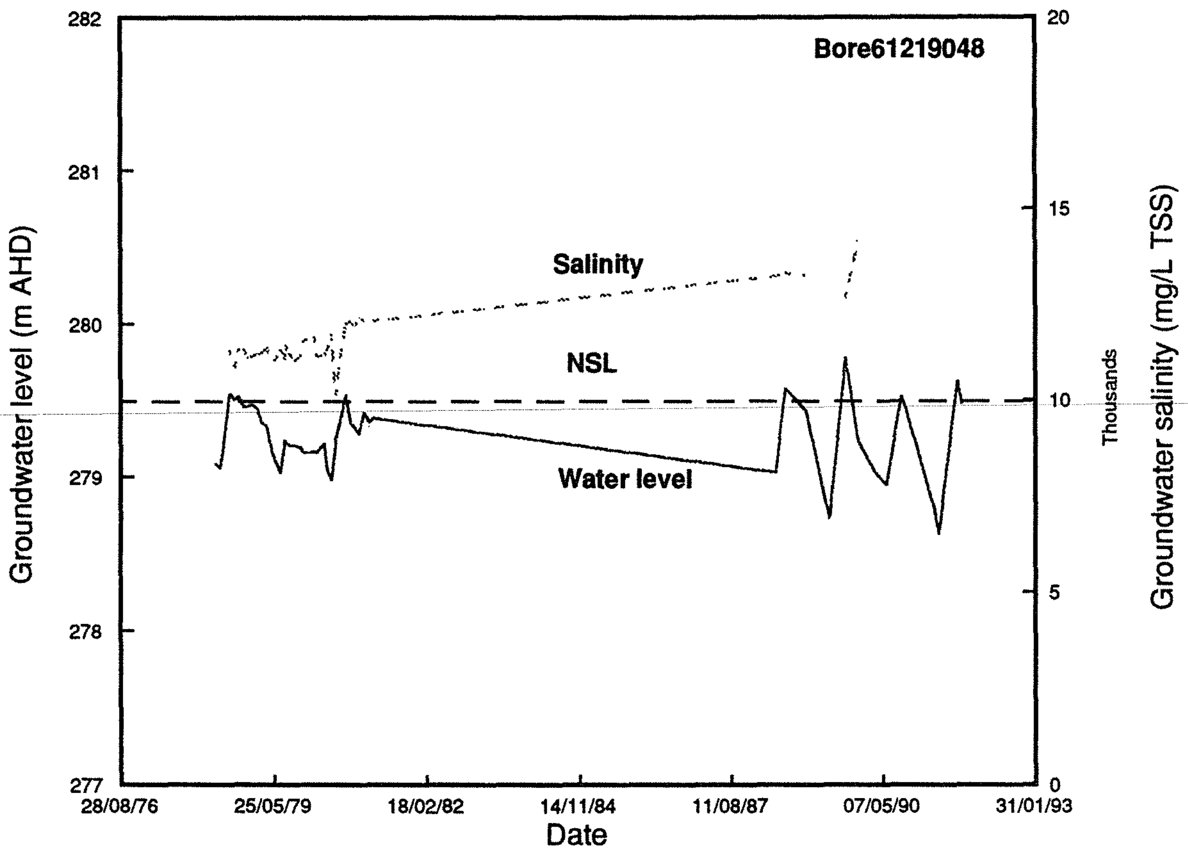
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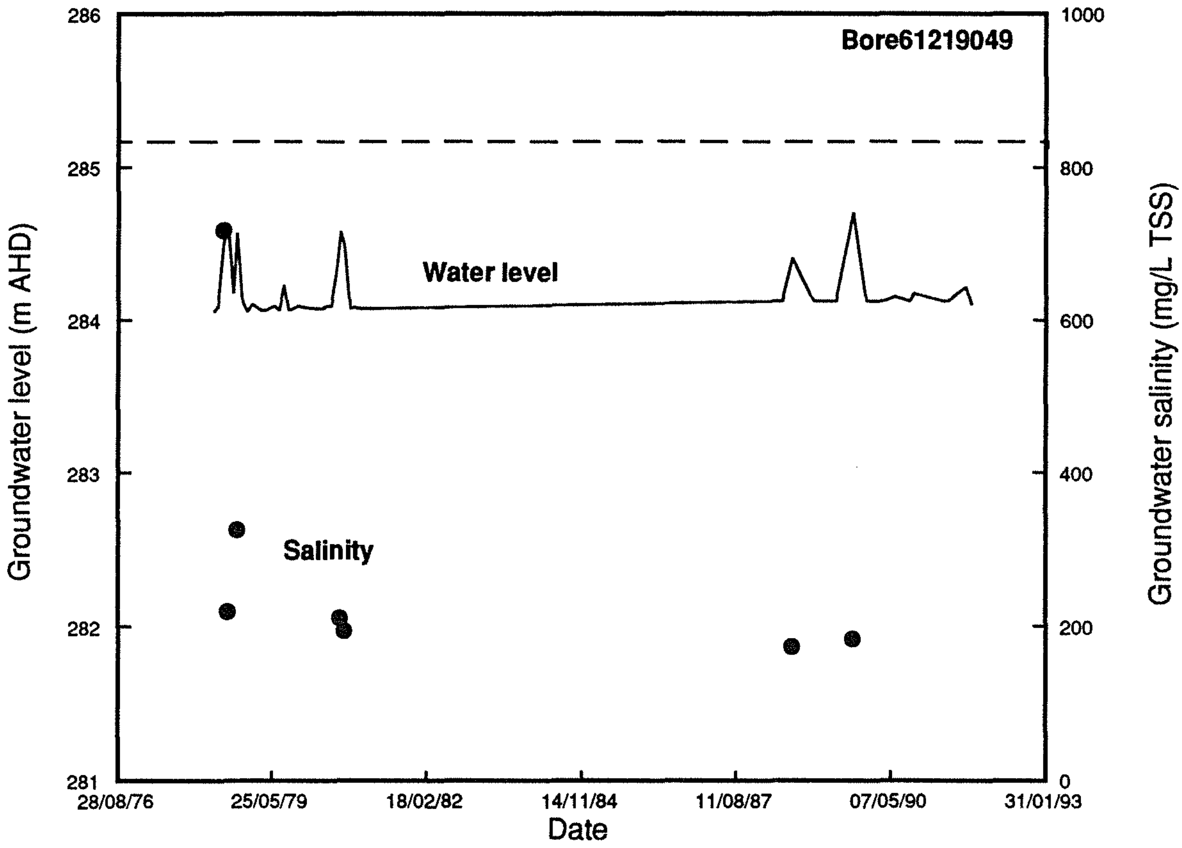
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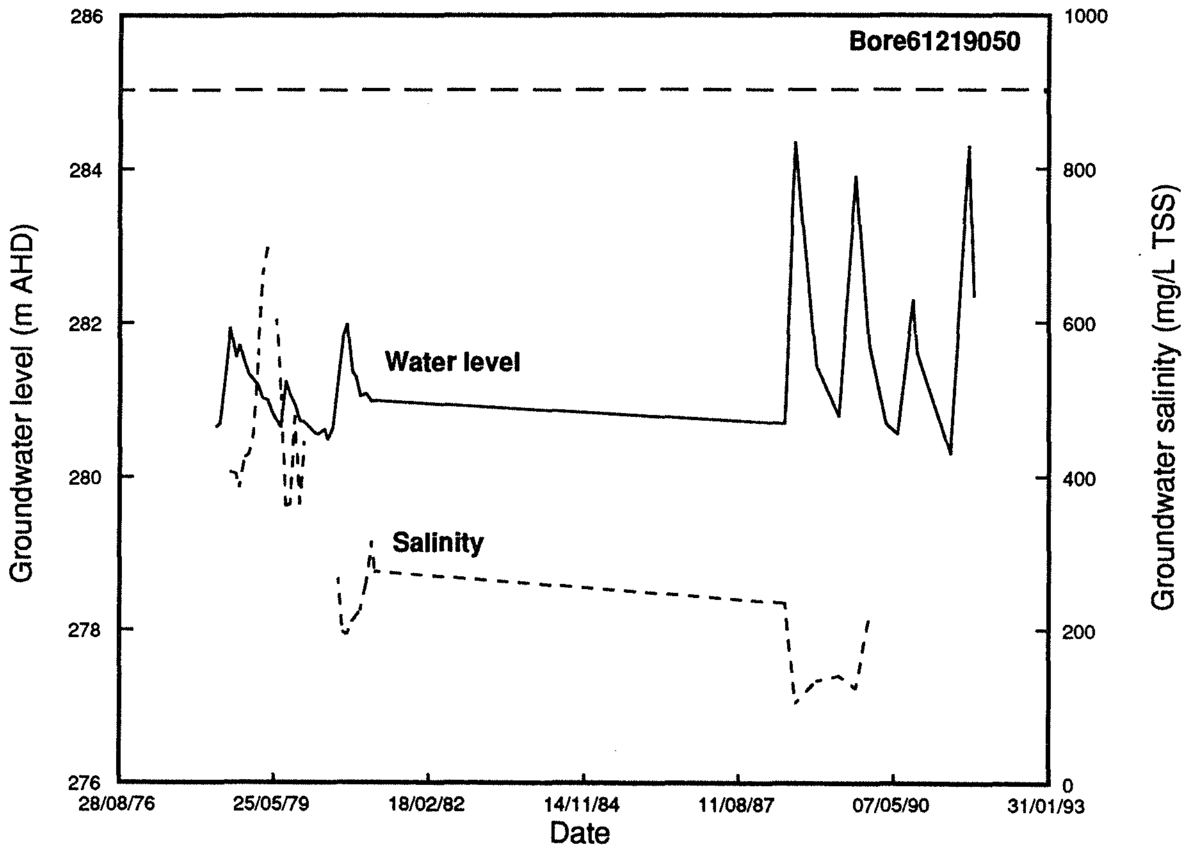
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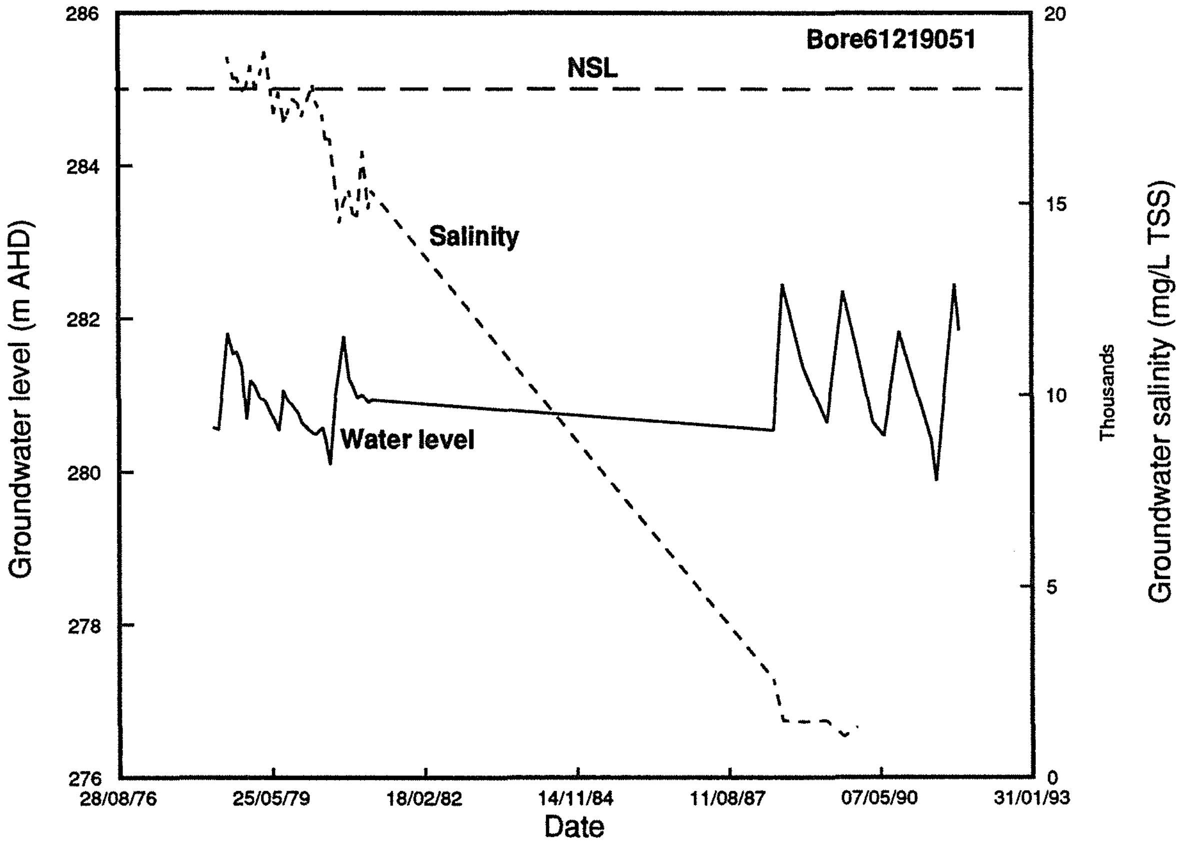

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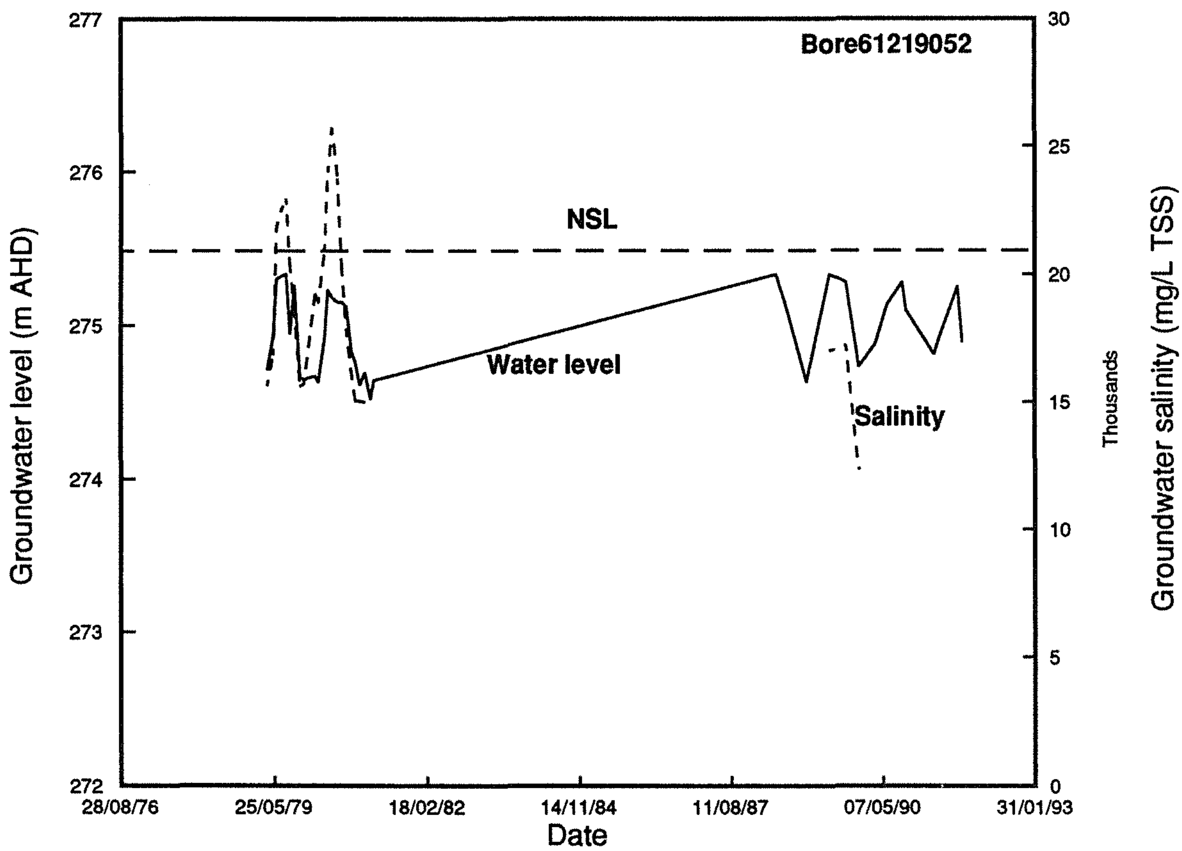

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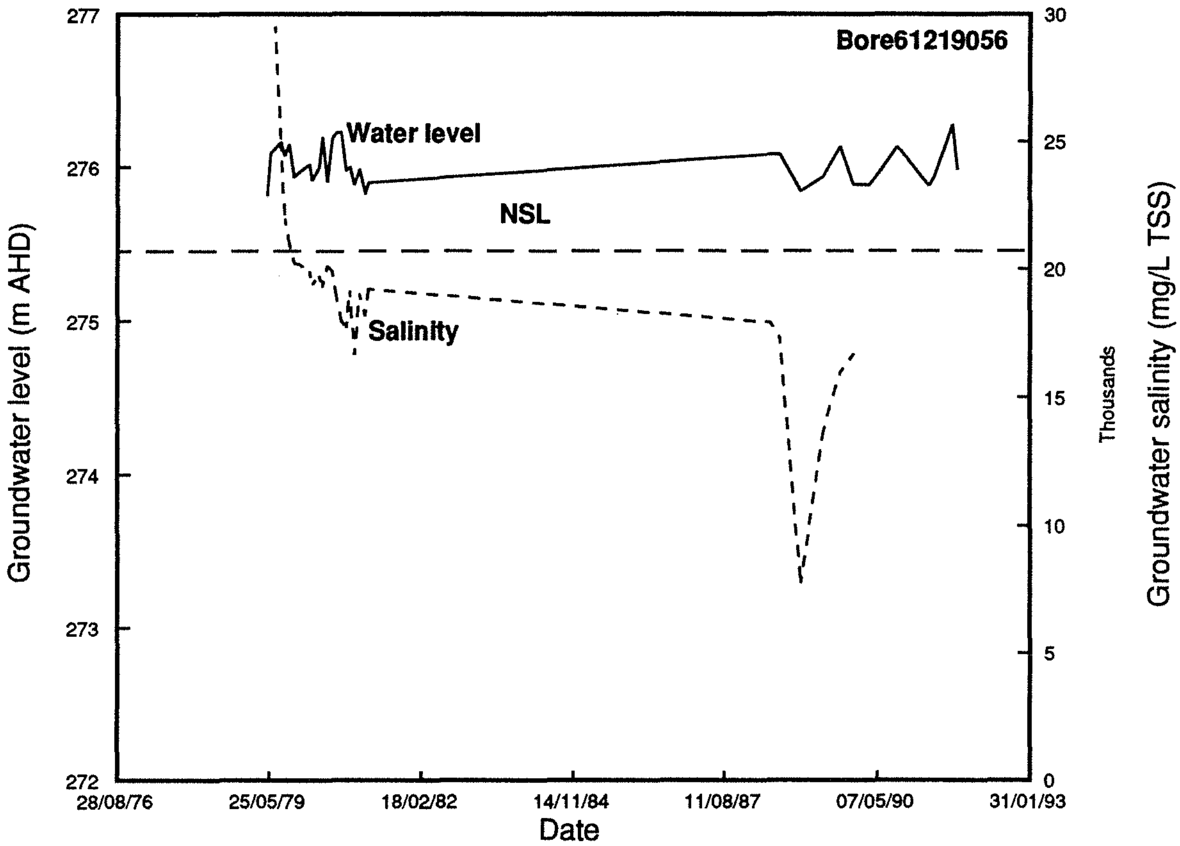
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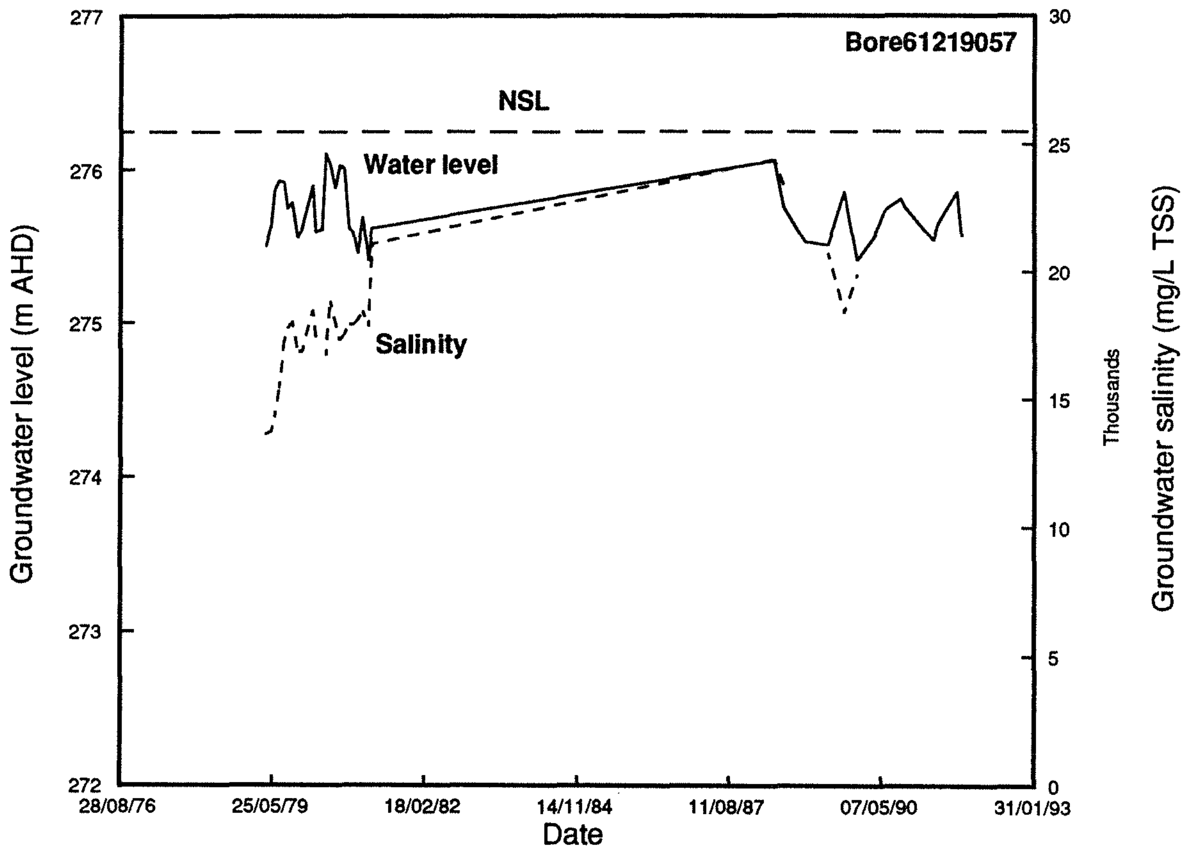
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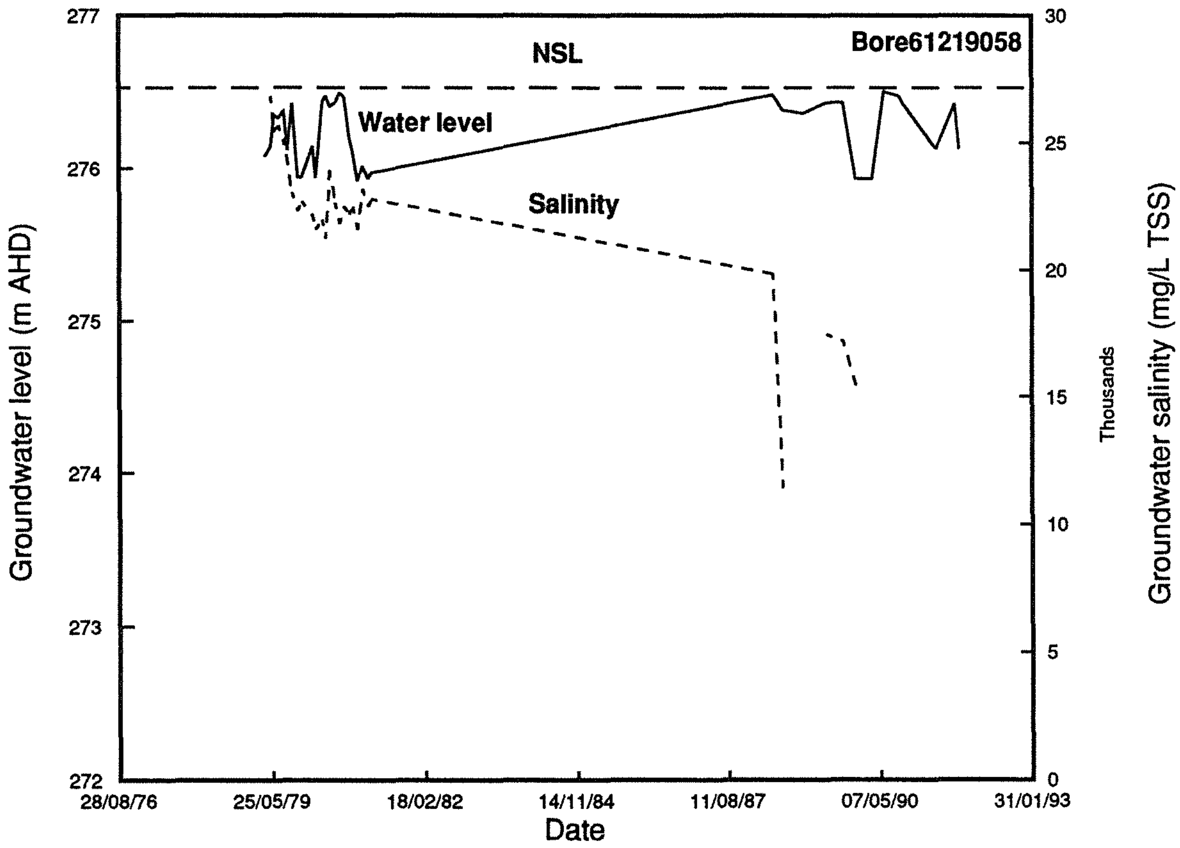
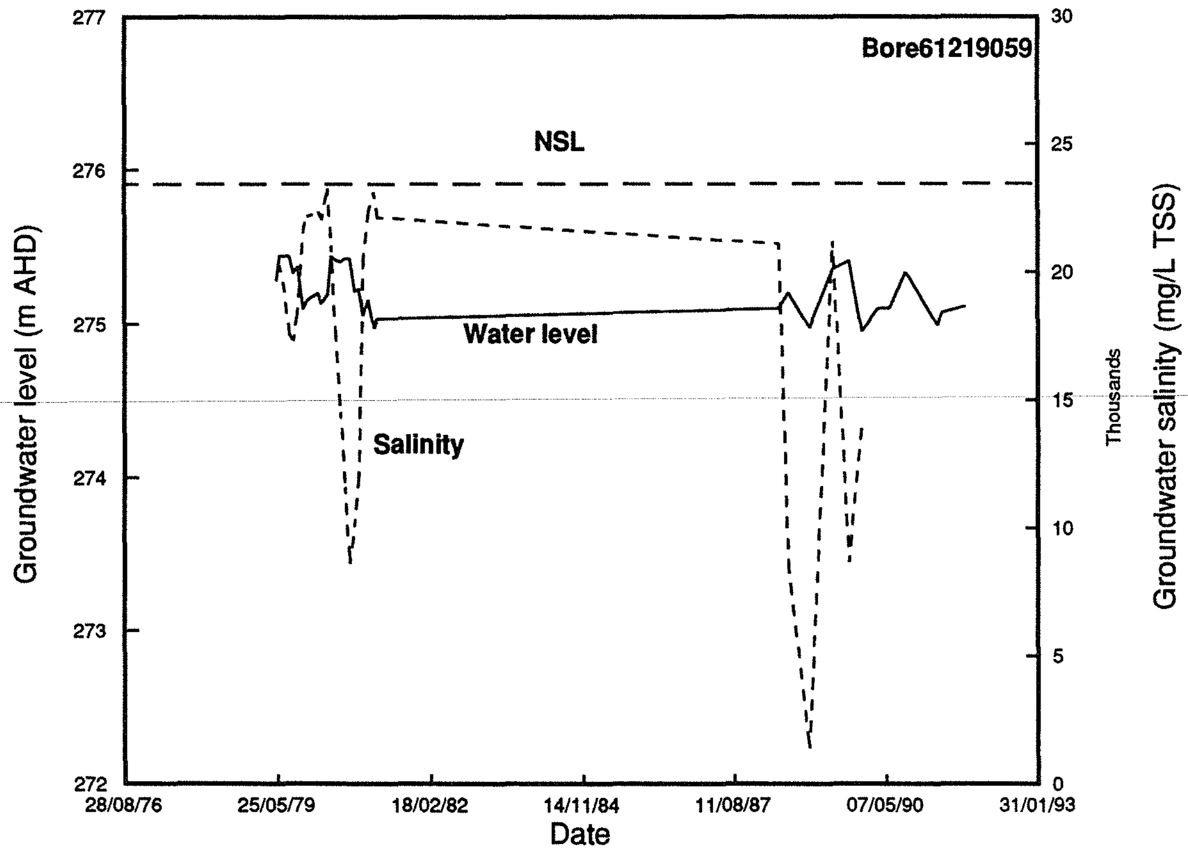
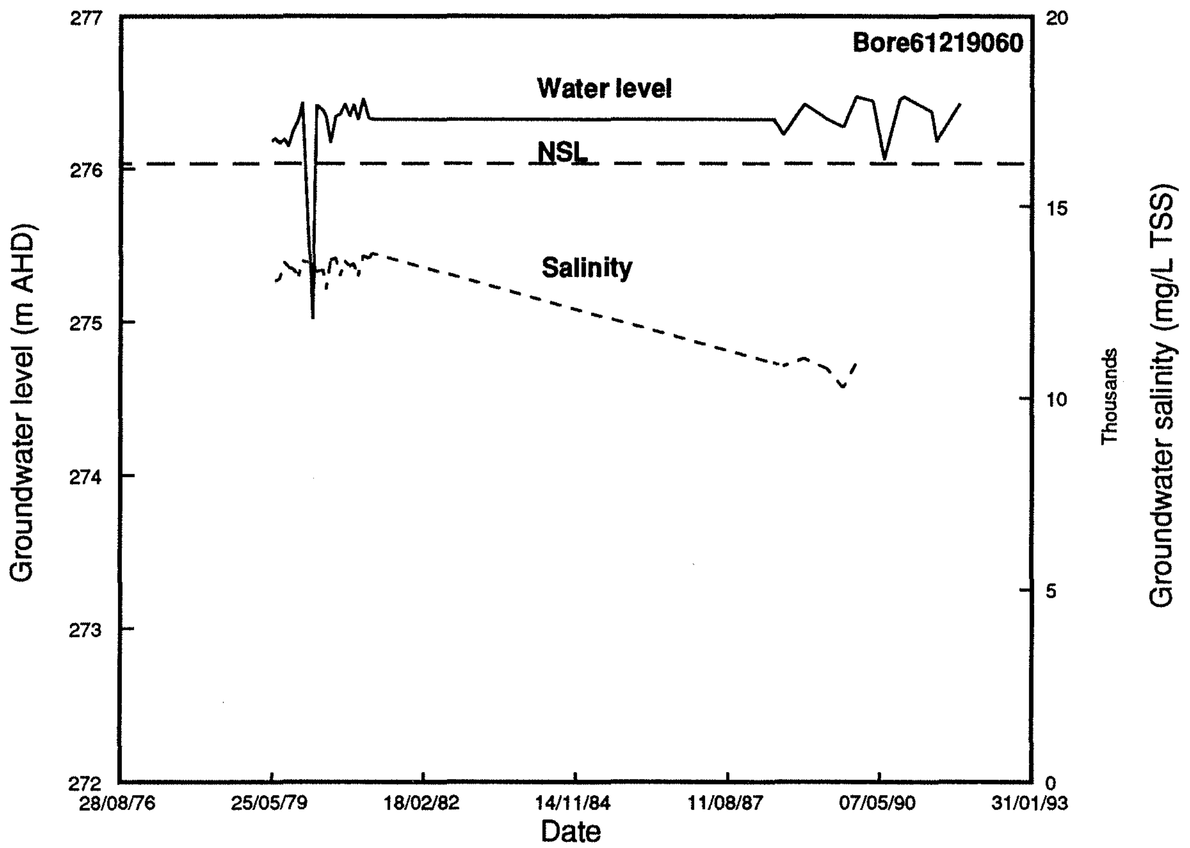
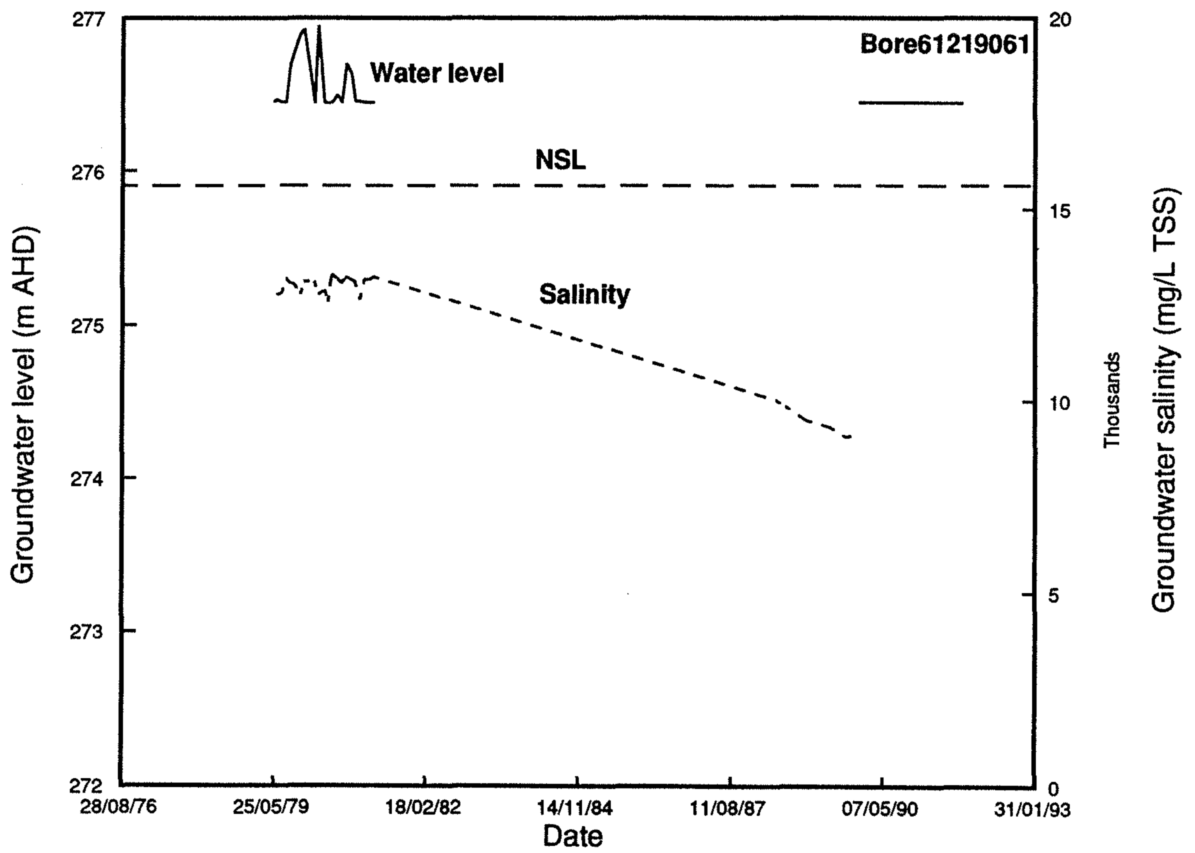
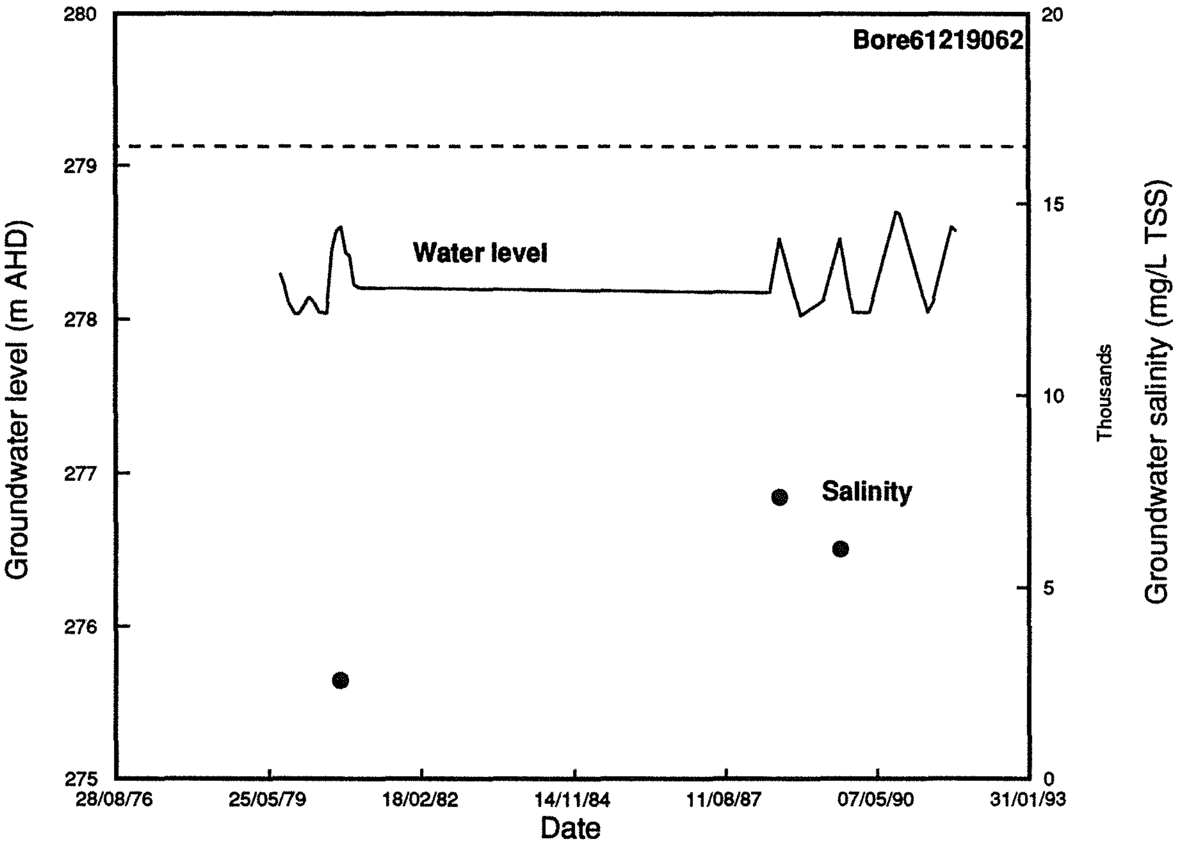
5
0
28/08/76
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93


Bore61219058
NSL
Water level
Salinity
Groundwater level (m AHD)
277
276
275
274
273
272
Groundwater salinity (mg/L TSS)
Thousands
30
25
20
15
10
5
0
28/08/76
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93
Date


Bore61219059
NSL
Water level
Salinity
Groundwater level (m AHD)
277
276
275
274
273
272
Groundwater salinity (mg/L TSS)
Thousands
30
25
20
15
10
5
0
28/08/76
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93
Date


Bore61219060
Water level
NSL
Salinity
Groundwater level (m AHD)
277
276
275
274
273
272
Groundwater salinity (mg/L TSS)
Thousands
20
15
10
5
0
28/08/76
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93
Date


Bore61219061
Water level
NSL
Salinity
Groundwater level (m AHD)
277
276
275
274
273
272
Groundwater salinity (mg/L TSS)
Thousands
20
15
10
5
0
28/08/76
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93
Date

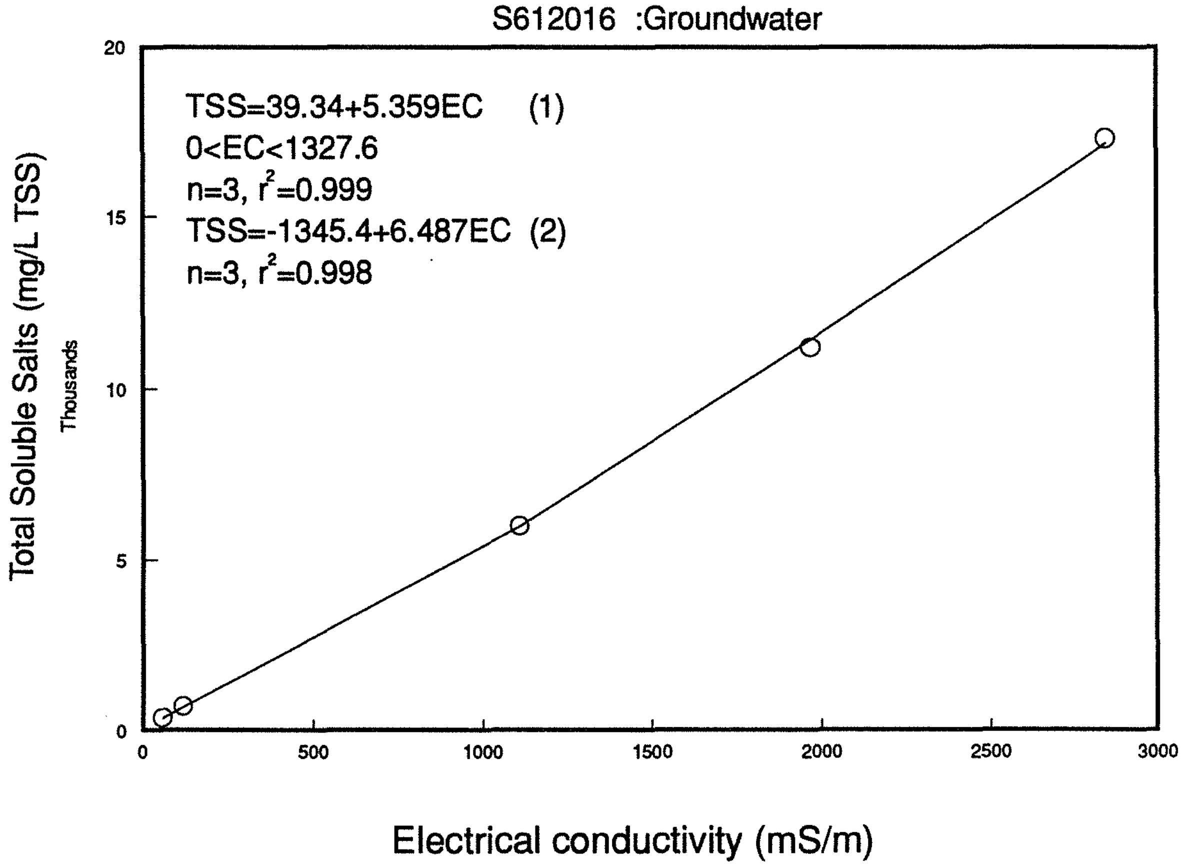


280
279
278
277
276
275
Groundwater level (m AHD)
Bore61219062
Water level
Salinity
20
15
10
5
0
Thousands
Groundwater salinity (mg/L TSS)
28/08/76
25/05/79
18/02/82
14/11/84
11/08/87
07/05/90
31/01/93
Date

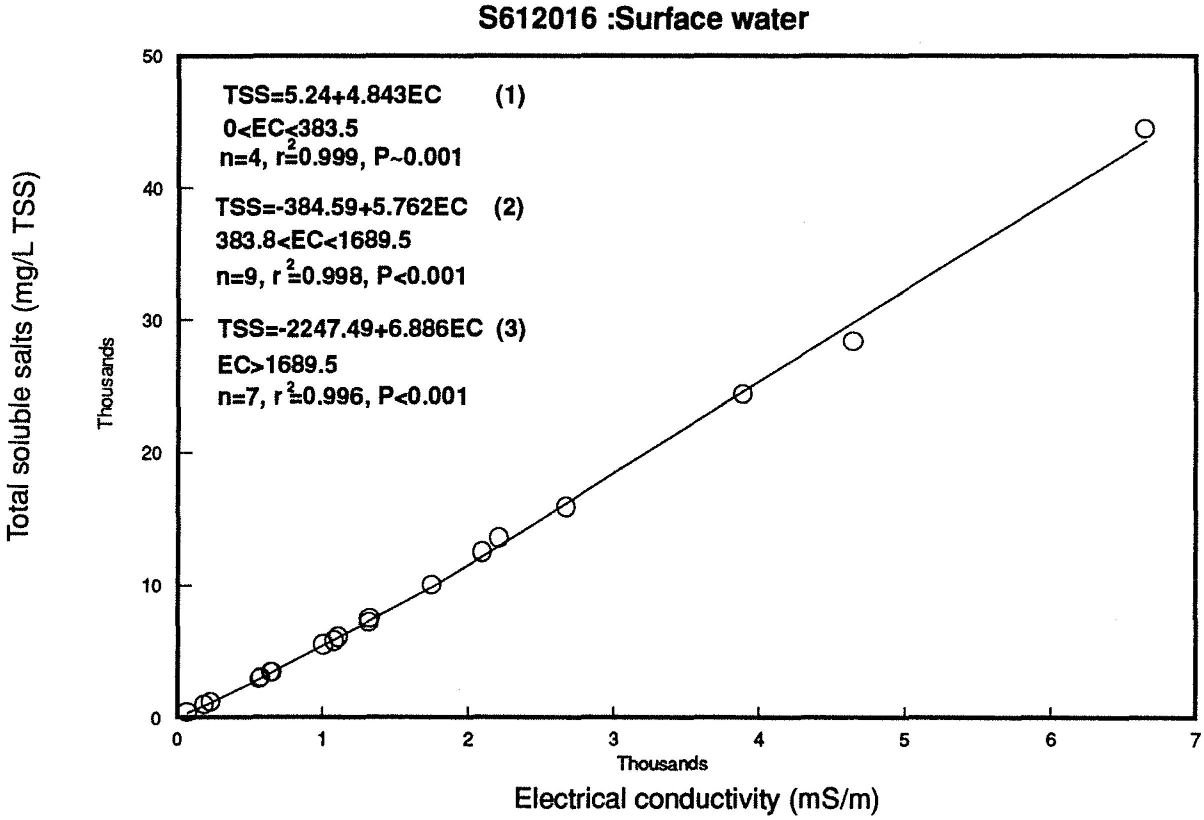
APPENDIX D

Relationship between salinity (TSS) and electrical conductivity (mS/m)

Relationship between TSS and EC

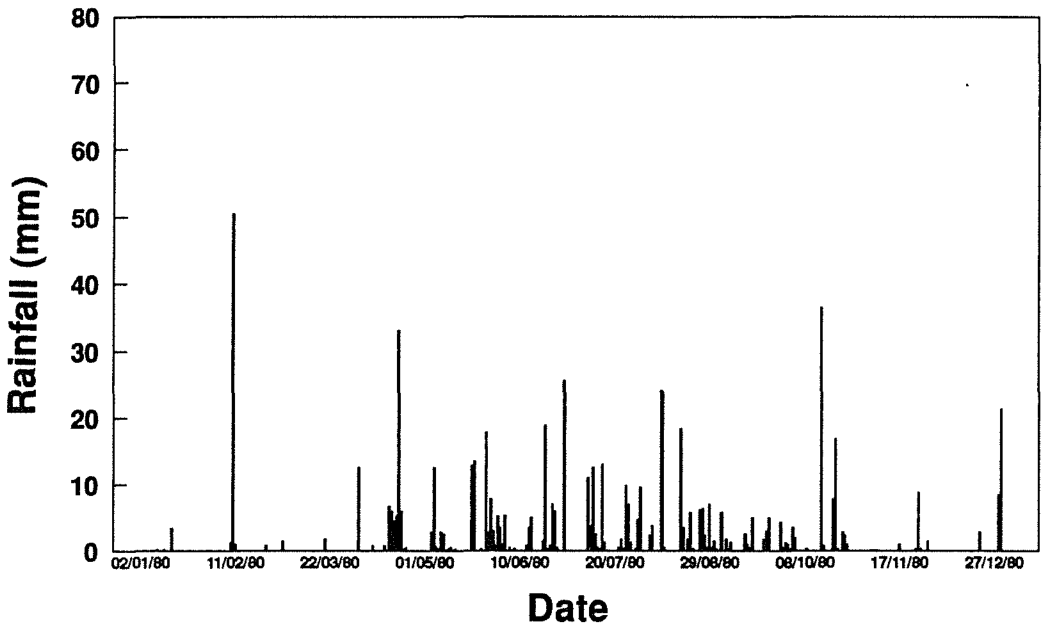


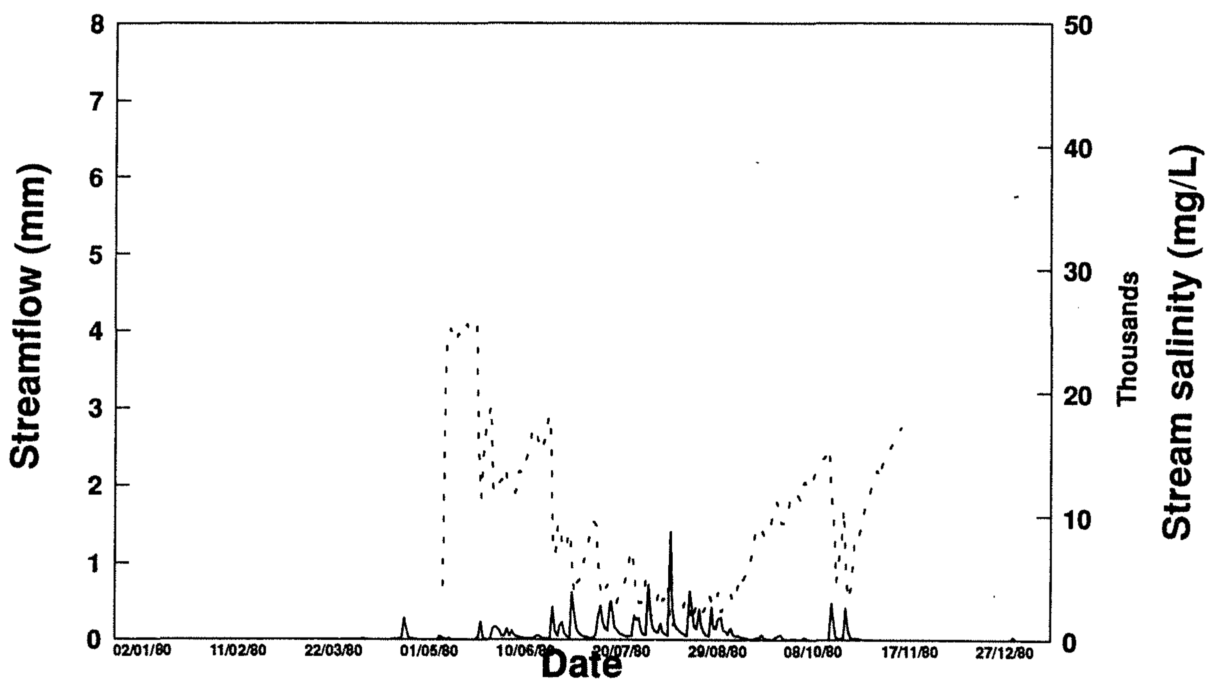
Relationship between TSS and EC

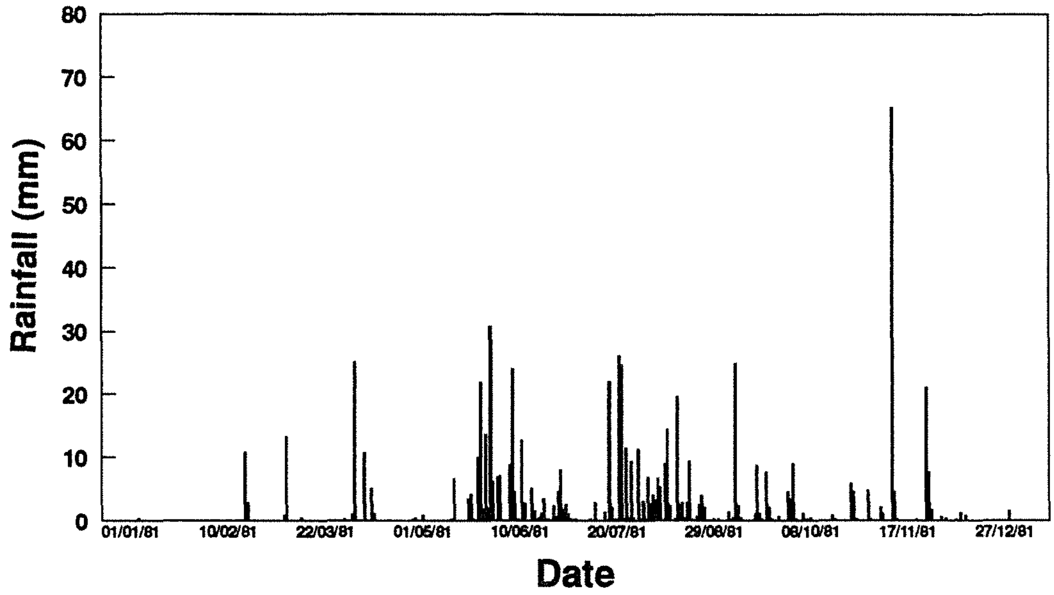


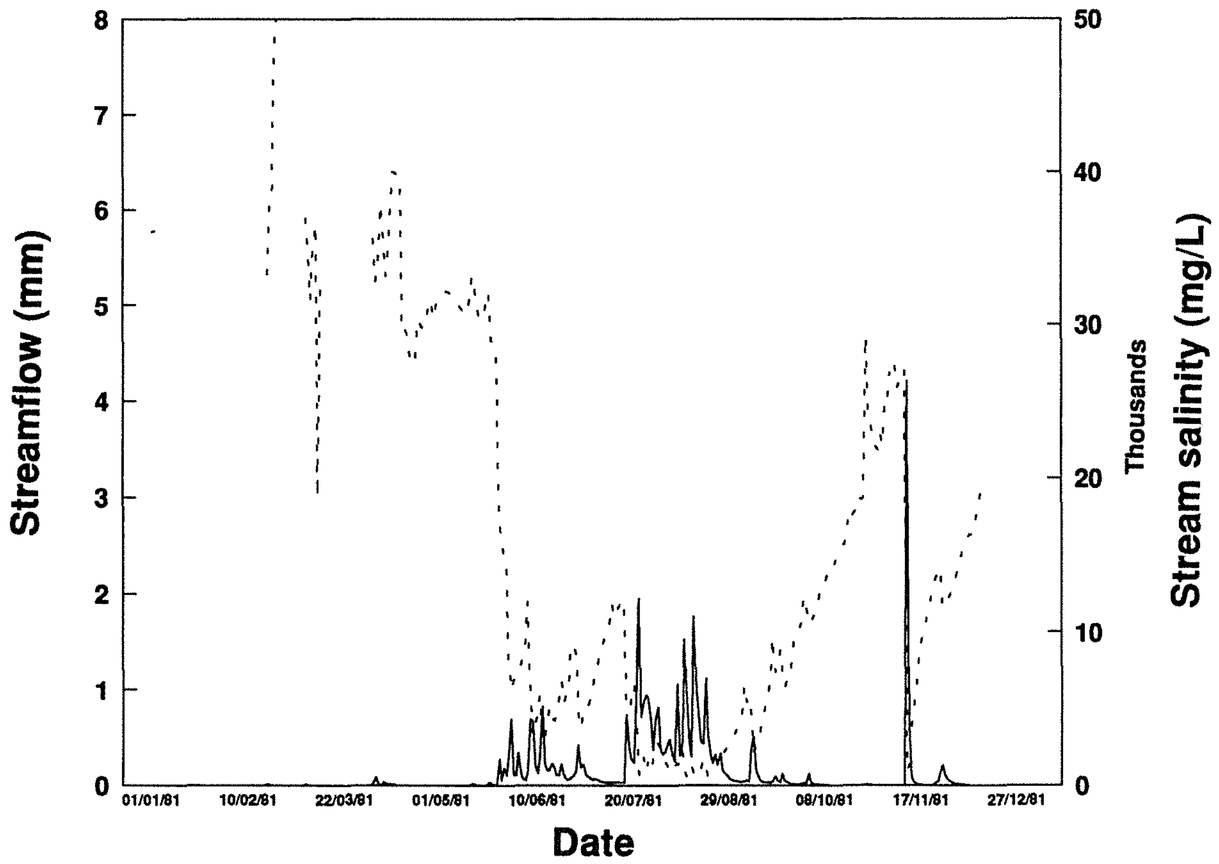
APPENDDIX E

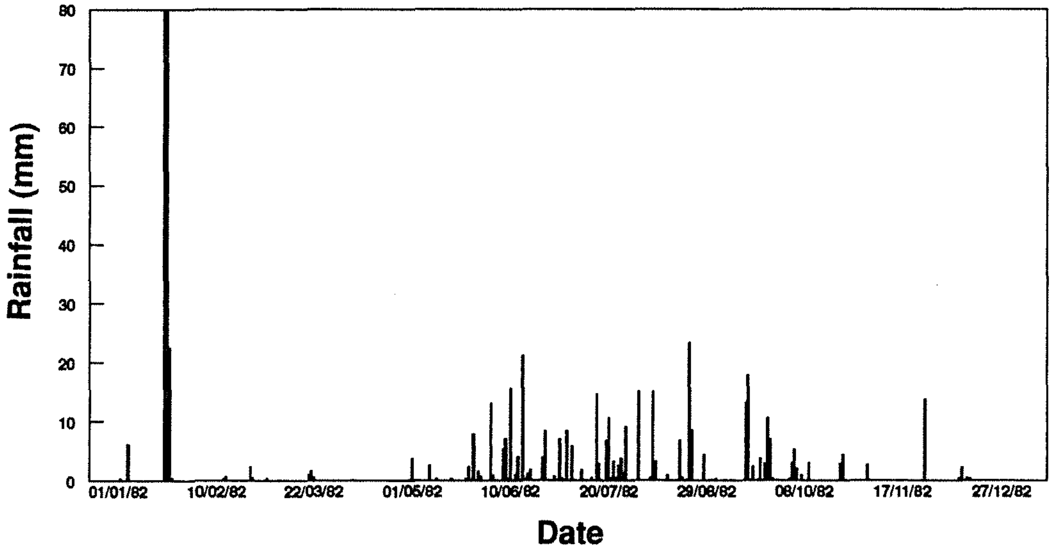
Streamflow and salinity graphs between 1980 and 1991.

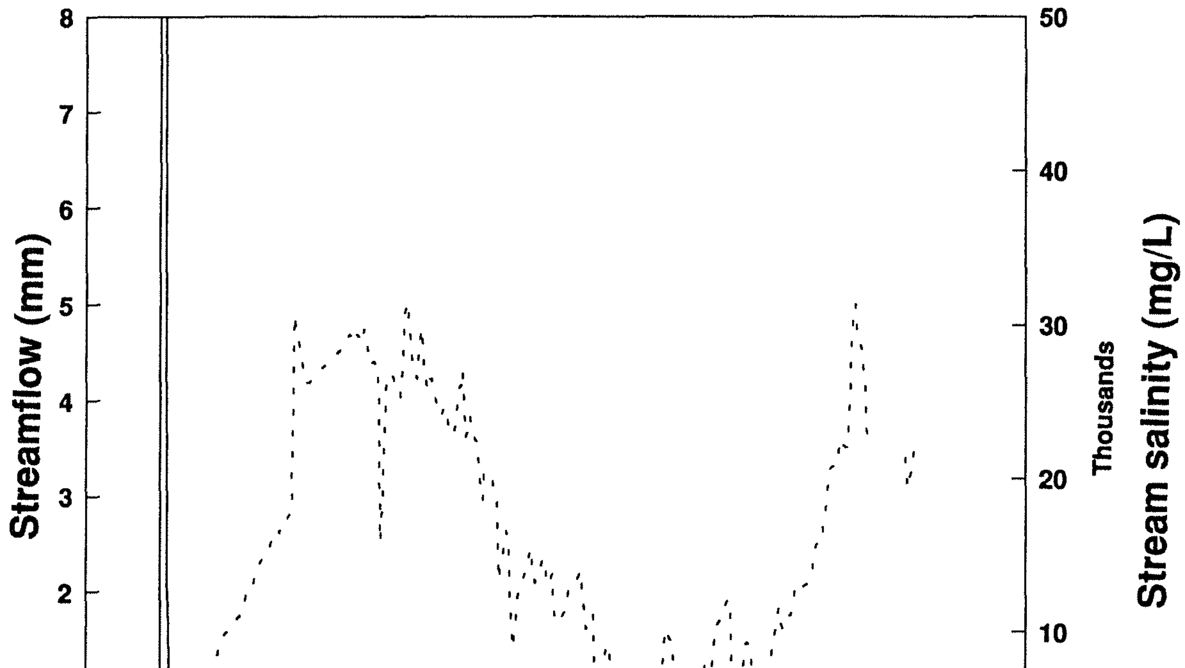

80
70
60
50
40
30
20
10
0
Rainfall (mm)
02/01/80
11/02/80
22/03/80
01/05/80
10/06/80
20/07/80
29/08/80
08/10/80
17/11/80
27/12/80
Date

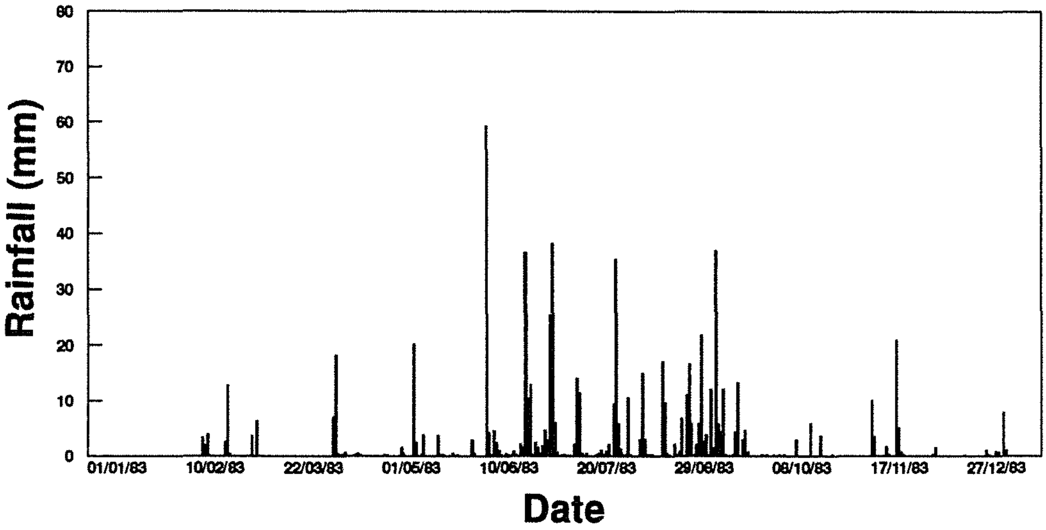

8
7
6
5
4
3
2
1
0
Streamflow (mm)
50
40
30
20
10
0
Thousands
Stream salinity (mg/L)
02/01/80
11/02/80
22/03/80
01/05/80
10/06/80
20/07/80
29/08/80
08/10/80
17/11/80
27/12/80
Date

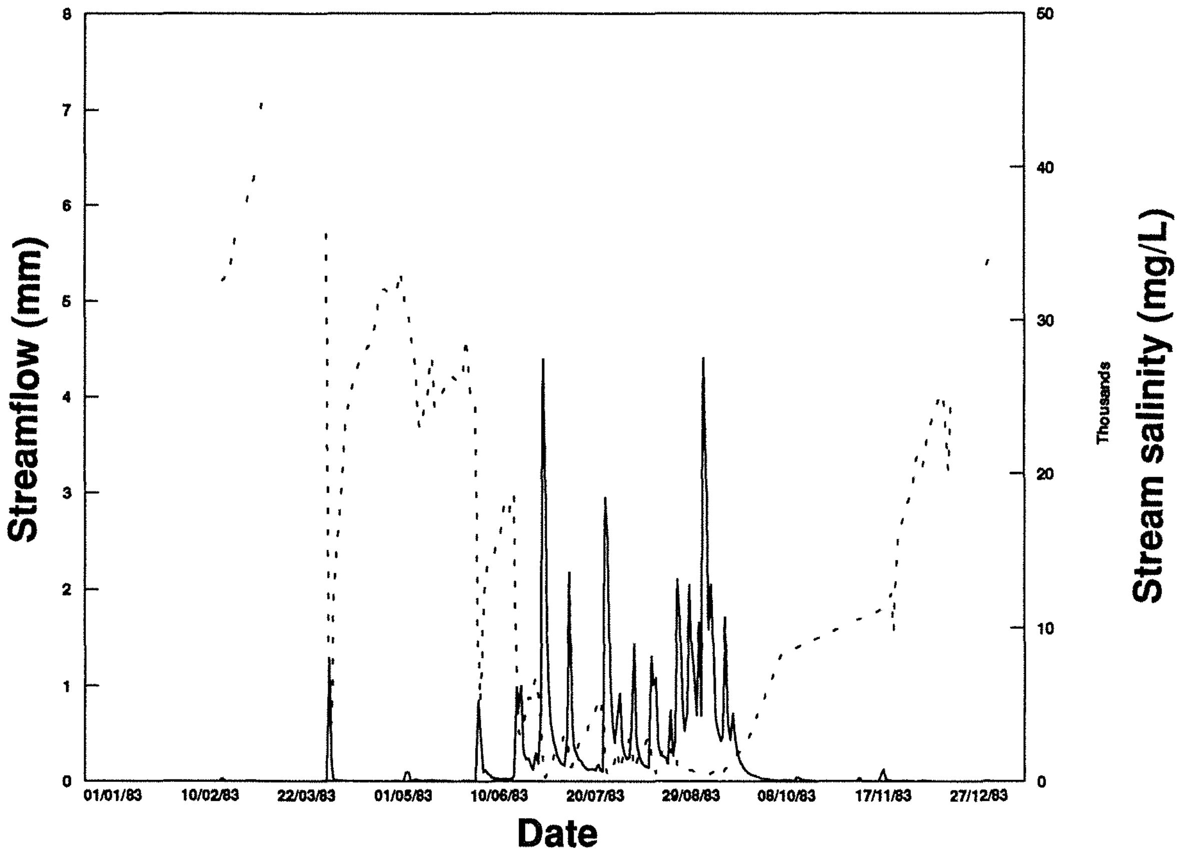

Rainfall (mm)
80
70
60
50
40
30
20
10
0
01/01/81
10/02/81
22/03/81
01/05/81
10/06/81
20/07/81
29/08/81
08/10/81
17/11/81
27/12/81
Date

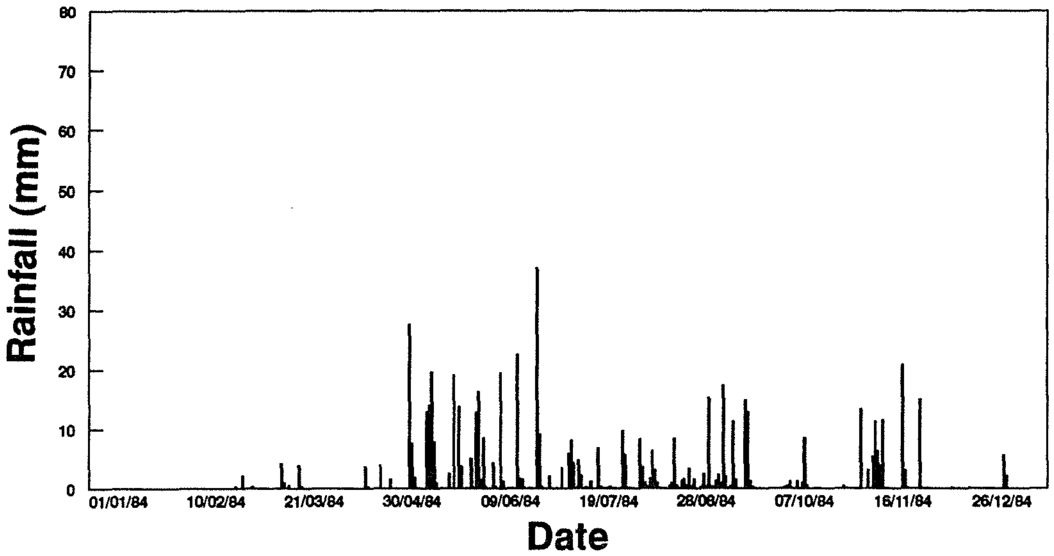

Streamflow (mm)
8
7
6
5
4
3
2
1
0
01/01/81
10/02/81
22/03/81
01/05/81
10/06/81
20/07/81
29/08/81
08/10/81
17/11/81
27/12/81
Date
50
40
30
20
10
0
Thousands
Stream salinity (mg/L)

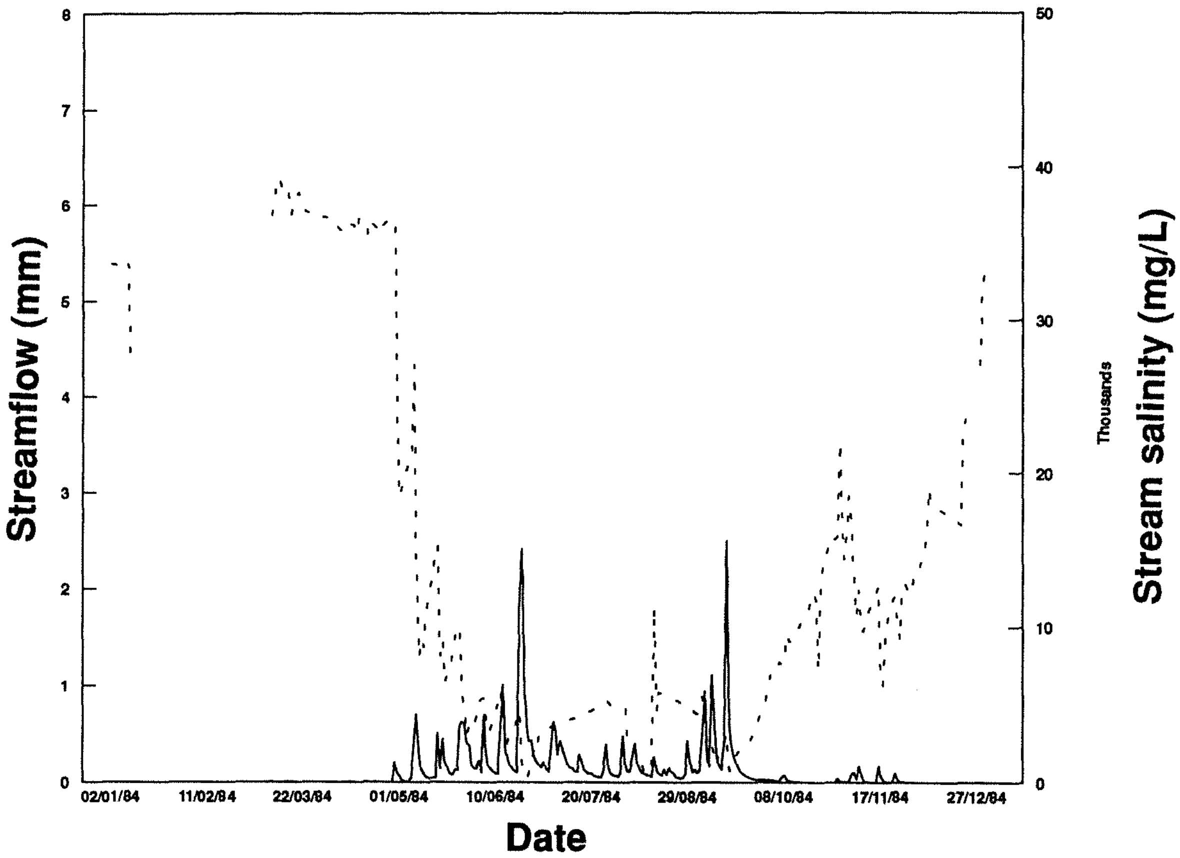

Rainfall (mm)
80
70
60
50
40
30
20
10
0
01/01/82
10/02/82
22/03/82
01/05/82
10/06/82
20/07/82
29/08/82
08/10/82
17/11/82
27/12/82
Date

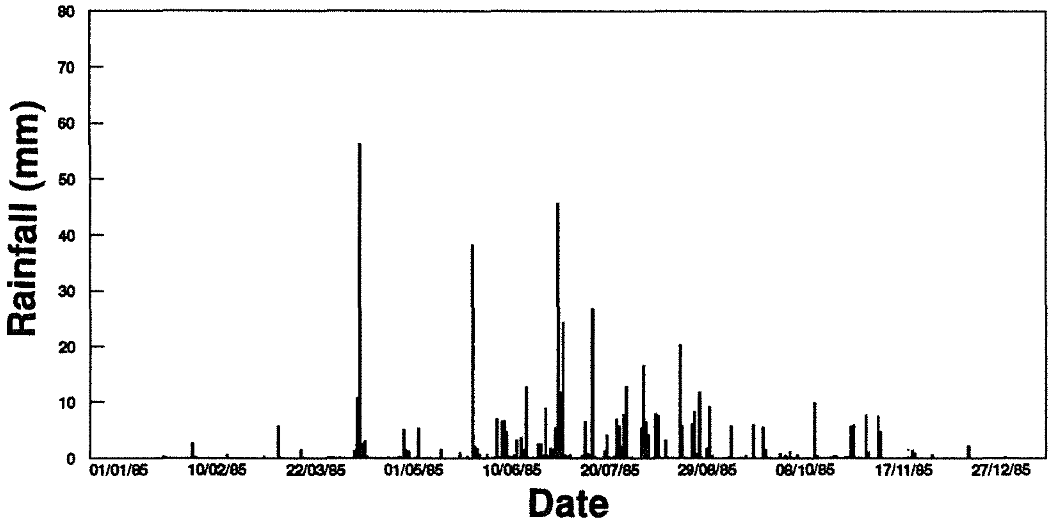

Streamflow (mm)
8
7
6
5
4
3
2
1
0
Thousands
Stream salinity (mg/L)
50
40
30
20
10
0
01/01/82
10/02/82
22/03/82
01/05/82
10/06/82
20/07/82
29/08/82
08/10/82
17/11/82
27/12/82
Date

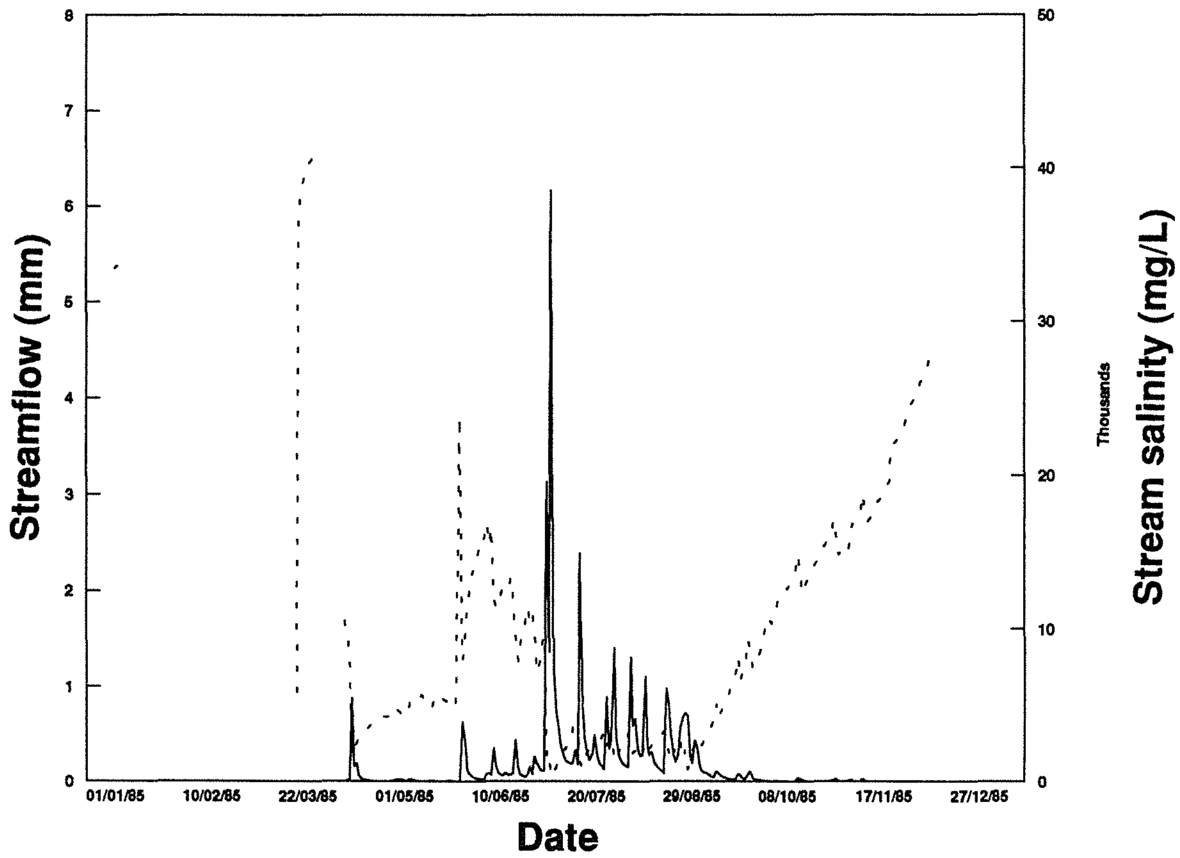

Rainfall (mm)
80
70
60
50
40
30
20
10
0
01/01/83
10/02/83
22/03/83
01/05/83
10/06/83
20/07/83
29/08/83
08/10/83
17/11/83
27/12/83
Date

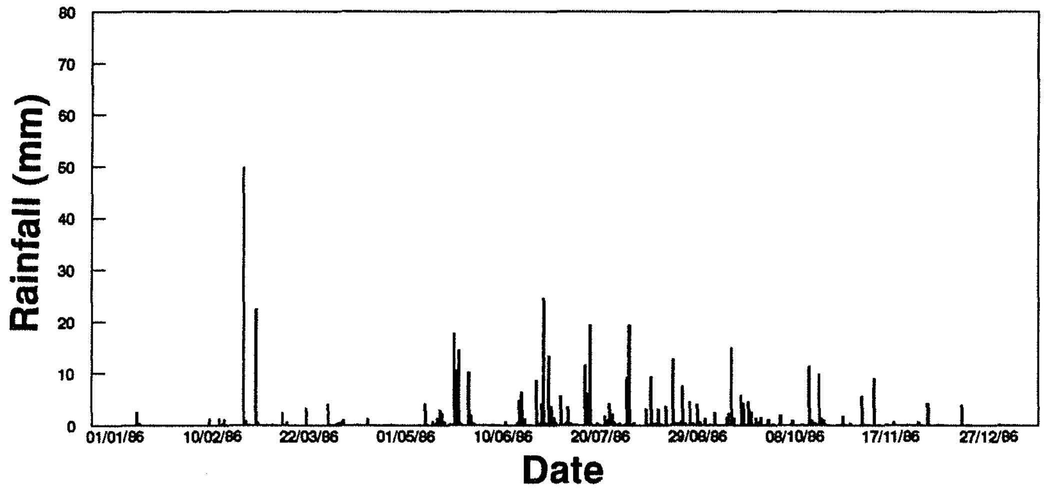

Streamflow (mm)
8
7
6
5
4
3
2
1
0
01/01/83
10/02/83
22/03/83
01/05/83
10/06/83
20/07/83
29/08/83
08/10/83
17/11/83
27/12/83
Date
50
40
30
20
10
0
Thousands
Stream salinity (mg/L)

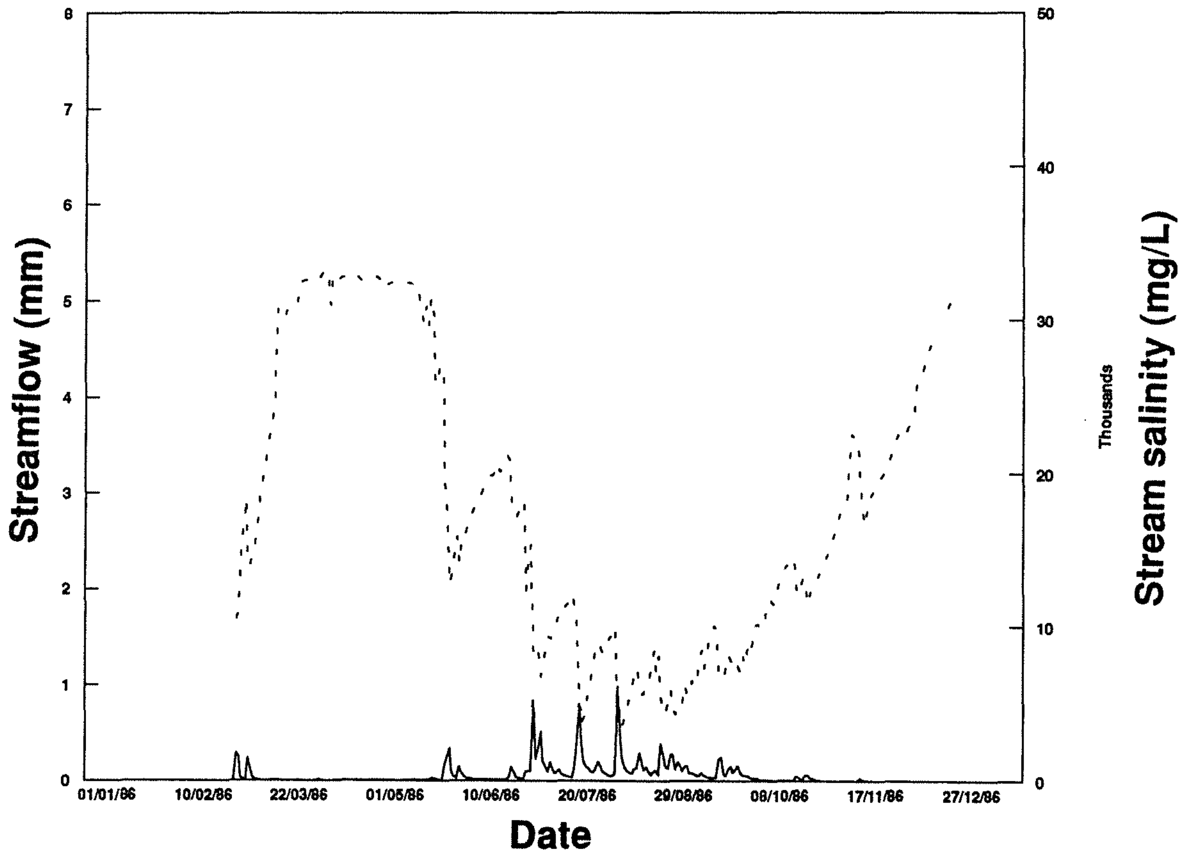

Rainfall (mm)
80
70
60
50
40
30
20
10
0
01/01/84
10/02/84
21/03/84
30/04/84
09/06/84
19/07/84
28/08/84
07/10/84
16/11/84
26/12/84
Date

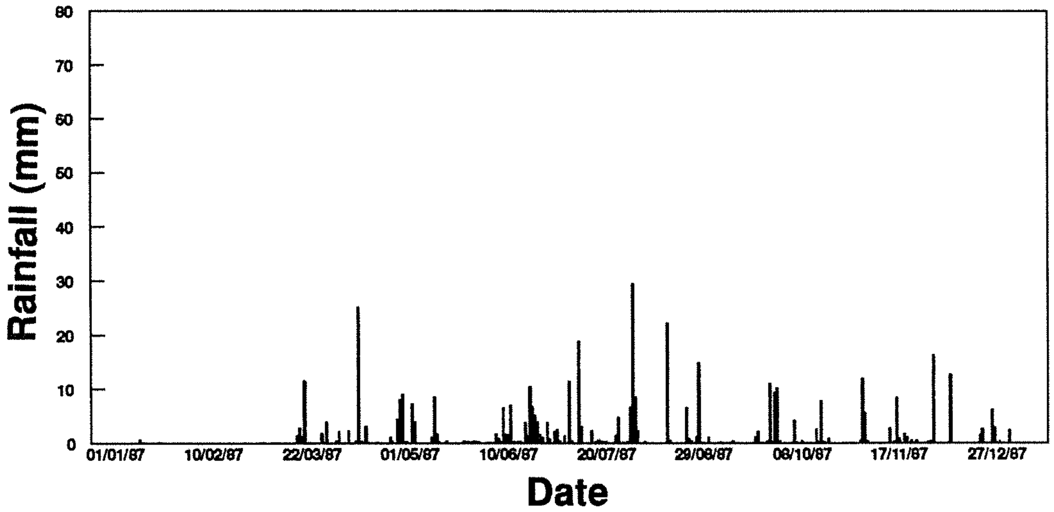

Streamflow (mm)
8
7
6
5
4
3
2
1
0
Stream salinity (mg/L)
Thousands
50
40
30
20
10
0
02/01/84
11/02/84
22/03/84
01/05/84
10/06/84
20/07/84
29/08/84
08/10/84
17/11/84
27/12/84
Date

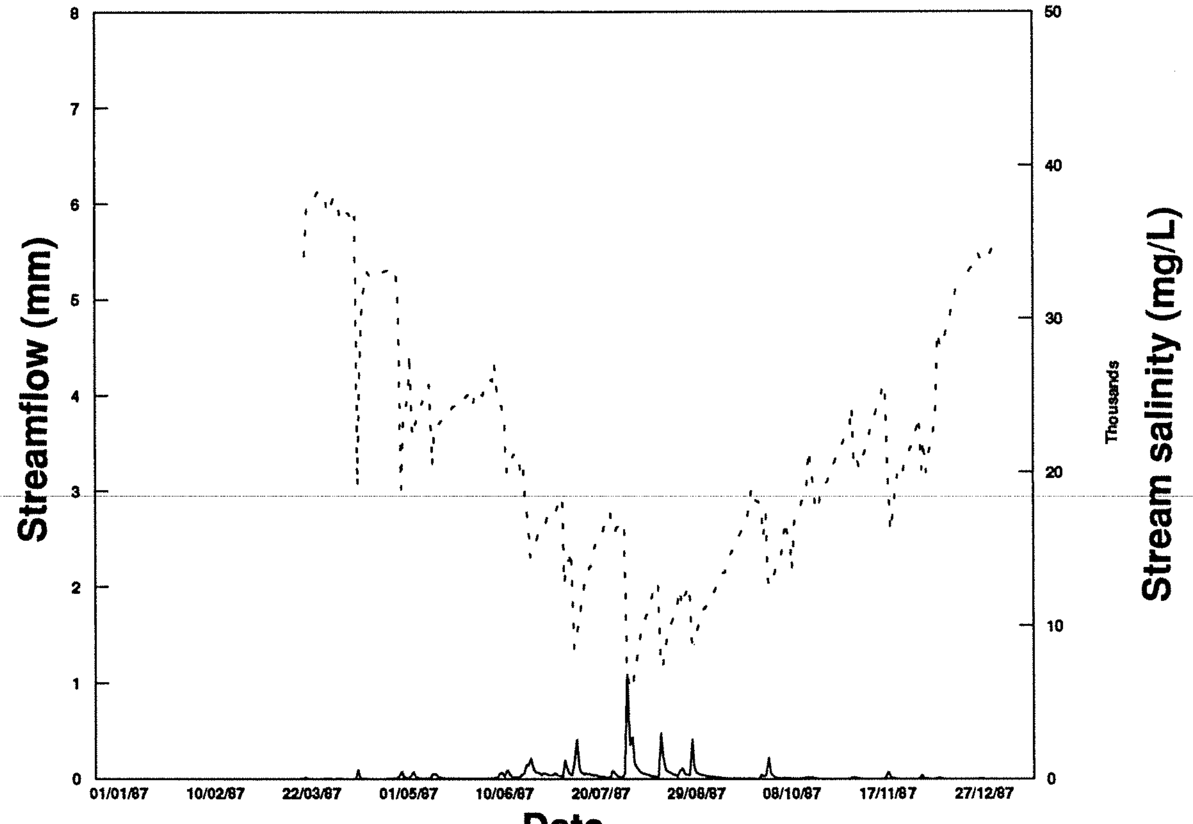

Rainfall (mm)
80
70
60
50
40
30
20
10
0
01/01/85
10/02/85
22/03/85
01/05/85
10/06/85
20/07/85
29/08/85
08/10/85
17/11/85
27/12/85
Date

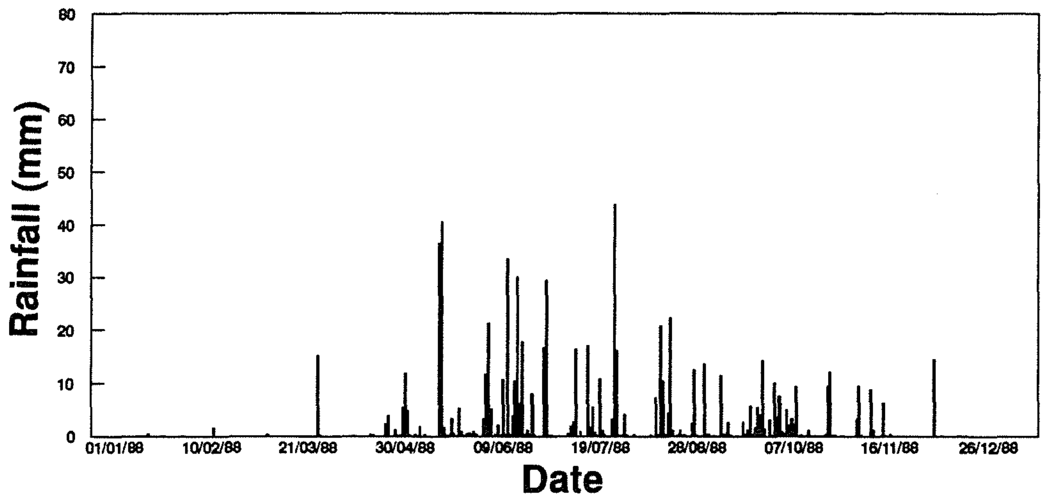

Streamflow (mm)
8
7
6
5
4
3
2
1
0
50
40
30
20
10
0
Thousands
Stream salinity (mg/L)
01/01/85
10/02/85
22/03/85
01/05/85
10/06/85
20/07/85
29/08/85
08/10/85
17/11/85
27/12/85
Date

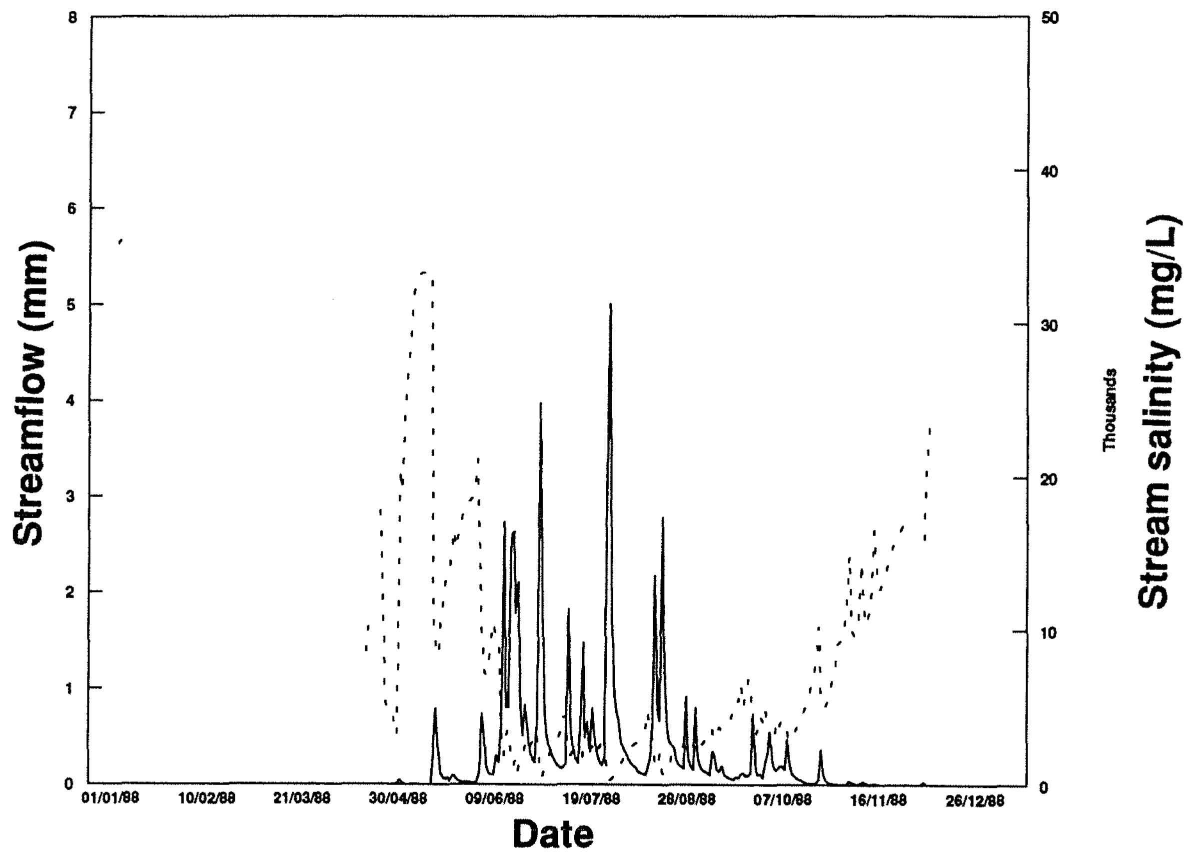

Rainfall (mm)
0
10
20
30
40
50
60
70
80
01/01/86
10/02/86
22/03/86
01/05/86
10/06/86
20/07/86
29/08/86
08/10/86
17/11/86
27/12/86
Date

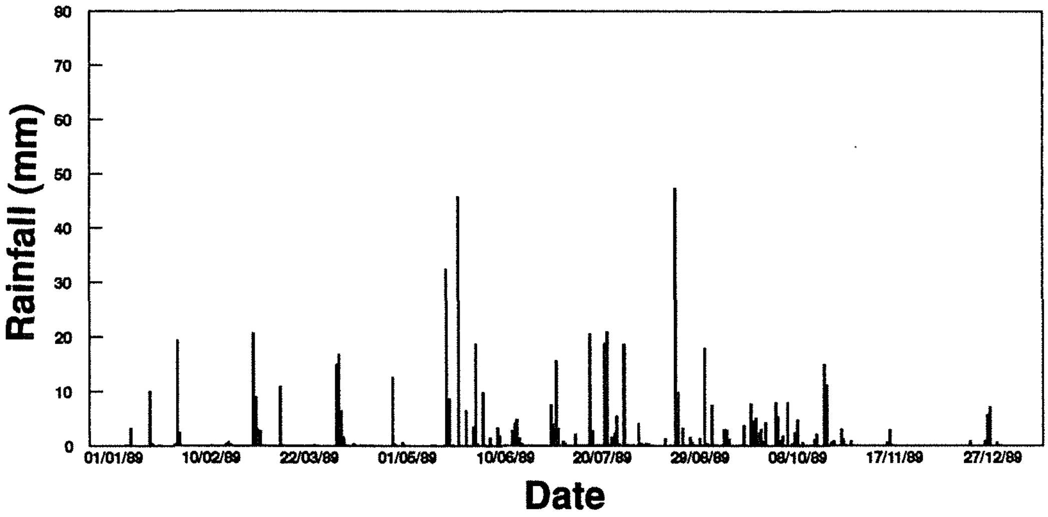

Streamflow (mm)
0
1
2
3
4
5
6
7
8
Stream salinity (mg/L)
Thousands
0
10
20
30
40
50
01/01/86
10/02/86
22/03/86
01/05/86
10/06/86
20/07/86
29/08/86
08/10/86
17/11/86
27/12/86
Date

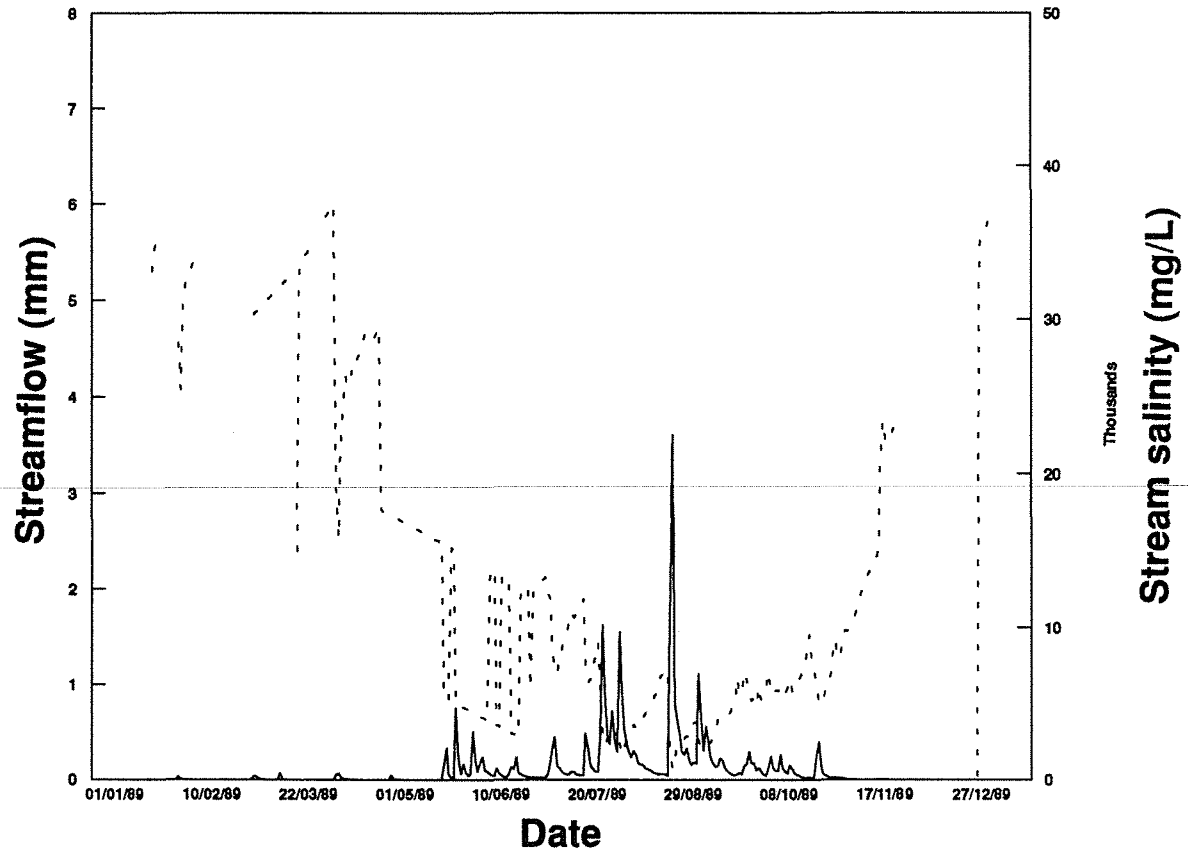

Rainfall (mm)
80
70
60
50
40
30
20
10
0
01/01/87
10/02/87
22/03/87
01/05/87
10/06/87
20/07/87
29/08/87
08/10/87
17/11/87
27/12/87
Date

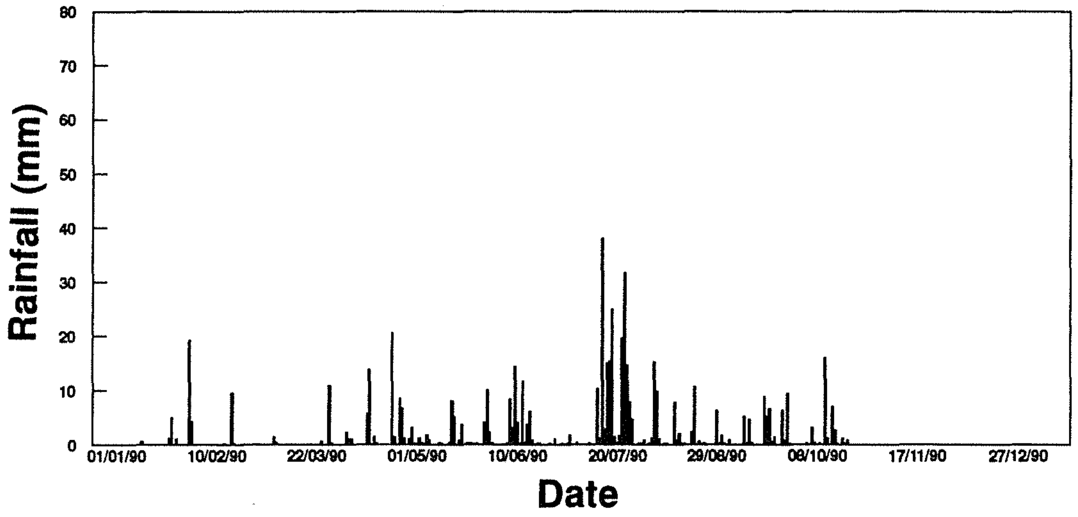

Streamflow (mm)
8
7
6
5
4
3
2
1
0
Stream salinity (mg/L)
Thousands
50
40
30
20
10
0
01/01/87
10/02/87
22/03/87
01/05/87
10/06/87
20/07/87
29/08/87
08/10/87
17/11/87
27/12/87
Date

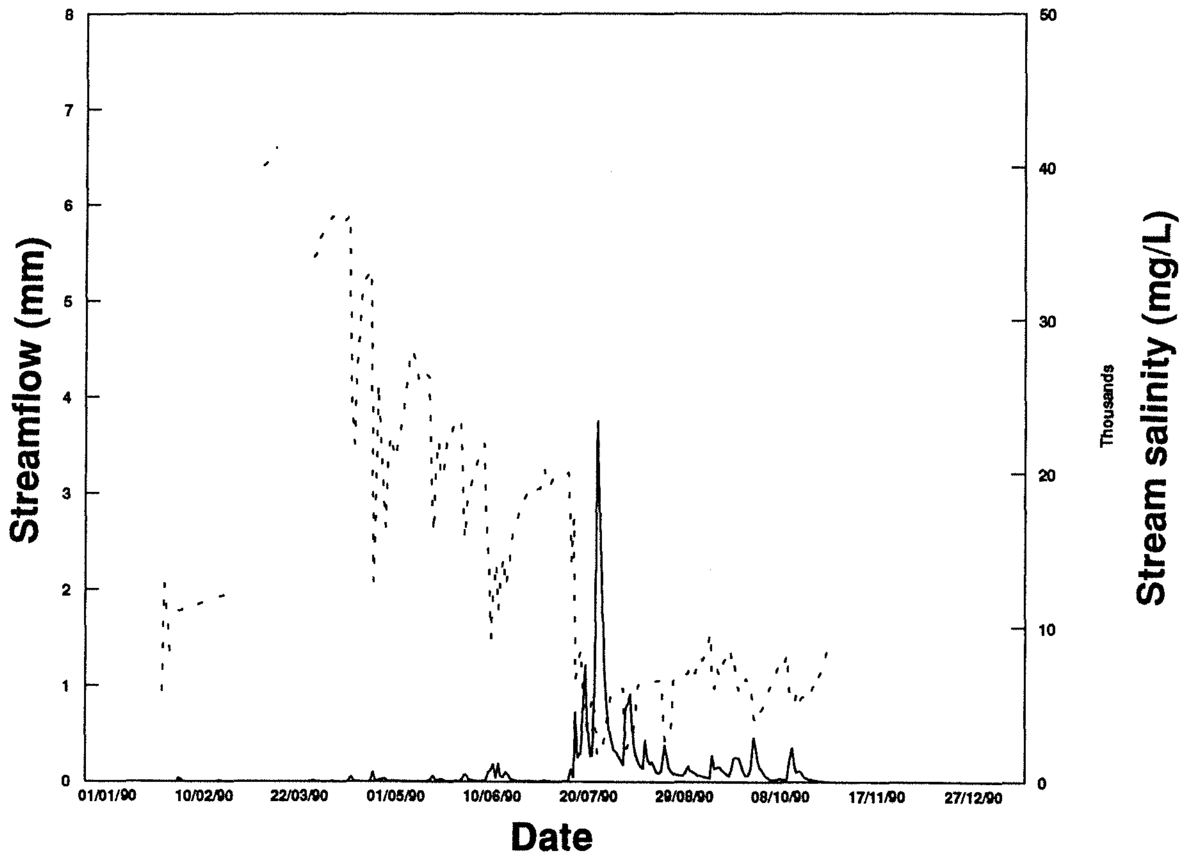

Rainfall (mm)
80
70
60
50
40
30
20
10
0
01/01/88
10/02/88
21/03/88
30/04/88
09/06/88
19/07/88
28/08/88
07/10/88
16/11/88
26/12/88
Date

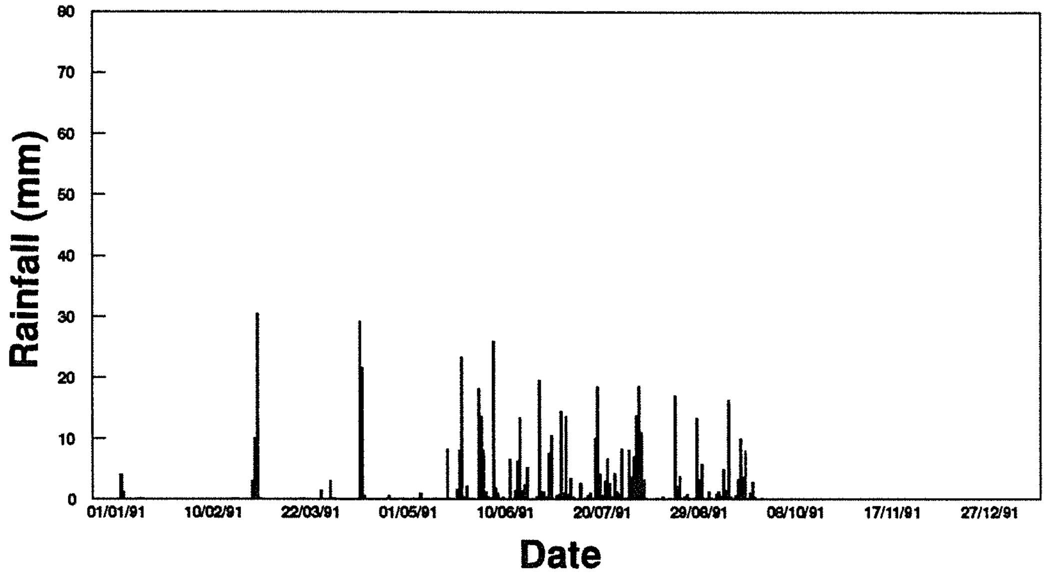

Streamflow (mm)
8
7
6
5
4
3
2
1
0
50
40
30
20
10
0
Thousands
Stream salinity (mg/L)
01/01/88
10/02/88
21/03/88
30/04/88
09/06/88
19/07/88
28/08/88
07/10/88
16/11/88
26/12/88
Date

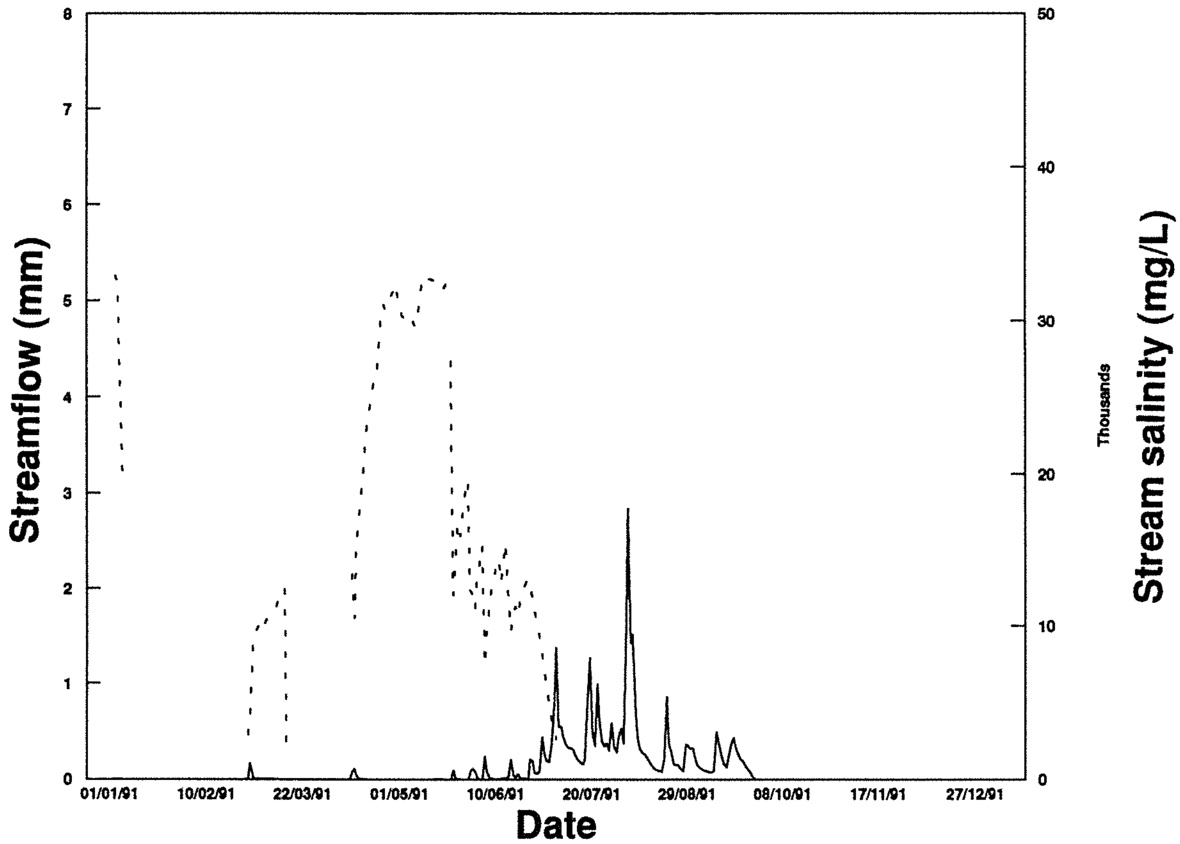

Rainfall (mm)
80
70
60
50
40
30
20
10
0
01/01/89
10/02/89
22/03/89
01/05/89
10/06/89
20/07/89
29/08/89
08/10/89
17/11/89
27/12/89
Date


Streamflow (mm)
8
7
6
5
4
3
2
1
0
Stream salinity (mg/L)
Thousands
50
40
30
20
10
0
01/01/89
10/02/89
22/03/89
01/05/89
10/06/89
20/07/89
29/08/89
08/10/89
17/11/89
27/12/89
Date


Rainfall (mm)
Date
80
70
60
50
40
30
20
10
0
01/01/90
10/02/90
22/03/90
01/05/90
10/06/90
20/07/90
29/08/90
08/10/90
17/11/90
27/12/90


Streamflow (mm)
Stream salinity (mg/L)
Thousands
Date
8
7
6
5
4
3
2
1
0
50
40
30
20
10
0
01/01/90
10/02/90
22/03/90
01/05/90
10/06/90
20/07/90
29/08/90
08/10/90
17/11/90
27/12/90


Rainfall (mm)
80
70
60
50
40
30
20
10
0
01/01/91
10/02/91
22/03/91
01/05/91
10/06/91
20/07/91
29/08/91
08/10/91
17/11/91
27/12/91
Date


Streamflow (mm)
8
7
6
5
4
3
2
1
0
Stream salinity (mg/L)
Thousands
50
40
30
20
10
0
01/01/91
10/02/91
22/03/91
01/05/91
10/06/91
20/07/91
29/08/91
08/10/91
17/11/91
27/12/91
Date

APPENDIX F

A model for streamflow and salinity components

A MODEL FOR STREAMFLOW AND SALINITY COMPONENTS

In the south-west of Western Australia 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:

$$Q_t = Q_r + Q_u + Q_g \qquad (1)$$

And the corresponding salt load:

$$L_t = L_r + L_u + L_g \qquad (2)$$
$$C_tQ_t = C_rQ_r + C_uQ_u + C_gQ_g \qquad (3)$$

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:

$$Q_r = Q_t - Q_b \qquad (4)$$
$$Q_u = Q_b(C_g - C_b)/(C_g - C_b) \qquad (5)$$
$$Q_g = Q_b - Q_u \qquad (6)$$

And if there is no surface runoff then:

$$Q_r=0.0 \quad (7)$$

$$Q_u=Q_t(C_g-C_t)/(C_g-C_u) \quad (8)$$

$$Q_g=Q_t - Q_u \quad (9)$$

During storm events the base flow was separated using a numerical algorithm developed by Lynne and Hollick (1979). The baseflow salinity (C_b) was considered the linear interpolation of the salinities at the start and end times of the storm flow.

All the hydrographs and chemographs were analysed with a set of values for C_u and C_g. During storm periods the volume of surface runoff and the corresponding salt loads were also calculated.

APPENDIX G

Computer programme

```
C     THIS PROGRAM IS WRITTEN TO DETERMINE STREAM SALINITY,
C     STREAM SALT LOAD AND STREAM FLOW COMPONENTS
c
C
      DIMENSION SALTMU(20,12), SALTMG(20,15), FLOWMR(20,15),
     + FLOWMU(20,15),
     + FLOWMG(20,15), FLOWMT(20,15), SALTMT(20,15), TSSMC(20,15),
     + RANM(20,15),
     + RANM1(15), RAIN(9000), TSST(9000), SALTT(9000),FLOWT(9000),
     + FLOWB(9000), FLOWR(9000), TSSCB(9000), IMNTH(9000),
     + IYEAR(9000)
     + , SALTMR(20,15), FLOWDG(9000), FLOWDU(9000), TSSCR(9000),
     + IDAY(9000) , LL(5000),sflowmt(20),sflowmr(20),sflowmu(20),
     + sflowmg(20),ssaltmr(20),ssaltmu(20),ssaltmg(20),ssaltmt(20),
     + iyer(20),sranmt(20)
      DATA  RN,TSSCU, TSSCG/0.5, 250.0, 15000.0/
      data a,area/0.65,16.6/
      CHARACTER*80 DUMMY


      OPEN(UNIT=11, FILE='basald4.dat', STATUS='OLD')
      OPEN(UNIT=21, FILE='junk.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
      READ(11,41) IDAY(1), IMNTH(1), IYEAR(1), SALTT(1),
     + FLOWT(1), TSST(1), RAIND
      DO 10 J=2,500000
      READ(11,41,END=99) IDAY(J),IMNTH(J), IYEAR(J), SALTT(J),
     + FLOWT(J),
     + TSST(J), RAIND
41    FORMAT(9X,i2,1X,I2,1X,I2,18X,F10.4,12X,F10.4,10X,F12.4,
     + 4X,F8.1,
     + 4X,F8.1)
      KK= KK+1
      RAIN(J) = RAIND
```

```
10    CONTINUE
99    CONTINUE
C
C     SEPERATION OF BASE FLOW AND DIRECT RUNOFF
C
      N=0
      DO 60 J=2, kk
      IF(FLOWT(J).EQ.0.0) GO TO 70
      FLOWR(J)=A*FLOWR(J-1)+0.5*(1.0+A)*(FLOWT(J)-FLOWT(J-1))
      IF(FLOWR(J).LT.0.009) FLOWR(J)=0.0
      FLOWB(J)=FLOWT(J)-FLOWR(J)
C
      IF(FLOWR(J-1).EQ.0.0.and.FLOWR(J).GT.0.0) THEN
       N=N+1
       LL(N)=j-1
c      write(21,111) n,j,imnth(j), flowt(j),
c    +  flowr(j), flowb(j)
       else
      endif
c     IF(FLOWR(J).GT.0.0) LL(N)=J-1
c0    CONTINUE
      IF(FLOWR(J).EQ.0.0.AND.FLOWR(J-1).GT.0.0) then
        N=N+1
        LL(N)=J
c       write(21,111) n, j, imnth(j), flowt(j),
c    +  flowr(j), flowb(j)
       ELSE
      ENDIF
      if(flowr(j).eq.0.0) then
          tsscb(j)=tsst(j)
          tsscr(j)=0.0
        else
       endif
111    FORMAT(3I5,12F10.2)
      GO TO 60
 70   CONTINUE
      FLOWR(J)=0.0
      FLOWB(J)=FLOWT(J)
      TSSCB(J)=TSST(J)
      TSSCR(J)=0.0
60      CONTINUE
C
       DO 20 I=2, N, 2
       DEL= LL(I)-LL(I-1)
c      write(21,*) tssdl
       TSSDL=(TSST(LL(I))- TSST(LL(I-1)))/DEL
```

```
c       IF(TSSDL.GE.0.0) TSSDL=0.0
        SDEL=0.0
        MM=LL(I-1)
c       tsscb(ll(i))=tsst(ll(i))
c       if(flowt(mm).eq.0.0) tsst(mm)=tsst(mm+1)
        DO 80 K=LL(I-1)+1, LL(I)
        SDEL= 1.0+SDEL
        TSSCB(K)= TSST(MM) + TSSDL*SDEL
c       write(21,*) tsst(ll(i-1)), tsst(ll(i))
c       write(21,*) tsscb(k), tsst(k), sdel, del,tssdl
        SALTR = SALTT(K) - TSSCB(K)*FLOWB(K)/1000.0
        IF(SALTR.LT.0.0) then
            TSSCB(K)=SALTT(K)*1000.0/FLOWB(K)
            salt=saltt(k)-tsscb(k)*flowb(k)/1000.0
            if(flowr(k).eq.0.0) go to 80
            tsscr(k)= salt*1000.0/flowr(k)
           else
          endif
          IF(FLOWR(K).LE.0.0) GO TO 80
          IF(SALTR.GT.0.0) THEN
          TSSCR(K)=SALTR*1000.0/FLOWR(K)
          ELSE
c          TSSCR(K)=0.0
c          tsscb(k)=tsst(k)
         ENDIF
80       CONTINUE
        tsscb(ll(i))=tsst(ll(i))
        if(flowr(ll(i)).le.0.0) go to 20
        salt=saltt(ll(i))-tsscb(ll(i))*flowb(ll(i))/1000.0
        tsscr(ll(i))=salt*1000.0/flowr(ll(i))
20       CONTINUE
        DO 130 J=1,1000
c      WRITE(21,111) IDAY(J), IMNTH(J),IYEAR(J), FLOWT(J),
c    + FLOWR(J), FLOWB(J),
c    + RAIN(J),
c    + TSSCB(J), TSST(J), tsscr(j),FLOWT(J)-FLOWR(J)-FLOWB(J),
c    + saltt(j)-(flowr(j)*tsscr(j)/1000.0+flowb(j)*tsscb(j)/1000.0)
c    + ,saltt(j)-flowt(j)*tsst(j)/1000.0
130     CONTINUE
C
C       CALCULATE EACH COMPONENT
C       NK=0
       ky=1
c      iyear1=iyear(1)
       DO 100 I=2, KK
       IDIFY = IYEAR(I)-IYEAR(I-1)
```

```
      IDIFF = IMNTH(I) - IMNTH(I-1)
       IF(FLOWT(I).NE.0.0) NK=NK+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
       IF(TSSCB(I).LE.TSSCU) THEN
          SUMSLTDU=SUMSLTDU+FLOWDU(I)*TSSCB(I)/1000.0
       ELSE
          SUMSLTDU=SUMSLTDU+FLOWDU(I)*TSSCU/1000.0
       ENDIF
      SUMFLTSS=SUMFLTSS + FLOWT(I)*TSST(I)/1000.0
      SUMSLTDR=SUMSLTDR + FLOWR(I)*TSSCR(I)/1000.0
      ELSE
c       if(imnth1.le.3) imnt1=imnth1+12
       imnt1=imnth1
c      WRITE(21,71) Ky, imnt1
      SALTMT(ky,IMNT1)=SUMSALTD
      FLOWMT(ky,IMNT1)=SUMFLOWD
      FLOWMR(ky,IMNT1) = SUMFLWDR
      FLOWMU(ky,IMNT1) = SUMFLWDU
      FLOWMG(ky,IMNT1) = SUMFLWDG
       SALTMU(ky,IMNT1) = SUMSLTDU
```

```
      SALTMG(ky,IMNT1) = SUMSLTDG
      SALTMR(ky,IMNT1) = SUMSLTDR
C      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(ky,IMNt1) = 0.0
       ELSE
       TSSMC(ky,IMNT1) =(SUMFLTSS/SUMFLOWD)*1000.0
      ENDIF

     RANM(ky,IMNT1) =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)
C      SMFLTSY=SUMFLTSS
     SUMSLTDR=FLOWR(I)*TSSCR(I)/1000.0
     SUMSLTDU=FLOWDU(I)*TSSCU/1000.0
     SUMSLTDG=FLOWDG(I)*TSSCG/1000.0
     SUMFLTSS=FLOWT(I)*TSST(I)/1000.0
     IMNT  = IMNTH1
     IYER(ky) = IYEAR1
     IMNTH1 = IMNTH(I)
     IYEAR1 = IYEAR(I)
    ENDIF
C     WRITE(21,111) IDAY(I), IMNTH(I), IYEAR(I), FLOWT(I),
C    + FLOWDU(I), FLOWDG(I)
    IF(IDIFY.EQ.0) GO TO 100
    IYEAR1=IYEAR(I)
    ky=ky+idify
    IMNTH1=IMNTH(I)
100  CONTINUE
c
C    SUM UP ALL MONTHLY VALUES
C
     do 200 i=1,ky-1
    NK=0
    SFLOWMT1=0.0
    SFLOWMR1=0.0
    SFLOWMU1=0.0
    SFLOWMG1=0.0
```

```
      SSALTMR1=0.0
      SSALTMU1=0.0
      SSALTMG1=0.0
      SSALTMT1=0.0
      SRANMT1 =0.0
      SUMFLTSY1=0.0
      DO 30 II=1, 12
      SFLOWMT1 = SFLOWMT1+ FLOWMT(i+1,II)
      SFLOWMR1 = SFLOWMR1+ FLOWMR(i+1,II)
      SFLOWMU1 = SFLOWMU1+ FLOWMU(i+1,II)
      SFLOWMG1 = SFLOWMG1+ FLOWMG(i+1,II)
      SSALTMR1 = SSALTMR1+ SALTMR(i+1,II)
      SSALTMU1 = SSALTMU1+ SALTMU(i+1,II)
      SSALTMG1 = SSALTMG1+ SALTMG(i+1,II)
      SSALTMT1 = SSALTMT1+ SALTMT(i+1,II)
      SRANMT1 = SRANMT1+ RANM(i+1,II)
c     write(21,*) sranmt1,sflowmu1,ranm(ky+1,ii)
30     CONTINUE
c     DO 330 II=4, 12
c     SFLOWMT1 = SFLOWMT1+ FLOWMT(i,II)
c     SFLOWMR1 = SFLOWMR1+ FLOWMR(i,II)
c     SFLOWMU1 = SFLOWMU1+ FLOWMU(i,II)
c     SFLOWMG1 = SFLOWMG1+ FLOWMG(i,II)
c     SSALTMR1 = SSALTMR1+ SALTMR(i,II)
c     SSALTMU1 = SSALTMU1+ SALTMU(i,II)
c     SSALTMG1 = SSALTMG1+ SALTMG(i,II)
c     SSALTMT1 = SSALTMT1+ SALTMT(i,II)
c     SRANMT1 = SRANMT1+ RANM(i,II)
330     CONTINUE
      SFLOWMT(i) = SFLOWMT1
      SFLOWMR(i) = SFLOWMR1
      SFLOWMU(i) = SFLOWMU1
      SFLOWMG(i) = SFLOWMG1
      SSALTMR(i) = SSALTMR1
      SSALTMU(i) = SSALTMU1
      SSALTMG(i) = SSALTMG1
      SSALTMT(i) = SSALTMT1
      SRANMT(i) = SRANMT1
c
c      WRITE(21,71) II, IYER, FLOWMR(II),FLOWMU(II), FLOWMG(II),
c    + FLOWMT(II),SALTMR(II), SALTMU(II), SALTMG(II), SALTMT(II),
c    + TSSMC(II), RANM(II)
71     FORMAT(1X, 2I10, 12F9.1)
c      TSSYEAR=(SSALTMT/SFLOWMT)*1000.0
c      do 200 i=1,ky-1
       WRITE(21,71) i,IYER(i), sranmt(i), SFLOWMT(i)/area,
```

```
     +  sflowmr(i)/area,
     +  sflowmt(i)*100/(sranmt(i)*area), sflowmr(i)*100/sflowmt(i),
     +  sflowmr(i)*100/(sranmt(i)*area)
200     continue
        do 400 i=1,ky-1
        WRITE(21,71) i,IYER(i), sranmt(i), SFLOWMT(i)/area,
     +  sflowmr(i)/area,sflowmu(i)/area,sflowmg(i)/area,sflowmr(i)*
     +  100.0/sflowmt(i),
     +  sflowmu(i)*100.0/sflowmt(i),sflowmg(i)*100.0/sflowmt(i)
400     continue
        do 450 i=1,ky-1
        salt5=0.0
        salt5=ssaltmr(i)/(area/10.0)
        ssaltmr(i)=sranmt(i)*7.5/100.0
        salt5=salt5-ssaltmr(i)
        salra=ssaltmu(i)/ssaltmg(i)
        ssaltmu(i)=ssaltmu(i)/(area/10.0)+salt5*salra
        ssaltmg(i)=ssaltmg(i)/(area/10.0)+salt5*(1.0-salra)
        ssaltmt(i)=ssaltmt(i)*10.0/area
        WRITE(21,71) i,IYER(i), sranmt(i), ssaltmt(i)
     +  ,ssaltmr(i),ssaltmu(i),ssaltmg(i),ssaltmr(i)*100./ssaltmt(i),
     +  ssaltmu(i)*100.0/ssaltmt(i),ssaltmg(i)*100.0/ssaltmt(i)
450     continue
c       WRITE(21,71) IMNT, IYER, (SFLOWMR*100.0/SFLOWMT),
c    +  (SFLOWMU*100.0/sflowmt)
c    +  , (SFLOWMG*100.0/SFLOWMT)
       STOP
       END
```