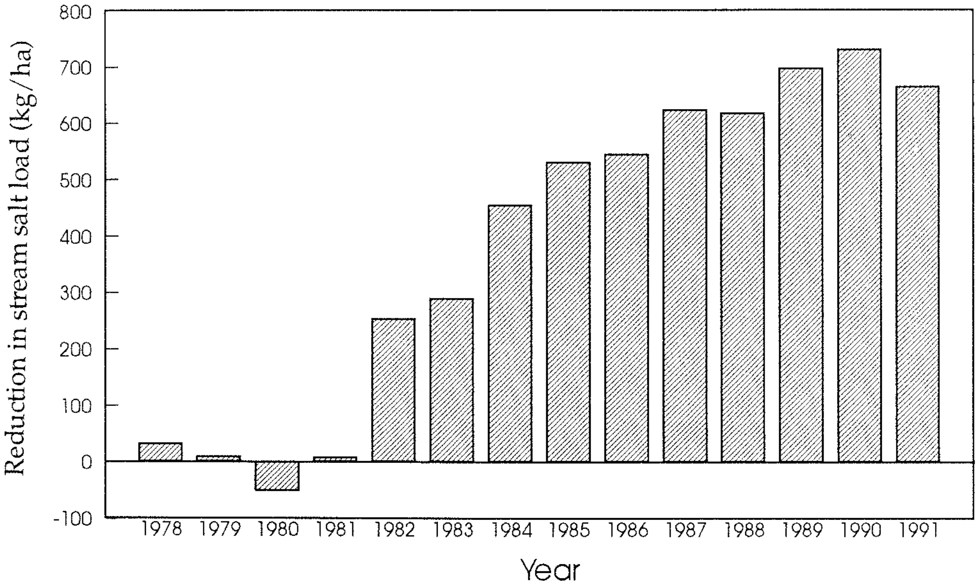
Water Authority
of Western Australia

STREAMFLOW AND SALINITY RESPONSE TO NON-VALLEY REFORESTATION AT PADBURY ROAD CATCHMENT IN THE SOUTH-WEST OF WESTERN AUSTRALIA



Report No. WS114
November 1992

Water Authority
of Western Australia

Water Resources Directorate
Surface Water Branch

STREAMFLOW AND SALINITY RESPONSE TO NON-VALLEY REFORESTATION AT PADBURY ROAD CATCHMENT IN THE SOUTH-WEST OF WESTERN AUSTRALIA

M A Bari

Water Authority of Western Australia
629 Newcastle Street
LEEDERVILLE WA 6007
Telephone (09) 420 2420

Report No. WS114
November 1992

SUMMARY

Padbury Reservoir was the source of drinking water supply to Balingup, a small town situated in the south-west of Western Australia. In 1970s salinity increased in the reservoir beyond 750 mg L^{-1} Total Soluble Salts (TSS), the appropriate limit of drinking water for this region. The increase in salinity occurred as a result of clearing native forest within the reservoir's catchment for pasture development in previous decades. Initiatives were taken to reverse the process by partial reforestation of the cleared land. A gauging station was established in 1978 at the Padbury Road catchment (a subcatchment of Padbury Reservoir catchment) to monitor the effects of reforestation on streamflow, stream salinity and stream salt load. During 1977-83, 76% of the cleared area in the Padbury Road catchment had been reforested with pines and eucalypts. Most of the reforestation took place on the mid and upslopes and very little at the lower slopes and valley floor. Groundwater observation bores were installed in 1989.

The groundwater levels beneath the reforested area have remained steady during 1989-92. The groundwater salinity under reforestation in the midslope areas has remained unchanged while in the upslope areas there was a declining trend. In the valley area beneath pasture, groundwater levels and groundwater salinity remained stable over the last four years.

During the study period (1978-91), reforestation has led to a systematic reduction in streamflow due to a reduction in the surface runoff and base flow components. The reduction in base flow was about three times greater than that of surface runoff. There was also a continuous reduction in stream salt load from the catchment. In most years the reduction in salt load was insufficient to reduce stream salinity that would have been occurred without reforestation. However, there has been an apparent decline in stream salinity since 1987. But this salinity reduction has not been enough to produce stream salinity below 750 mg L^{-1} TSS. To date, it is not clear if reforestation is an appropriate strategy to reduce stream salinity in small water supply catchments like this one.

Since 1978, the annual rainfall has been 8% below the long term average of 880 mm and often below 800 mm. If the long term average rainfall had occurred during this investigation, the reduction in streamflow would have been less. But it is not clear how this would have affected stream salinity.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

Padbury Reservoir was the source of drinking water supply for Balingup, a small town situated about 180 km south of Perth, Western Australia. In 1970s salinity in the reservoir increased beyond 750 mg L^{-1} Total Soluble Salts (TSS), the appropriate limit of drinking water for this region (Nat. Health and Med. Res. Council, 1987). This led to numerous consumer complaints. The primary cause of the salinity increase has been extensive clearing of native forest within the Padbury Reservoir catchment over the last forty years.

In Australia, land and stream salinity has increased due to the replacement of deep-rooted, perennial vegetation with shallow-rooted agricultural crops and pastures (Wood, 1924; Peck and Williamson, 1987; Schofield et al., 1988; Ruprecht and Schofield, 1989; Schofield and Ruprecht, 1989; Allison, et al., 1990; Ruprecht and Schofield, 1991). As a result of this landuse change, groundwater recharge has increased and groundwater levels have risen. 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).

One approach to reclaim the salinised lands and streams is to reforest cleared land. Partial reforestation was considered most promising because annual evapotranspiration exceeds annual rainfall. Therefore, only a part of the catchment would require reforesting to control the rising groundwater table and hence the land and stream salinity.

In 1976, the State Government purchased most of the cleared farm land in the Padbury Reservoir catchment to establish reforestation. The main objectives were stream salinity reduction and wood production. During 1977-83 all suitable areas of the reservoir catchment were planted, mainly with pines and eucalypts.

Padbury Road catchment (a subcatchment of Padbury Reservoir catchment) was instrumented in 1978 to monitor the effects of reforestation on streamflow and salinity (Fig. 1). Reforestation commenced in 1977. The primary aim of the study was to reduce groundwater levels and hence stream salinity in a relatively short period of time (~ 10 years). The specific objectives were to:

(i) determine the effects of reforestation on streamflow;

(ii) quantify the magnitude and duration of stream salinity and stream salt load changes due to reforestation;

(iii) assess the spatial and temporal variations in groundwater levels and groundwater salinity.

Hydrological data from Padbury Road catchment has previously been reported by Bell et al. (1987); Borg, et al. (1988) and Schofield, et al. (1989). This report presents the most comprehensive and up to date analysis of groundwater, streamflow and stream salinity data within the Padbury Road catchment.

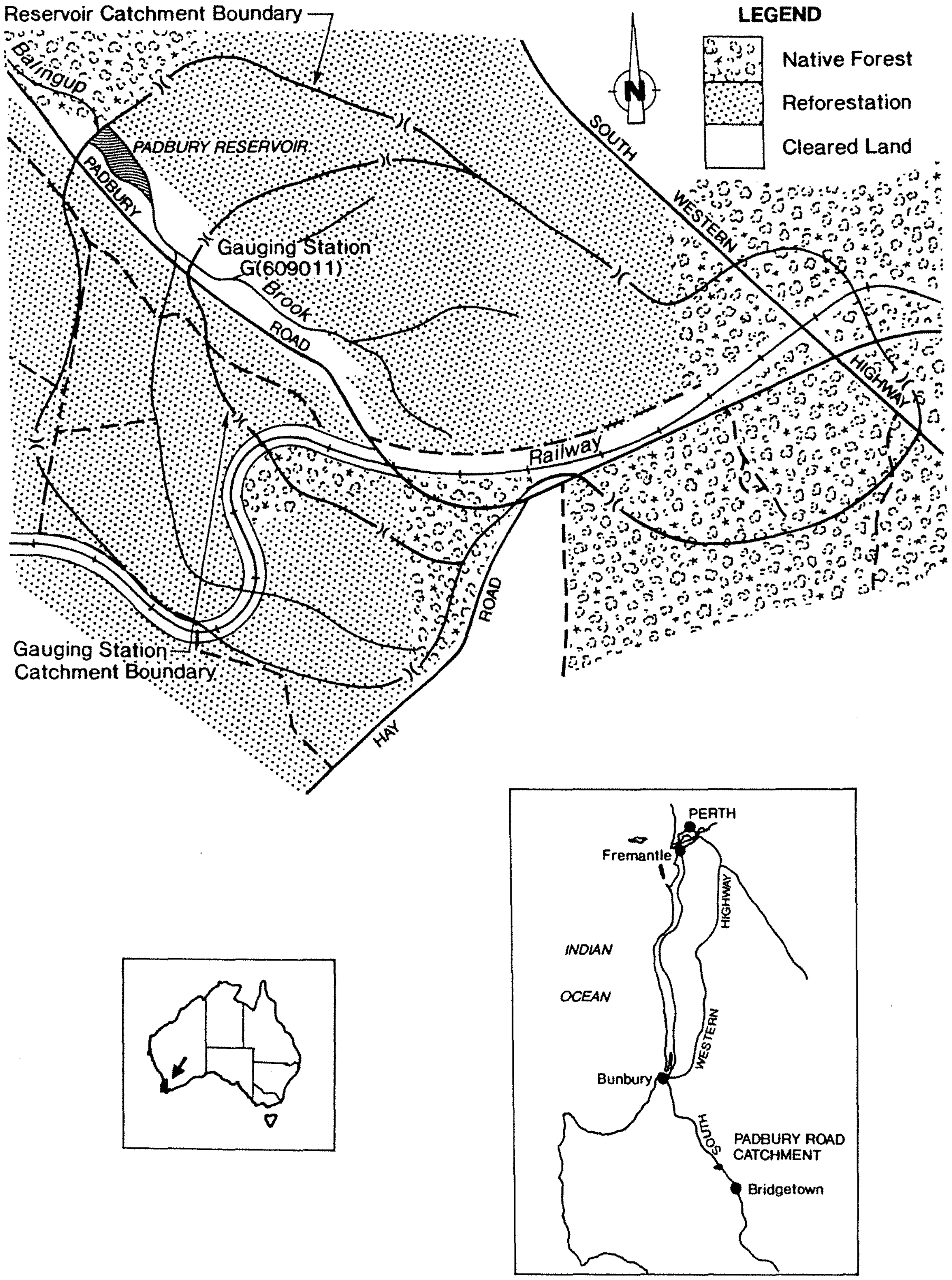


Figure 1 Location of the study area

2 SITE DESCRIPTION

2.1 *Location and climate*

Padbury Road catchment is located in the south-west of Western Australia, approximately 180 km south of Perth (Fig. 1). 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 880 mm yr^{-1} (Hayes and Garnaut, 1981) and the annual average pan evaporation is 1300 mm (Luke et al., 1988).

2.2 *Site History*

Progressive clearing at Padbury Road catchment for pasture development commenced in the 1910s (Table 1). By 1976, 63.5% of the catchment had been cleared with most of the clearing occurring on the lower and mid slopes. The State Government purchased the farm in 1976 as part of a programme to reforest farmland within the Padbury Reservoir catchment. The land use history of the catchment has been detailed by Bell et al. (1987).

2.3 *Topography, Soil and Geology*

Elevation of Padbury Road catchment ranges from 185 to 290 m AHD (Fig. 2). The upslope forested portion of the catchment is flatter than the reforested zone. The surface soil is highly permeable. The soil types are typical of the south-west of Western Australia. The upslope areas consist of sands, duricrust and gravels over mottled clays and the valley areas consists of red earths, laterites and yellow duplex soils. The soil profile varies between a few metres to about 20 m thick.

2.4 *Vegetation*

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

Table 1: Clearing and reforestation history at Padbury Road catchment

Year	Cleared land (ha)	Reforestation (ha)	Native forest (ha)
1911	10	--	147.5
1932	23	--	134.5
1936	63	--	94.5
1952	68	--	89.5
1963	92	--	65.5
1966	98	--	59.5
1976	100	--	57.5
1977	46	54	57.5
1980	35	65	57.5
1983	28	74	55.5
1987	28	74	55.5
1992	28.5	74	55.0

used for intensive sheep grazing. The upslope native vegetation is dominated by jarrah (*Eucalyptus marginata*) and marri (*E. calophylla*). Along the stream line there are some shrubs and river red gums (*E. rudis*).

In 1977, 43 ha and 11 ha of the catchment area were planted with pines (*Pinus radiata*) and eucalypts (*E. globulus*) respectively. Pines were planted on the eastern side slope of

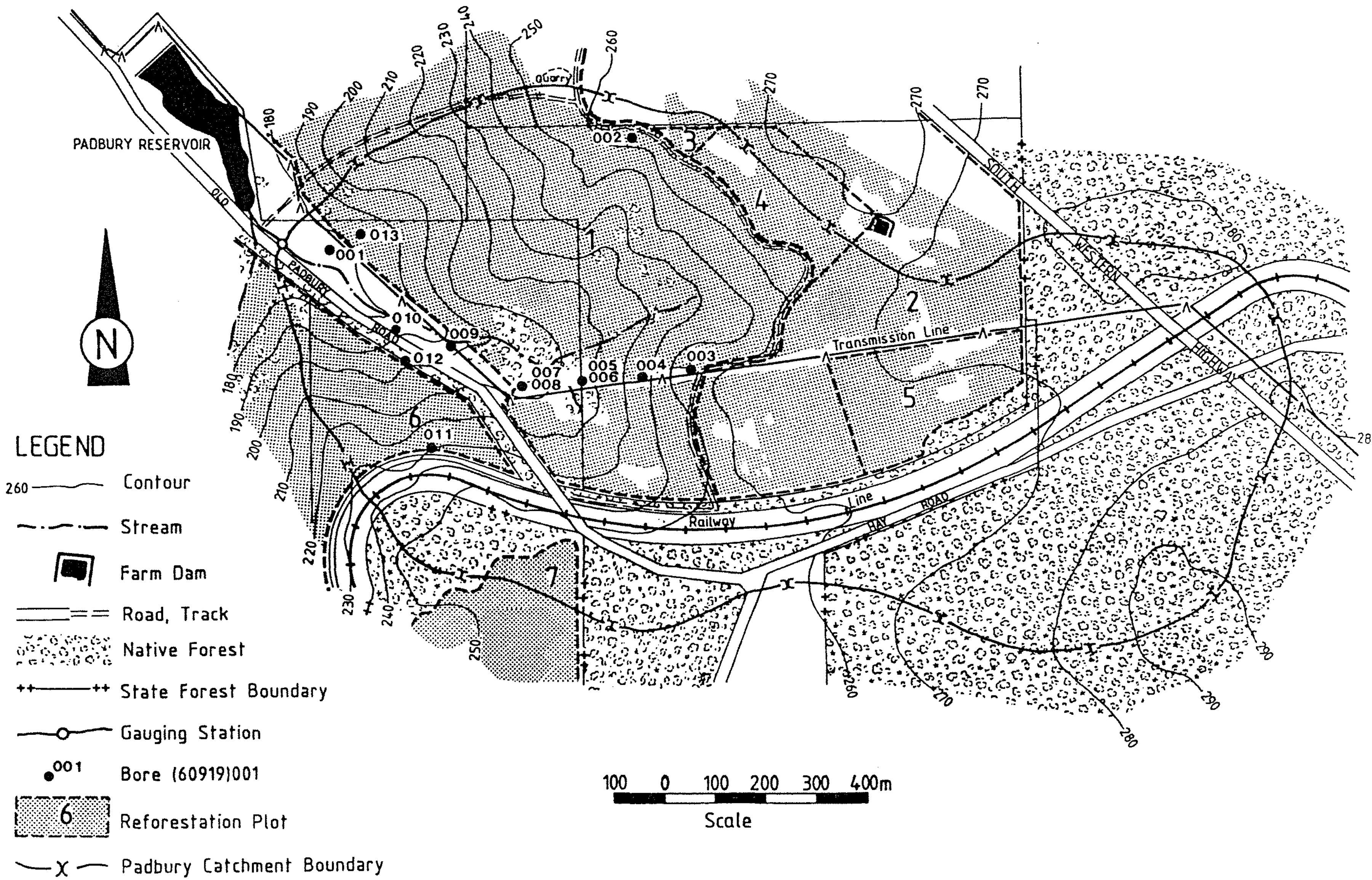


Figure 2 Reforestation layout and hydrometric network

the catchment while eucalypts were established on the upslope areas. Between 1978 and 1980 a further 11 ha were planted with pines and eucalypts. In 1983, the upslope areas south of the railway line, were planted with pines. The initial density of eucalypt plantation was 625 stems per hectare (sph), and there has been no thinning since. Pines were planted at a density of 1100 to 1330 sph and after 6 to 7 years thinned to 600-700 sph. Trees were not pruned at the Padbury Road catchment.

2.5 Hydrology

The area of Padbury Road catchment is 157.5 ha (Fig. 2). The gauging station was established in 1978. Over the study period (1978-91), the average stream salinity was 1000 mg L^{-1} Total Soluble Salts (TSS). The depth to groundwater level across the catchment varied from 0 m (i.e. at ground surface) to 15 m. The average groundwater salinity was 2000 mg L^{-1} TSS.

3 HYDROLOGICAL DATA COLLECTION

3.1 Rainfall

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

3.2 Groundwater

A network of 13 monitoring bores were installed at Padbury Road catchment in 1989 (Fig. 2). A group of 2 bores were drilled at two monitoring points, to provide shallow (<10 m depth) and deep (>10 m) groundwater information.

Most of the bores were monitored for water level and salinity once a month (Appendix A). Salinity was measured from the samples collected within the screen area of the bores. The groundwater salinity (Total Soluble Salts, TSS) was determined using a relationship between TSS (mg L^{-1}) and electrical conductivity (m Sm^{-1}).

3.3 Streamflow

A calibrated, V notch weir was installed at the outlet of the catchment in 1978. 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. Electrical conductivity of stream water has been recorded continuously since the installation of the weir. A few samples were analysed for major ions from which a relationship between salinity (TSS) and electrical conductivity (m Sm^{-1}) was developed. The flow-weighted mean daily stream salinity (or simply stream salinity, S) was computed as:

$$S=(\Sigma S_i Q_i)/\Sigma Q_i$$

where Q_i and S_i are streamflow volumes and salinity at 15 minutes interval. From the daily stream salinity and flow, annual stream salinity was calculated in the same way.

4 RESULTS

4.1 Annual Rainfall

During the study period (1978-91), the average annual rainfall was 8% lower than the long term average of 880 mm. in only two years (1978 and 1988) was rainfall considerably higher than the long term average (Table 2).

4.2 Groundwater level and salinity response

Groundwater levels beneath the reforestation remained stable during the 1989-92 period. Since 1989, the groundwater salinity beneath reforestation in upslope areas (bore 002) has steadily declined while in the mid slope areas (bore 004) it has remained unchanged (Fig. 3a).

Groundwater levels and groundwater salinity under pasture in the valley area remained unchanged during the period of 1989-92 (Fig. 3b).

4.3 Streamflow and stream salinity response

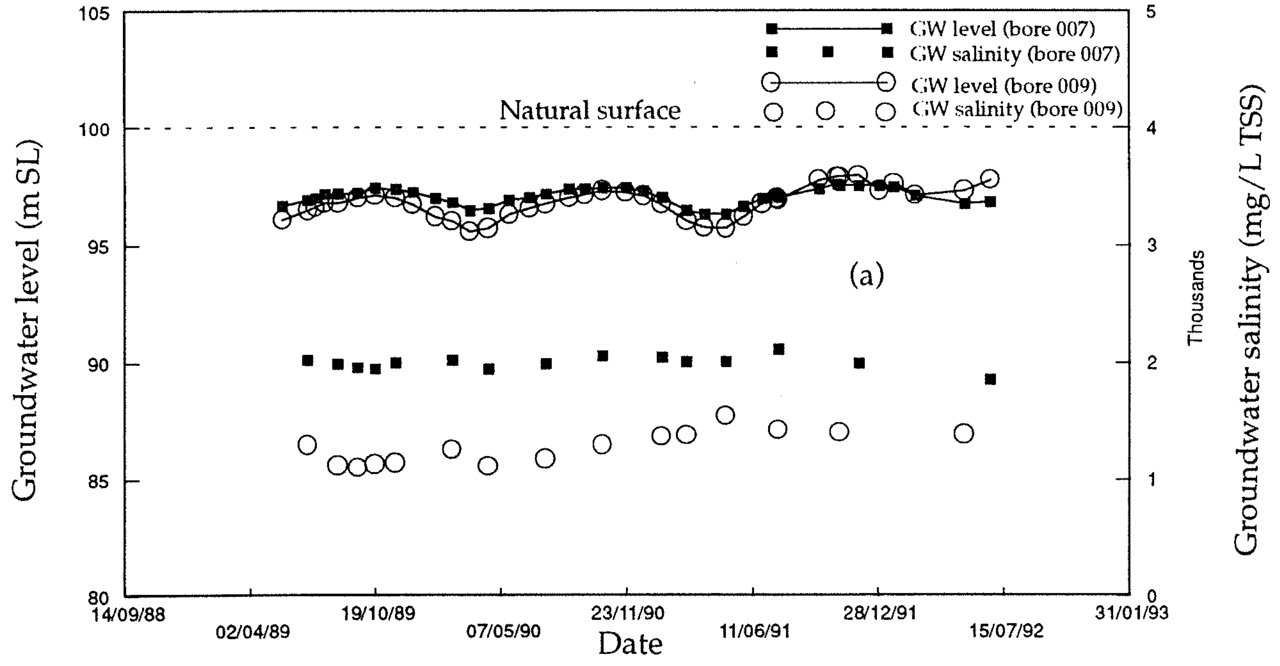
4.3.1 Seasonal Variations

Generally, streamflow commences in April/May, following a significant rainfall event, and ceases in November or early December. Most of the streamflow occurrs 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 5000 mg L^{-1} TSS. Mid-winter high flows are much lower in salinity at around 300 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 B.

Table 2 Annual water and salt balance at Padbury Road catchment

Year	Rainfall (mm)	Streamflow (mm)	Surface runoff (mm)	Baseflow (mm)	Salt fall (kg/ha)*	Salt load (kg/ha)	Stream salinity (mg/L TSS)	Salt output/fall ratio
1978	984.0	116.2	27.69	88.52	123.0	904.2	778.0	7.35
1979	625.8	42.6	9.97	32.66	78.2	598.9	1405.2	7.66
1980	864.6	92.7	21.66	62.62	108.1	897.6	968.3	8.31
1981	779.1	68.4	18.13	50.30	97.4	764.6	1117.4	7.85
1982	677.9	22.5	6.10	16.40	84.7	419.1	1861.9	4.95
1983	956.5	98.4	27.43	70.96	119.6	628.6	638.9	5.26
1984	734.0	16.1	4.74	11.30	91.8	276.6	1724.6	3.01
1985	811.2	21.1	8.13	12.93	101.4	272.0	1291.6	2.68
1986	632.3	3.3	1.46	1.85	79.0	72.4	2183.3	0.92
1987	687.5	2.6	1.30	1.29	85.9	58.5	2265.6	0.68
1988	1056.1	45.4	16.57	28.77	132.0	368.4	812.4	2.79
1989	779.5	5.4	2.72	2.72	97.4	76.7	1410.9	0.79
1990	864.7	15.2	5.75	9.46	108.1	117.0	769.2	1.08
1991	933.2	35.5	11.13	24.39	116.6	236.9	666.9	2.03
Mean	813.0	41.2	11.62	29.60	101.6	406.6	991.7	
Min.	632.3	2.6	1.30	1.29	79.0	58.5	666.9	
Max.	1056.1	116.2	27.69	88.52	132.0	904.2	2265.6	
CV	0.17	0.90	0.79	0.95	0.17	1.33		

* Total Soluble Salts (mg L^{-1}) of rainfall was calculated according to Hingston and Gailitis (1977).



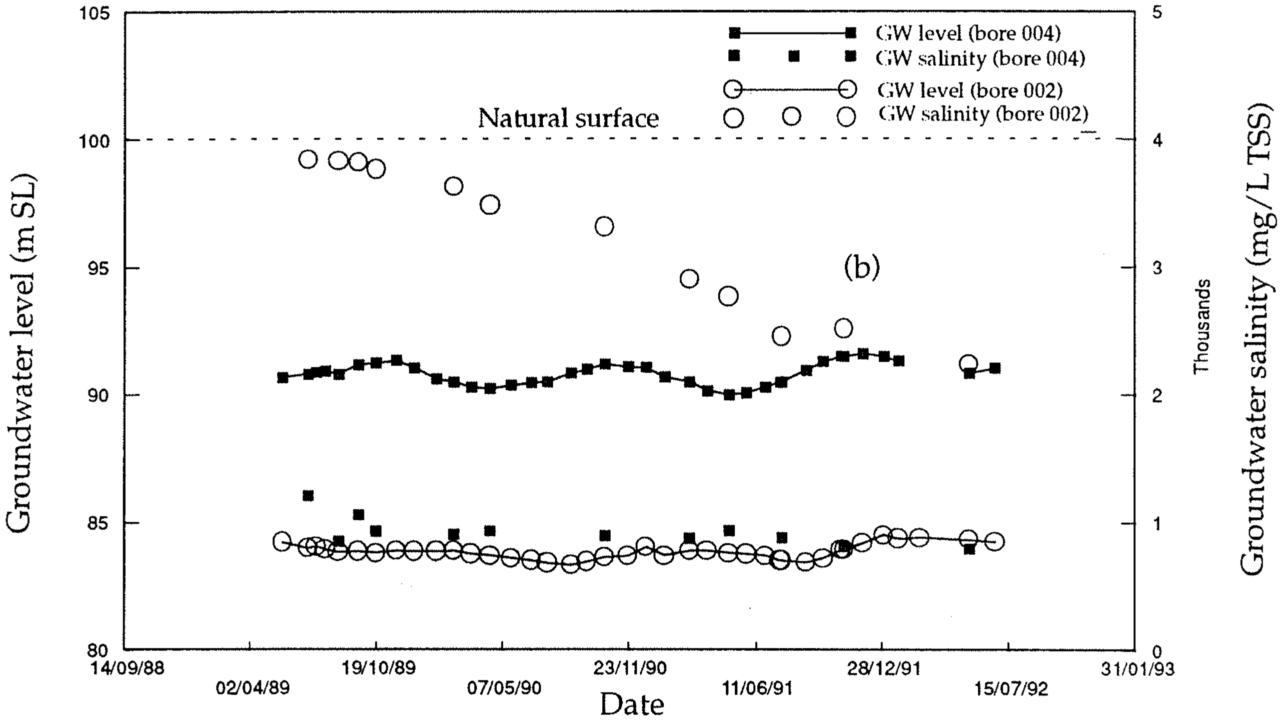


Figure 3 Groundwater level and salinity at (a) valley floor and (b) upslope reforestation

4.3.2 Streamflow and Salt Load

The hydrology of the catchments in the south-west of Western Australia is characterised by the surface runoff and base flow. The base flow component is composed of a shallow, seasonal, relatively fresh groundwater system and a deep, permanent more saline groundwater system. Both the surface runoff and base flow components discharge salt into the stream.

The daily streamflow was separated into surface runoff and base flow components using the numerical algorithm developed by Lynne and Hollick (1979). The computer programme for calculating surface runoff and base flow components are given in Appendix C. Surface runoff ranged from 1.3 mm to 27.7 mm and averaged 11.6 mm. The base flow component was highly variable with time. During the study period the average base flow was 29.6 mm, but ranged from 1.3 mm to 88.5 mm. As a proportion of total streamflow, surface runoff was 28% and the base flow was 72% (Table 2).

The annual stream salt load ranged from 58.5 $kgha^{-1}$ TSS to 904.2 $kgha^{-1}$ TSS. During the study period (1978-91), the average salt fall on the catchment was 101.6 $kgha^{-1}$ TSS. The annual stream salinity ranged from 667 mg L^{-1} TSS to 2266 mg L^{-1} TSS (Table 2).

4.3.3 Streamflow and Reforestation

There was no pretreatment data at this study catchment. The effects of reforestation on streamflow and salinity for the first few years are negligible. Therefore, the first four years' data (1978-81) were considered as the 'pretreatment' data. The regression equation between the streamflow and rainfall during the 'pretreatment' period was developed (Fig. 4). Based on the regression equation, annual streamflow that would have occurred without reforestation was estimated for the study period. The difference between the observed and the estimated streamflow was considered to be the effects of reforestation.

During 1982-91, streamflow declined at an average rate of 60 mm yr^{-1} due to the higher evapotranspiration of the plantations. After 1983 streamflow reduction was more

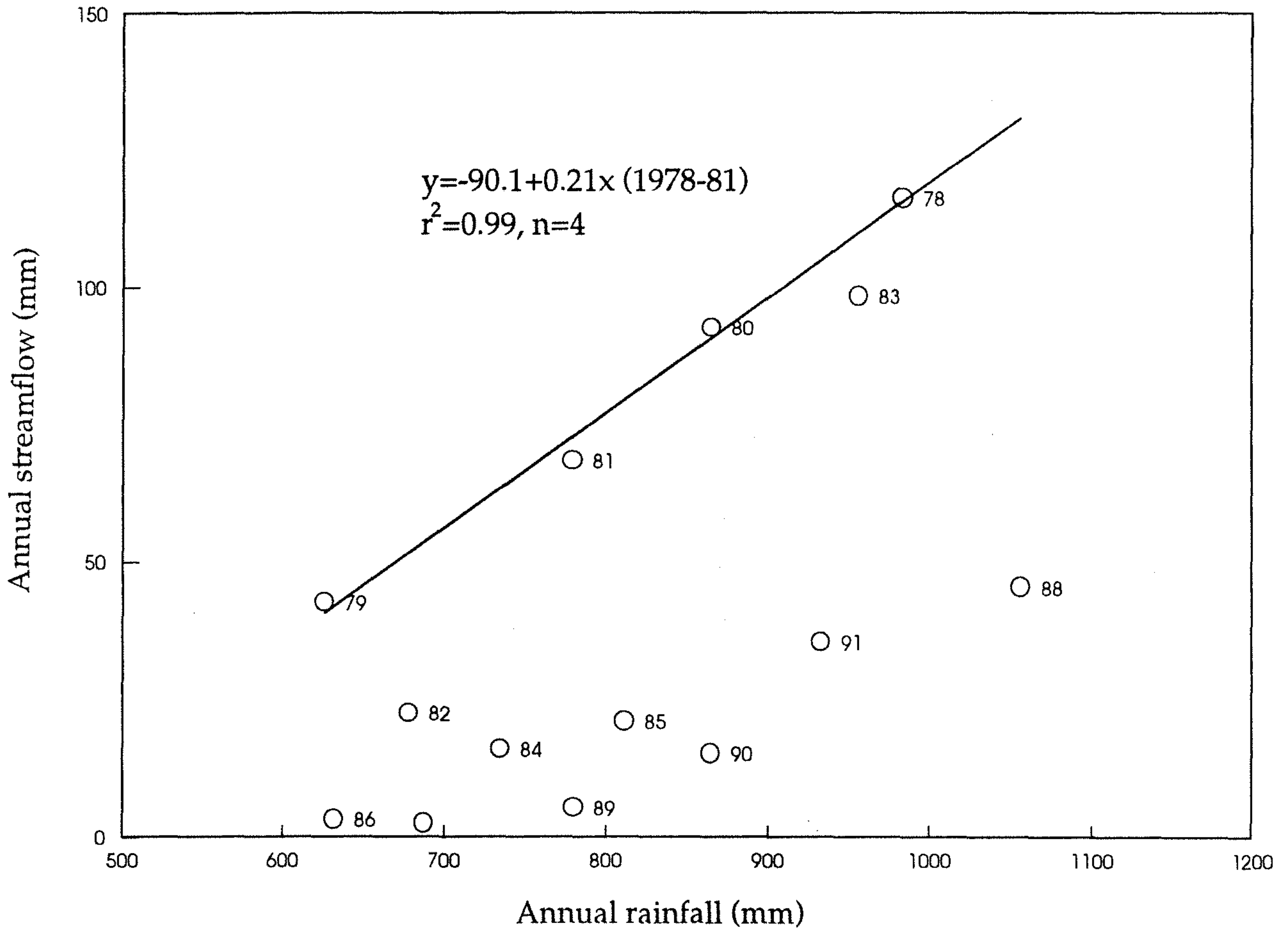


Figure 4 Relationship between annual streamlfow and rainfall at Padbury road catchment

systematic with time. The maximum reduction was 8% of rainfall in 1990 (Fig. 5). The average reduction was about 67% of streamflow that would have occurred without reforestation.

The reduction in base flow was about three times greater than the surface runoff component (Fig. 6). However the reduction in surface runoff and base flow components showed similar trends with the reduction in streamflow yield.

4.3.4 Reforestation and Stream Salinity

The relationships between streamflow, stream salinity and stream salt load during the 'pretreatment' period is shown in Fig. 7. Since 1981, there has been a substantial decrease in stream salinity and salt load for a particular flow volume. For example, the observed streamflow, salinity and stream salt load in 1984 was 16 mm, 1725 mg L^{-1} TSS and 277 $kgha^{-1}$ TSS respectively (Table 2). If there had been 16 mm streamflow without reforestation, the corresponding stream salinity and stream salt load would had been 2410 mg L^{-1} TSS and 412 $kgha^{-1}$ TSS respectively (Fig. 7).

The changes in stream salinity and salt load due to reforestation were calculated from the relationships between the streamflow, stream salinity and salt load between the 'pretreatment' and treated periods. The stream salinity increases as flow decreases (Fig. 7a). But streamflow has decreased due to reforestation (Fig. 4). So the changes in stream salinity due to reforestation is not the difference between the observed salinity and the salinity predicted by the regression equation (Fig. 7a). In fact it is the difference between the observed salinity and the salinity predicted by the regression equation (Fig. 7a) for the flow that would have occurred without reforestation (Fig. 4). This procedure for changes in stream salinity calculation is illustrated in Fig. 8. For example, If there had been no reforestation in 1984, the streamflow and stream salinity would had been 63.4 mm (Fig. 4) and 1140 mg L^{-1} (Fig. 7a) respectively. Therefore, the increase in stream salinity due to reforestation was 585 mg L^{-1} TSS.

The changes in stream salinity due to reforestation is shown in Fig. 9a. After 1983 stream

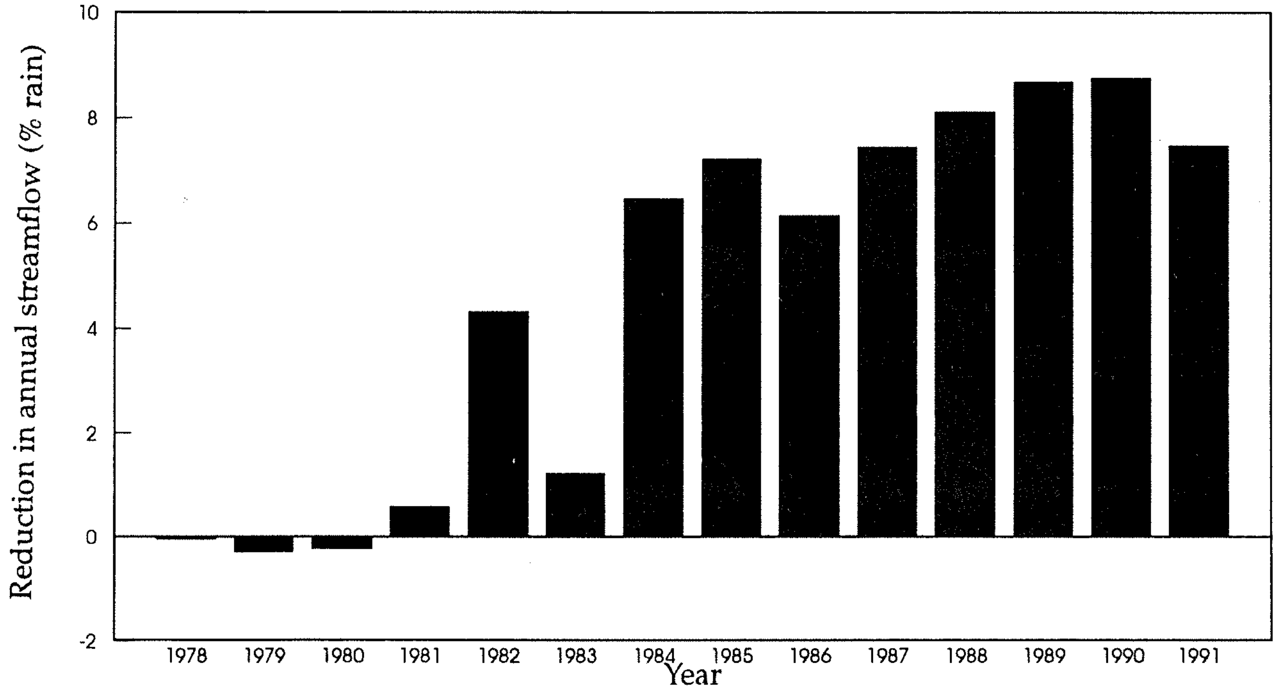


Figure 5 Reduction in streamflow due to reforestation

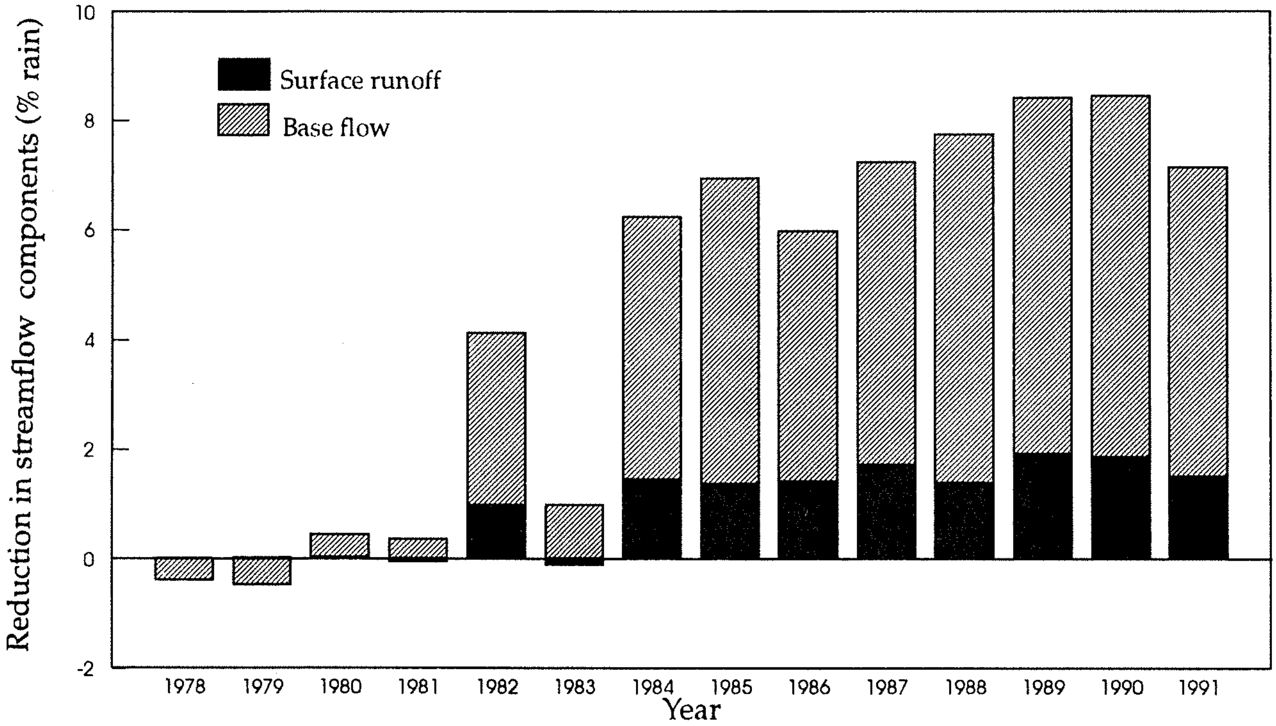


Figure 6 Reduction in surface runoff and base flow components

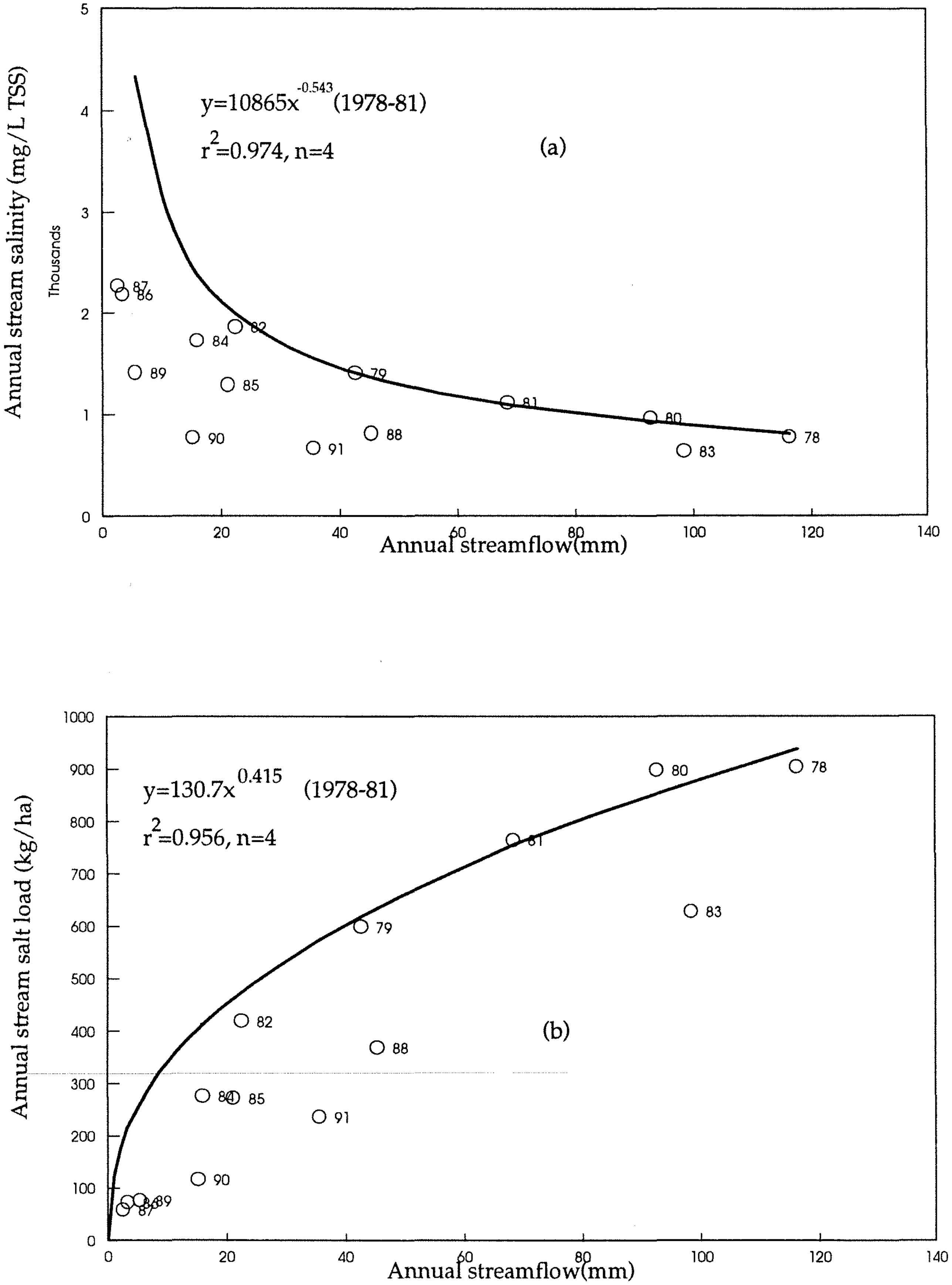


Figure 7 Relationship between streamflow and (a) flow-weighted stream salinity, (b) stream salt load

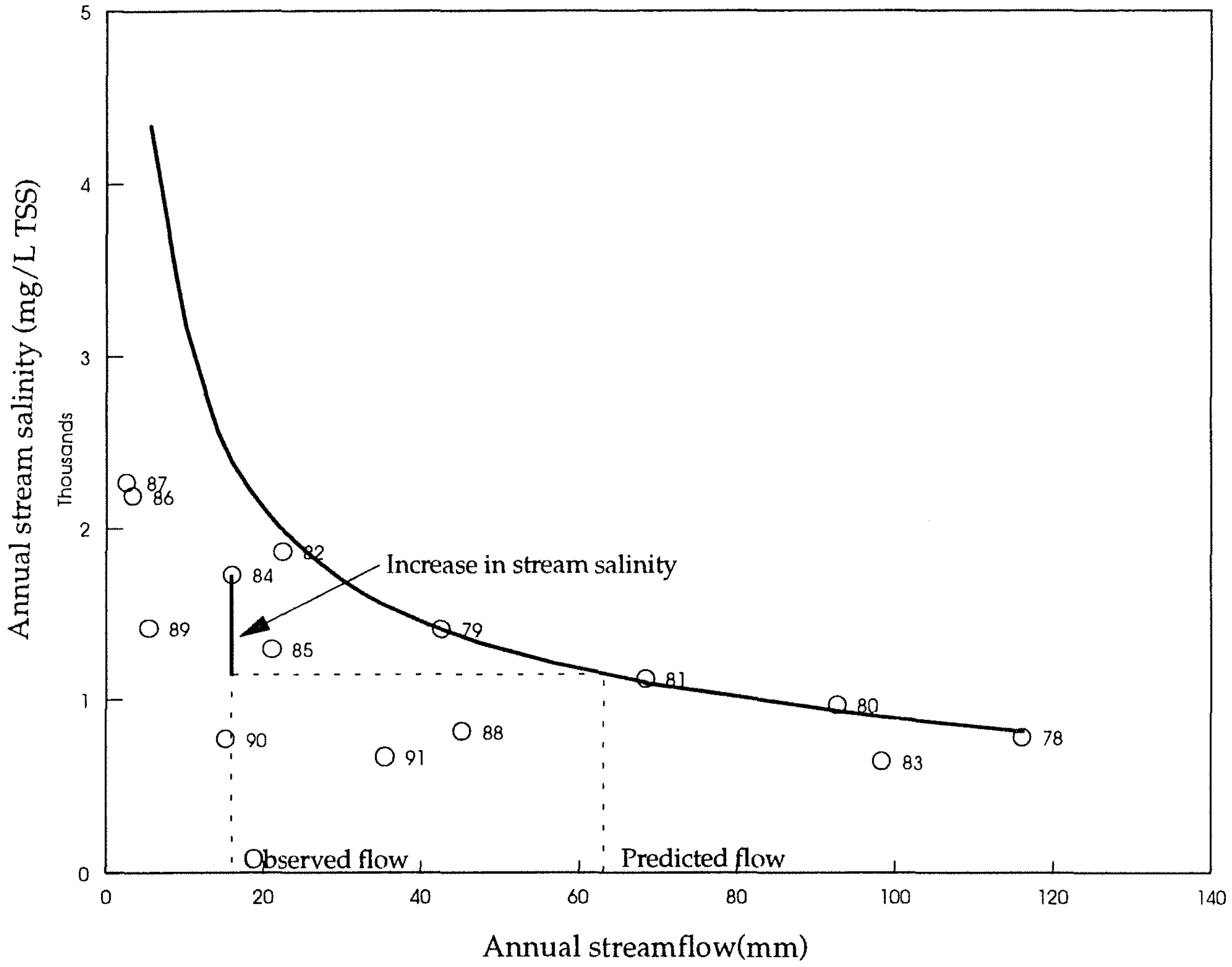


Figure 8 Calculation of stream salinity changes due to reforestation

salinity increased considerably. The highest increase of 1000 mg L^{-1} TSS was in the low rainfall year of 1987. However, since 1987 there has been a trend of reducing stream salinity. In 1991, stream salinity was 200 mg L^{-1} TSS lower than what would have occurred without reforestation. But stream salinity remained higher than 750 mg L^{-1} TSS, the appropriate limit of drinking water (Table 2).

Stream salt load decreased substantially following reforestation. Since 1983 the reduction in stream salt load has been systematic and continuous. The maximum reduction of 730 kg ha^{-1} TSS occurred in 1990 (Fig. 9b). The ratio of salt load to salt fall on the catchment from rainfall changed dramatically. The salt load/fall ratio changed from a maximum of 8.3 (1980) to a minimum of 0.7 (1987) (Table 2).

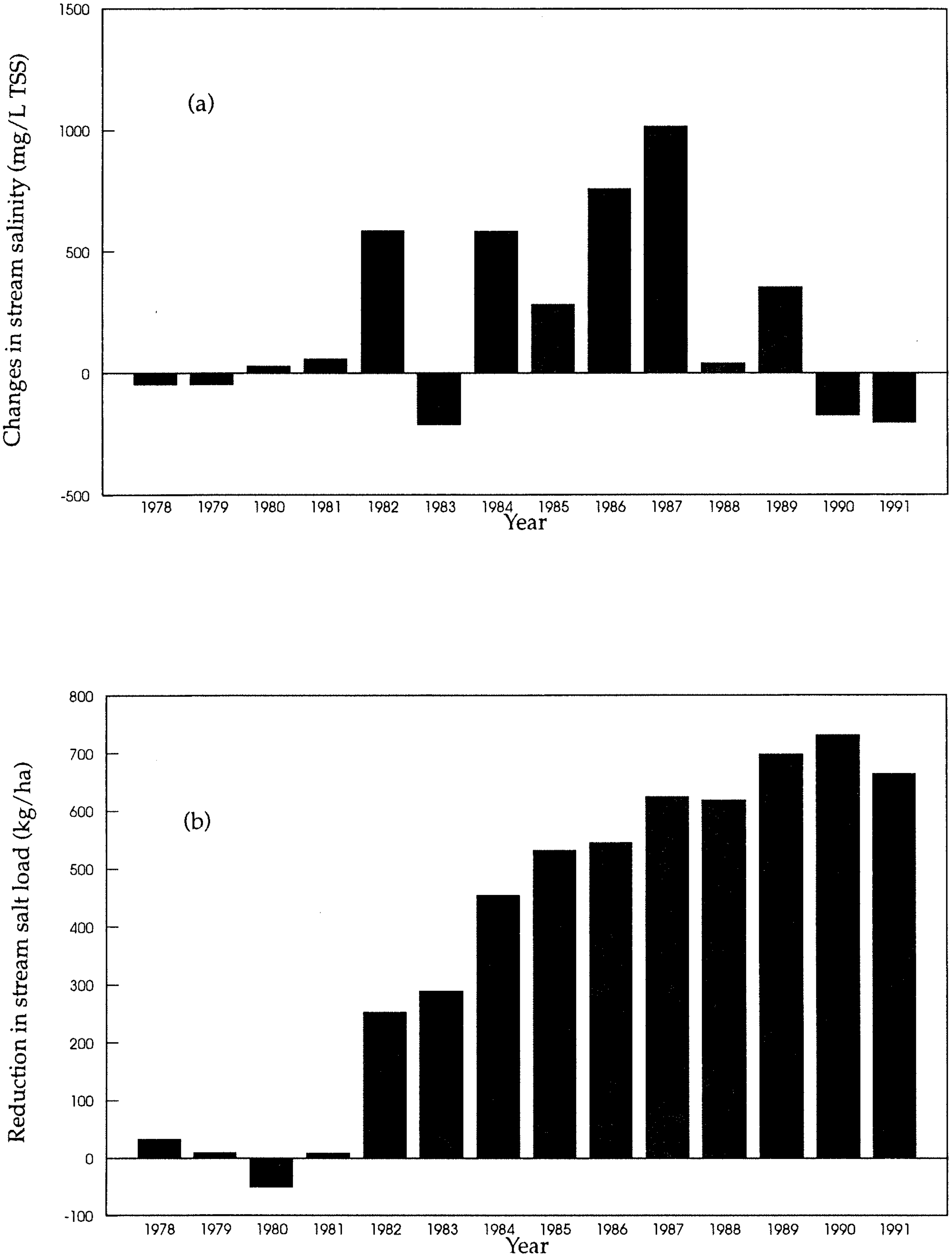


Figure 9 Changes in (a) stream salinity and (b) stream salt load due to reforestation

5 DISCUSSION

5.1 *Rainfall*

The average annual rainfall during the study period (1978-91) was 8% lower than the long term average (1926-81) of 880 mm. If long term average rainfall conditions had prevailed, it is likely that the reduction of streamflow would have been less. But it is not clear how this would have affected stream salinity. 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.

5.2 *Groundwater Level and Salinity*

In the south-west of Western Australia, groundwater levels decline substantially beneath reforestation. A decline of 2 to 7 m has been observed (Schofield et al., 1989; Bell et al., 1990; Schofield, 1990; Schofield and Bari, 1991; Schofield et al., 1991; Bari and Schofield, 1991;Bari, 1992a; Bari and Schofield, 1992). Generally, 10 years after reforestation, the reduction in groundwater level slows down as it establishes to a new equilibrium (Bari, 1992a). At Padbury Road catchment, beneath reforestation on the mid slopes and pasture in the valley floor, the groundwater level remained steady between 1989 and 1992. This means the groundwater level may have already stabilised before monitoring commenced.

Groundwater salinity beneath reforestation on mid slope areas and pasture in the lower slopes remained unchanged. 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 systematic decline in groundwater salinity beneath reforestation on upslope areas 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 (Fig. 3b).

5.3 Streamflow and Stream Salinity

The hydrology of the south-west of Western Australia is characterised by low surface runoff, high seasonal subsurface flow and little permanent groundwater flow (Stokes and Loh, 1982; Stokes, 1985). The shallow subsurface flow and deep groundwater flow comprise base flow. The surface runoff was 28% of the total streamflow over the study period. On Padbury Road catchment, surface runoff was generated from the valley area, close to the stream and gullies. During winter, a seasonal shallow groundwater system develops around the valley area and results in surface runoff during storm events. The seasonal fresh groundwater system contributes significantly to streamflow with only small salt loads (Stokes and Loh, 1982; Bari and Boyd, 1992; Bari, 1992b). The primary source of stream salts was the deep groundwater system (Wood, 1924) which contributes very little flow. As a consequence of clearing, the groundwater table rises and discharges throughout the year to the valley area along the stream lines. However, streamflow does not occur during the dry months because potential evapotranspiration exceeds the discharge from the deep groundwater system.

Sometimes the observed daily stream salinity was higher than the groundwater salinity (5000 mg L^{-1} TSS), particularly at the onset of winter (Appendix B). This is attributed to the concentration of salts at or near the groundwater discharge 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.

In 1960s, when Padbury Reservoir was established, stream salinity in its catchment was about 500 mg L^{-1} TSS. By the mid 1970s, stream salinity exceeded 1000 mg L^{-1} TSS. This is a typical pattern of stream salinity response to agricultural clearing.

5.4 Effects of Reforestation on Streamflow

Since 1981, streamflow has decreased substantially due to reforestation. Most of the decrease occurred in the surface runoff and base flow components (Fig. 6). The higher reduction in base flow component was due to the abstraction and transpiration from the seasonal groundwater by trees. Transpiration appears to be limited to the abstraction of water by shallow roots of young trees from the seasonal groundwater and very little from deep groundwater. Similar results were found in the south-west of Western Australia (Bari, 1992b).

The reduction in streamflow was systematic except for the years 1983, 1986 and 1991 (Fig. 5). The apparent lower streamflow reduction may be attributable to the thinning of tree densities during those three years.

The streamflow is still declining and it is not at equilibrium (Fig. 5). During the last five years, the average streamflow was 2% of annual rainfall (Table 2). Therefore, what the streamflow will be in future is uncertain. Other forested catchments in the region with similar annual rainfall and pan evaporation, annual streamflow ranges between 2 to 10% of rainfall (Public Works Dept., 1984). However, the native forest in those catchments consists of native, mature jarrah trees. Very little is known about the water use of jarrah compared to young pines and eucalypts. There are also some evidence that young pines and eucalypts consume more water than mature ones (Kuczera, 1987).

5.5 Effects of Reforestation on Stream Salinity and Salt Load

Groundwater contributes upto 95% stream salt load in the south-west of Western Australia (Stokes and Loh, 1982; Stokes, 1985). There is also evidence that salt is transported from the groundwater table to the upper soil layer by capillary action. The transported salt is then discharged to the stream through shallow subsurface flow (Williamson et al., 1987). The base flow consist of shallow subsurface flow and deep groundwater flow. Therefore, a reduction in base flow should be accompanied by a decline in stream salt load. This is supported by the results of this study (Fig. 9b).

However, in most of the years the stream salinity was greater than what could have expected without reforestation (Fig. 9a). That means the reduction in streamflow was more than required to counter balance the reduced stream salt load. This may also be attributable to the transpiration of water by young trees mainly from seasonal groundwater and very little from deep groundwater. However, since 1987 there has been a trend of higher stream salinity reduction (Fig. 9a). This might mean the trees are now mature enough to have a deep root system to extract deep groundwater.

At Padbury Road catchment, the majority of the valley areas were not reforested (Fig. 2). If the valley areas had been reforested, the higher transpiration by trees could have led to a bigger reduction in groundwater level in the valley areas and subsequently salt discharge to the stream. This may have resulted in a greater reduction in stream salinity.

5.6 The Use of the Reforestation as a Salinity Control

The results demonstrate that reforestation lowers streamflow and stream salt load. For a particular flow volume, stream salinity declined (Fig. 7a). In terms of reducing stream salinity that would have occurred without reforestation, the effects of reforestation is still uncertain (Fig. 9a). However, stream salinity increased until 1987, particularly in the low rainfall years, and appears to have declined since then. But the apparent salinity reduction was not enough to produce stream salinity below 750 mg L^{-1} TSS (Table 2). If the valley areas had been planted, reforestation possibly would have resulted in greater reduction in stream salinity. To date it is not clear if reforestation is an appropriate strategy to reduce stream salinity in a small water supply catchment like this one.

But results from Padbury Road catchment have excellent implications for large salt-affected water supply catchments in the south-west of Western Australia. For example, Wellington Dam catchment, some 50 km north of Balingup, has a catchment area of 2830 km^2 and annual rainfall ranges from 600 mm to 1200 mm. About 50% of salt and less than 10% of inflow to the reservoir originates from the region with less than 700 mm rainfall. In 1980s more than 6500 ha of cleared land was planted in this region and another 3500 ha is being planted. The main objective was to control and reduce stream salt discharge to the reservoir (Loh, 1988; Schofield, et al., 1989; Bari, 1992b). Results from Padbury Road catchment supports the reforestation programme at Wellington Dam catchment.

6 CONCLUSIONS

6.1 Groundwater Level and Salinity

(i) Groundwater levels beneath reforestation and pasture remained steady during 1989-92 period.

(ii) The groundwater salinity beneath pasture in the valley floor and reforestation on the mid slope areas did not change. Beneath reforestation on the upslope areas, groundwater salinity declined systematically over the last four years.

6.2 Streamflow and Stream Salt Load

(i) Reforestation has resulted in a systematic and continuous decrease in streamflow. The highest streamflow reduction was about 8% of annual rainfall. The decrease in streamflow may partially be attributable to the lower rainfall during the study period.

(ii) The reduction in base flow was about three times greater than that of surface runoff.

(iii) Since reforestation, there has been a continuous reduction in stream salt load. The highest reduction was about 730 $kgha^{-1}$ TSS in 1990.

(iv) Since reforestation, stream salinity (compared with predicted salinity if there had been no reforestation) has increased until 1987. The increase was greatest in the low rainfall years. Since 1987, observed salinity has been less than what would have occurred without reforestation. To date, it is unclear if reforestation is an appropriate strategy to reduce stream salinity in a small water supply catchment like this one.

7 RECOMMENDATIONS

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

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

- Bore monitoring should be continued to determine future groundwater level and salinity behaviour under reforestation, native forest and valley area.

8 ACKNOWLEDGMENTS

I am 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 A. Gower, Dr R. Froend and Mr D. Boyd for comments on an earlier draft of this report. I would also like to thank Mr I. Logan for preparing the figures.

9 REFERENCES

Allison, G.B., Cook, P.G., Barnett, S.R., Walker, G.R., Jolly, I.D. and Hughes, M.W. (1990). Land clearance and river salinities in Western Murray Basin, Australia. J. Hydrol., 119:1-20.

Bari, M.A. (1992a). Trees lower groundwater level and salinity. A National Conference on Veg. and Water Manag., 23-36 March 1992, Adelaide, Greening Australia, 3 pp.

Bari, M.A. (1992b). Early streamflow and salinity response to partial reforestation at Batalling Creek catchment in the south-west of Western Australia. Water Authority of W.A., Surface Water Branch Rep. No. WS 107, 82 pp.

Bari, M.A. and Schofield, N.J. (1992). Lowering of a shallow, saline groundwater table by extensive eucalypt reforestation. J. Hydrol., 133:273-291.

Bari, M.A. and Boyd, D.W. (1992). Water and salt balance of a partially reforested catchment in the south-west of Western Australia. Water Authority of W.A., Surface Water Branch Rep. No. WS 98, 136 pp.

Bari, M.A. and Schofield, N.J. (1991). Effects of Agroforestry-pasture associations on groundwater level and salinity. Agroforestry Systems. 16:13-31.

Bell, R.W., Schofield, N.J., Loh, I.C. and Bari, M.A. (1990). Groundwater response to reforestation in the Darling Range of Western Australia. J. Hydrol. 119:179-200.

Bell, R.W., Loh, I.C. and Borg, H. (1987). The effect of non-valley reforestation on water quality and quantity in the Padbury Reservoir catchment and its regional implications. Water Authority of W.A., Surface Water Branch Rep. No. WS 5, 74 pp.

Borg, H., Bell, R.W. and Loh, I.C. (1988). Streamflow and stream salinity in a small water supply catchment in south-west Western Australia after reforestation. J. Hydrol., 103:323-333.

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

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

Hingston, F.J. and Gailitis, V. (1977). The geographic variations of salt precipitated over Western Australia. Aust. J. Soil Res. 14:319-335.

Kuczera, G. (1987). Prediction of water yield reductions following a bushfire in ash-mixed species eucalypt forest. J. Hydrol., 94:215-236.

Loh, I.C. (1988). The history of catchment and reservoir management on Wellington Reservoir catchment, Western Australia. Surface Water Branch, Water Authority of W.A., Rep. No. WS 35, 39 pp.

Lynne, B.D. and Hollick, M. (1979). Stochastic time-varying rainfall-runoff modelling. Hydrol. and Water Resour. Symp., 10-12 September 1979, Perth, The Institution of Engineers, Australia, 89-92 pp.

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

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

National Health and Medical Research Council (1987). Guidelines for drinking water quality in Australia. Aust. Govt. Pub. Serv. Canberra, 33 pp.

Peck, A.J. and Williamson, D.R. (Editors) (1987). Hydrology and salinity in the Collie River Basin, Western Australia. J. Hydrol., 94:1-198.

Pittock, A.B. (1988). Actual and anticipated changes in Australia's climate. In : G.I. Pearman (Editor) GREENHOUSE - Planning for Climate Change , CSIRO Melb. Aust., pp 35-51.

Public Works Dept. of Western Australia (1984). Streamflow records of Western Australia to 1982, Vol. 1, basins 601-612. Public Works Dept. of W. A., Water Resour. Branch, 438 pp.

Ruprecht, J.K. and Schofield, N.J. (1989). Analysis of streamflow generation following deforestation in the south-west of Western Australia. J. Hydrol., 105:1-17.

Ruprecht, J.K. and Schofield, N.J. (1991). Effects of partial deforestation on hydrology and salinity in high salt storage landscapes, I. Extensive block clearing. J. Hydrol., 129:19-38.

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

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

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

Schofield, N.J. (1990). Effects of trees on saline groundwater tables. In : Ed. P.R. Scott (Editor), Agroforestry - Integration of trees into the Agricultural Landscape. Western

Australian Dept. of Agric., Div. of Resour. Manag. Tech. Rep. No. 102, 67 pp.

Schofield. N.J. and Bari, M.A. (1991). Valley reforestation to lower saline groundwater tables :results from Stene's Farm Western Australia. Aust. J. Soil. Res., 29:635-650.

Schofield, N.J., Bari, M.A., Bell, D.T., Boddington, W.J., George, R.J. and Pettit, N.E. (1991). The role of trees in land and stream salinity control in Western Australia. In: National Conference on The Role of Trees in Sustainable Agriculture. Albury, 21-43.

Stokes, R.A. and Loh, I.C. (1982). Streamflow and solute characteristics of a forested and deforested catchment pair in south Western Australia. In: National Symp. on Forest Hydrology, Proc. The Institution of Engineers, Australia, Melbourne, 60-66.

Stokes, R.A. (1985). Stream water and chloride generation in a small forested catchment in south Western Australia. Water Authority of Western Australia, Surface Water Branch, Rep. No. WH 7, 176 pp.

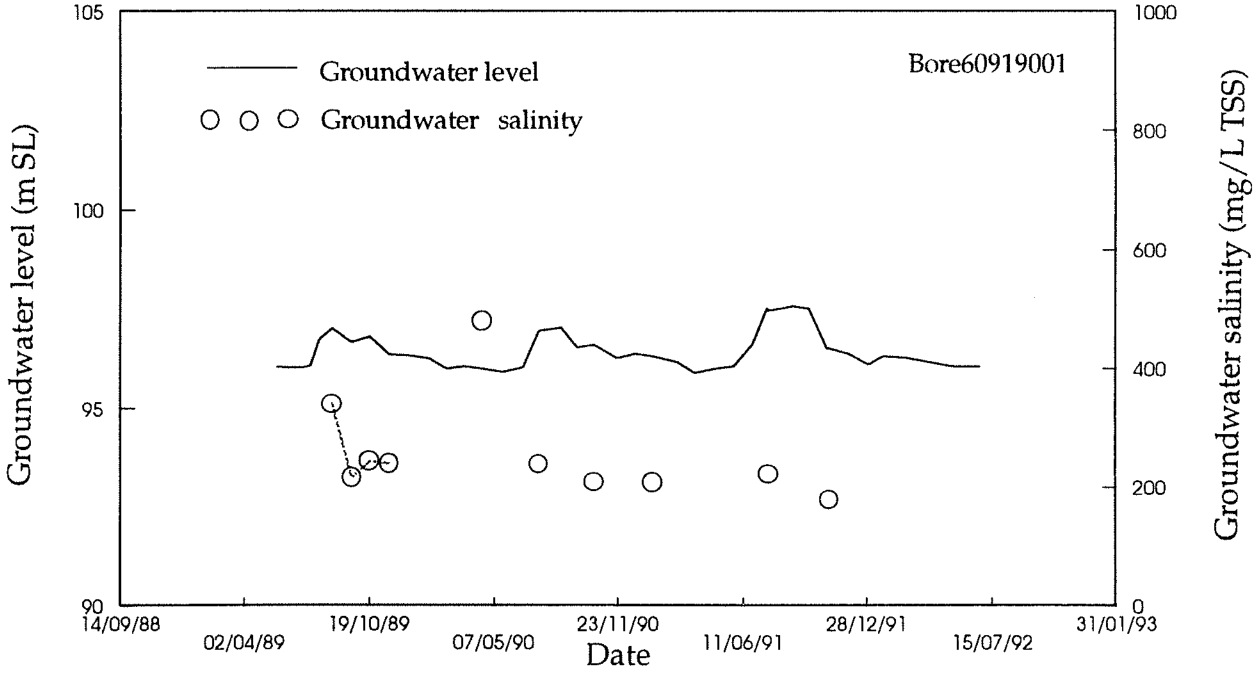
Williamson, D.R., Stokes, R.A. and Ruprecht, J.K. (1987). Response of input and output of water and chloride to clearing for agriculture. J. Hydrol., 94:1-28.

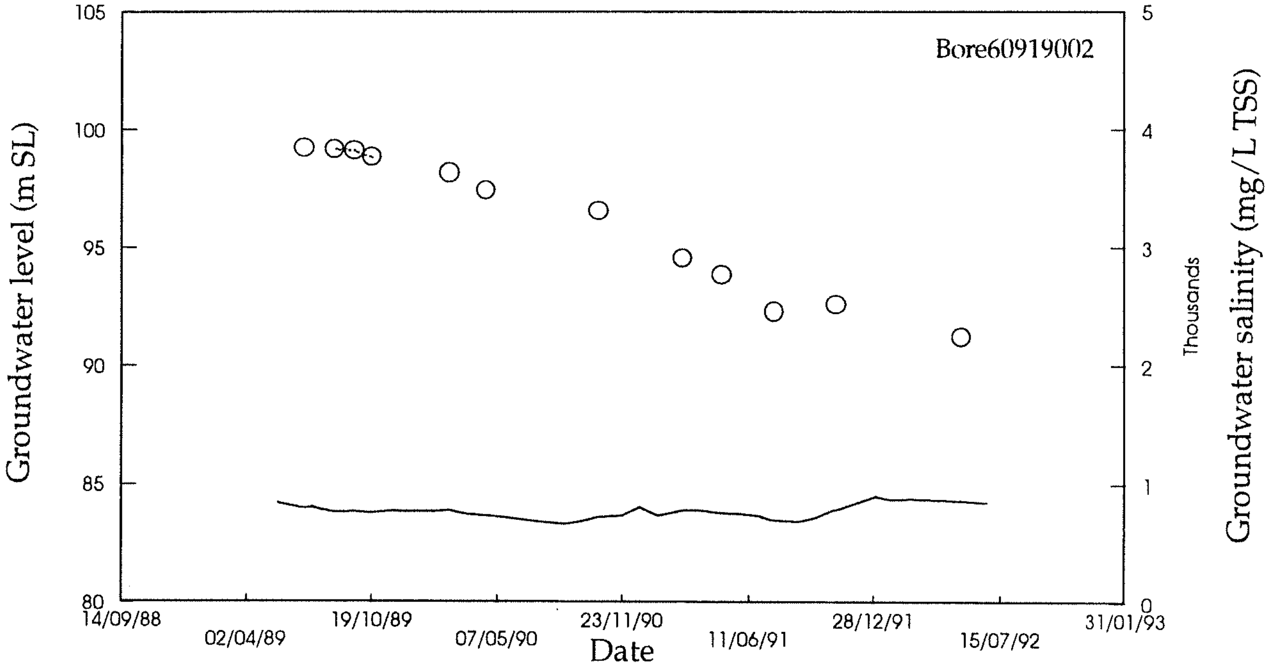
Williamson, D.R. (1986). The hydrology of salt affected soils in Australia. Reclam. Reveg. Res. 5:181-196.

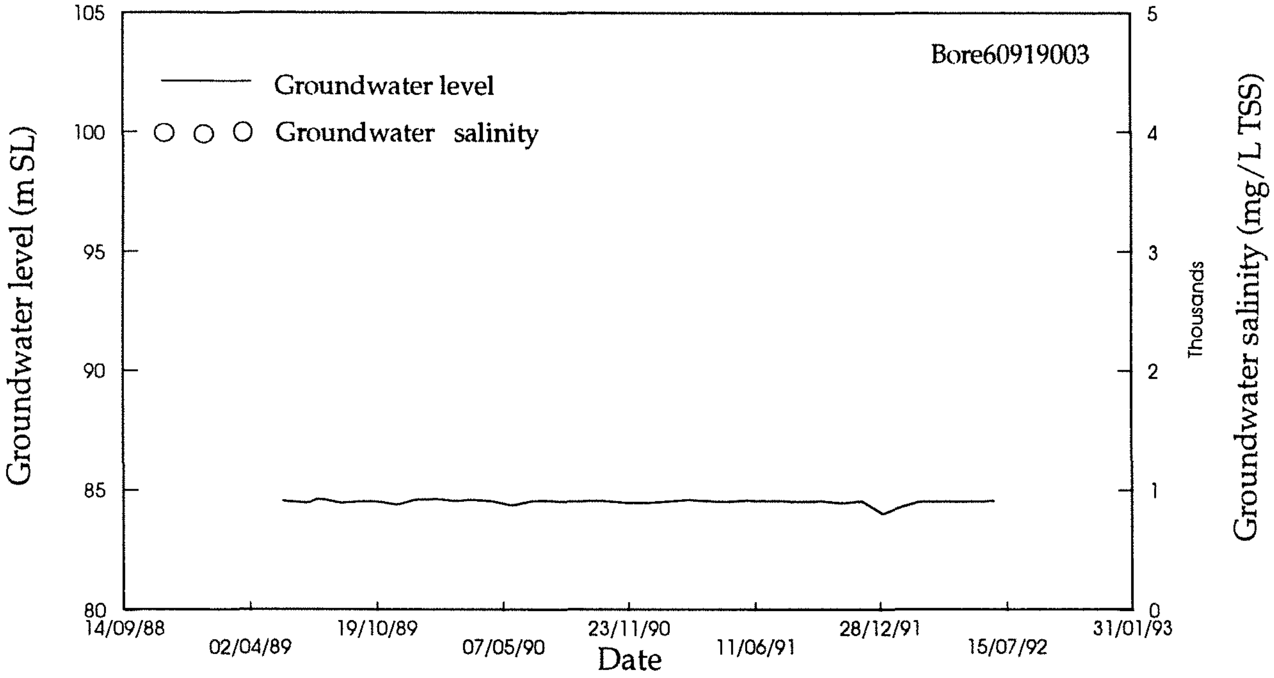
Wood, W.E. (1924). Increase of salt in soil and streams following the destruction of native vegetation. J. Roy. Soc. West. Aust., 10:35-47.

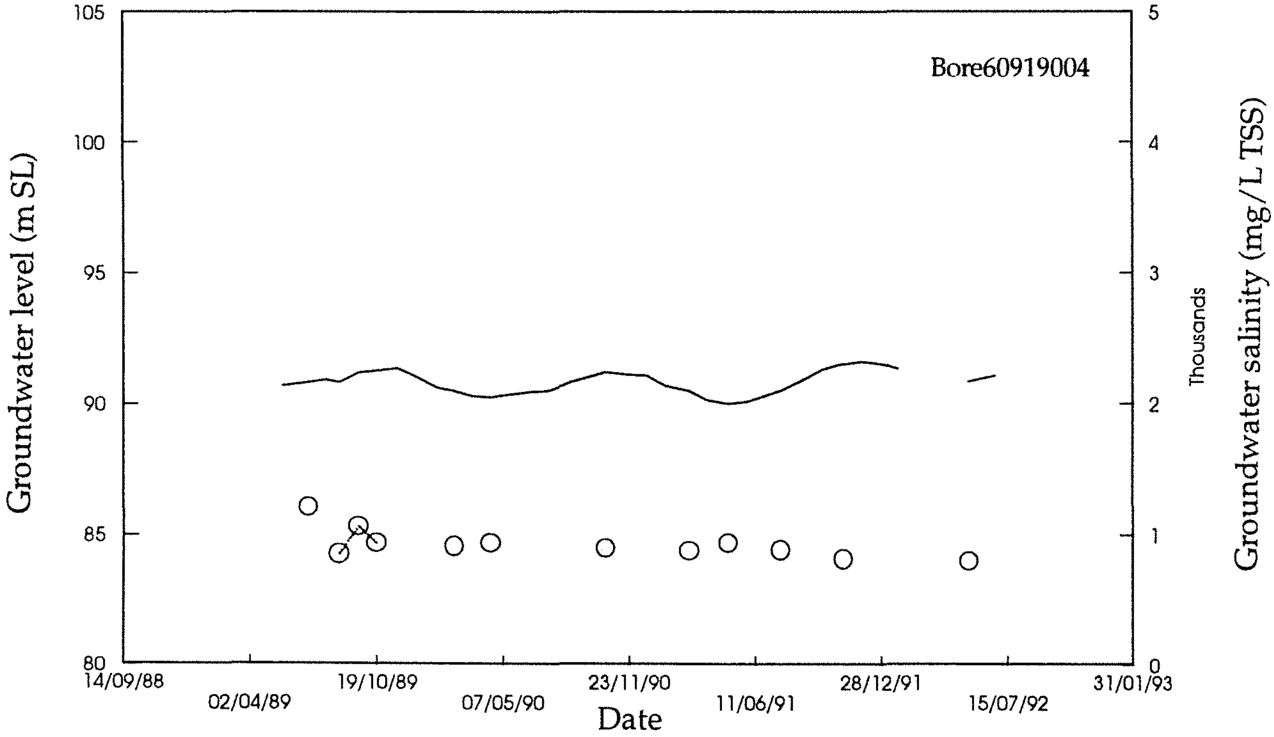
APPENDIX A

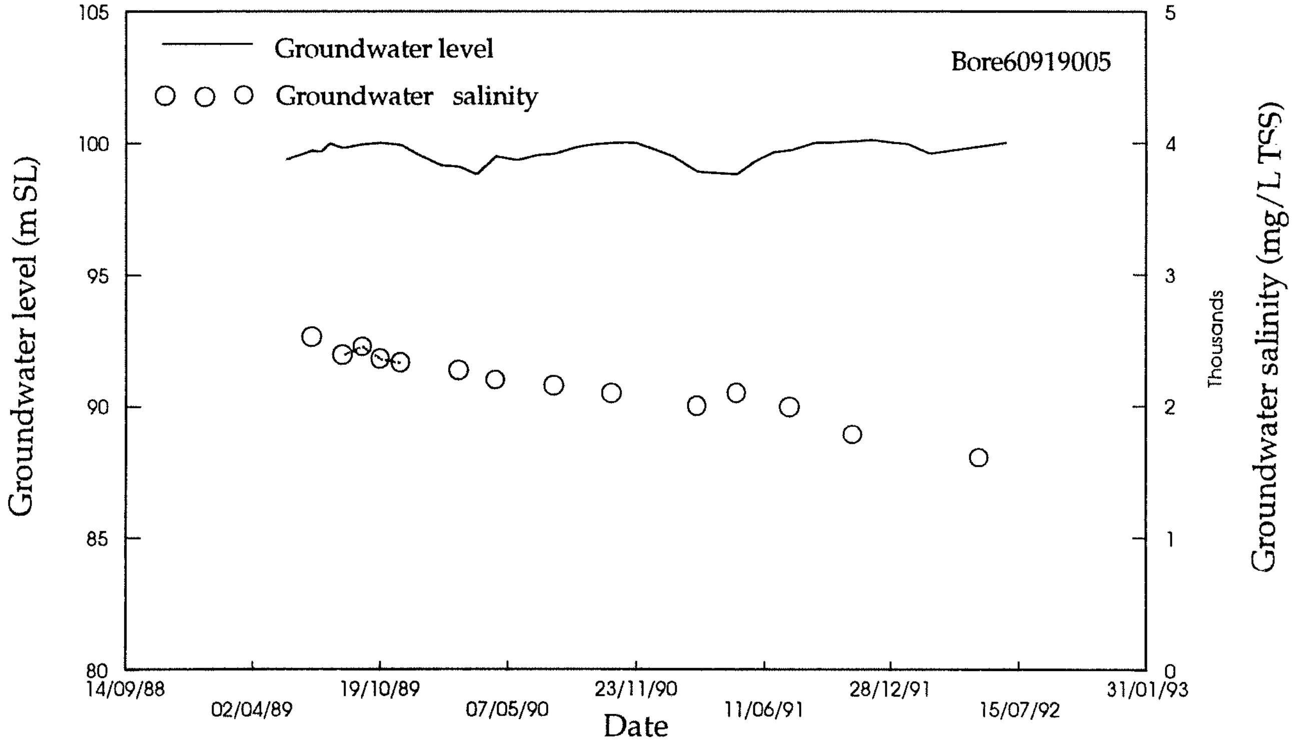
Groundwater level and salinity graphs between 1989 and 1992

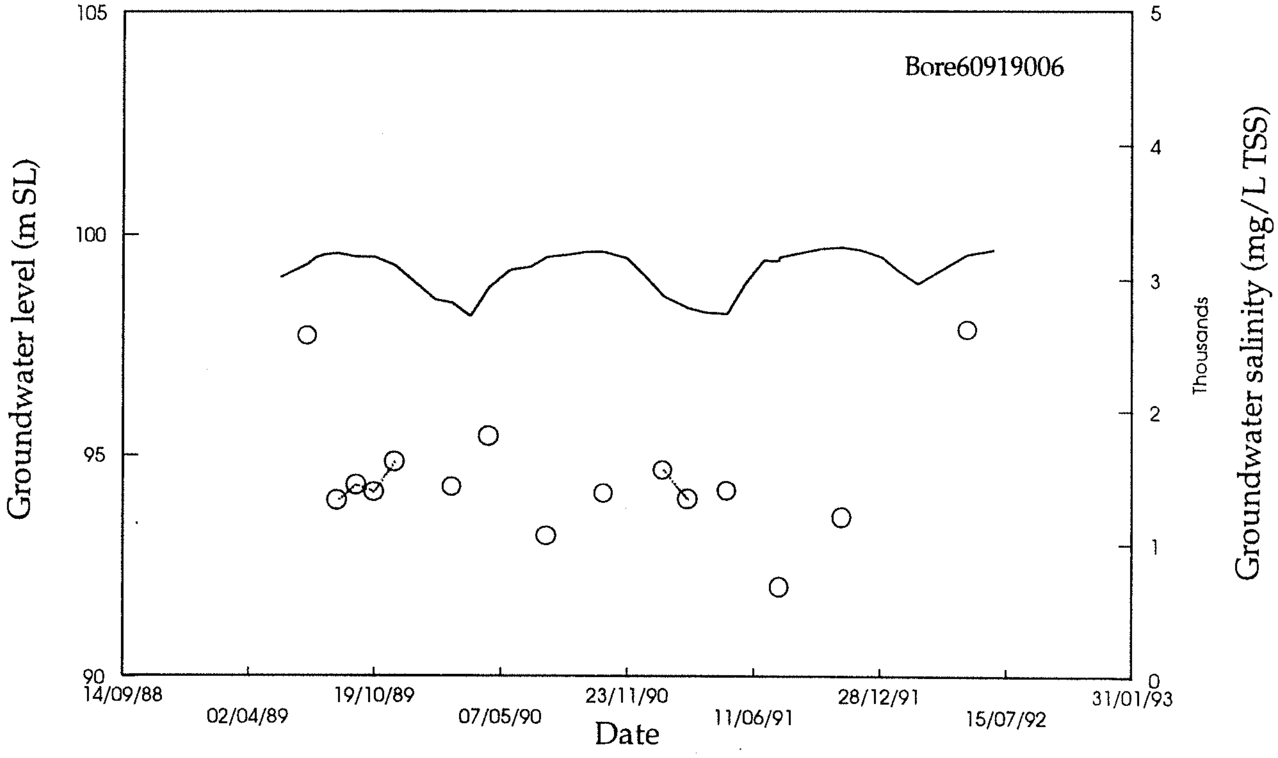

Groundwater level
Groundwater salinity
Bore60919001
Groundwater level (m SL)
Groundwater salinity (mg/L TSS)
105
100
95
90
1000
800
600
400
200
0
14/09/88
02/04/89
19/10/89
07/05/90
23/11/90
11/06/91
28/12/91
15/07/92
31/01/93
Date

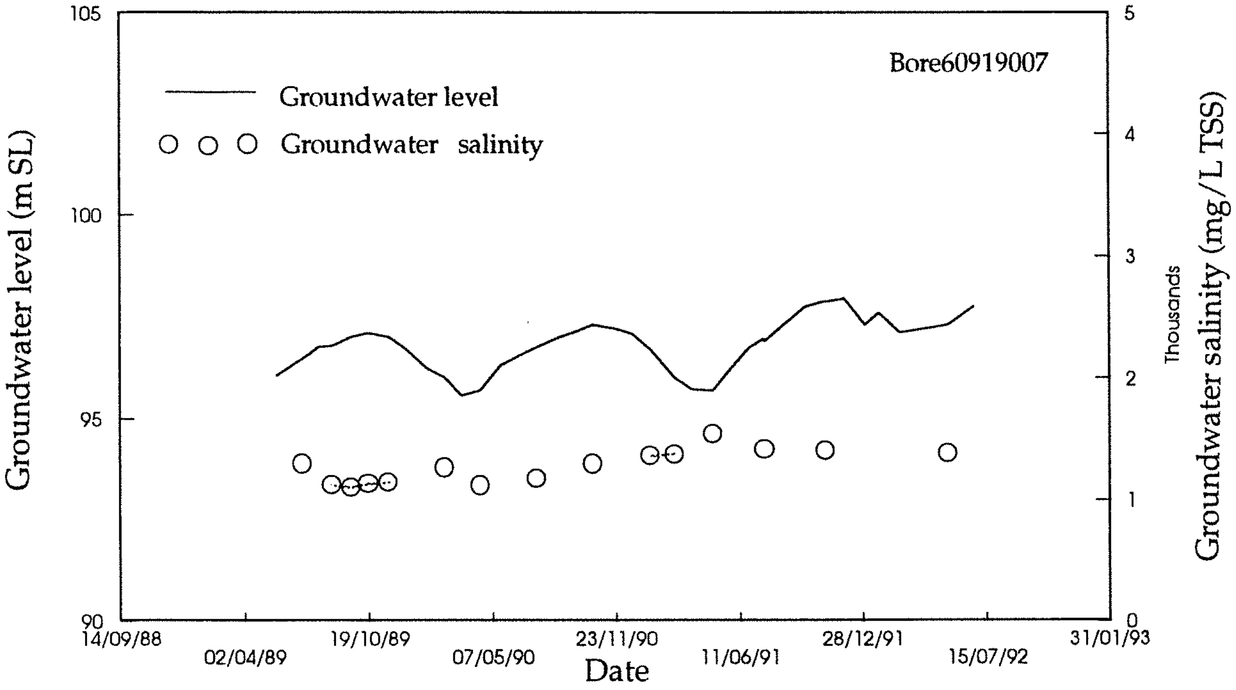

Bore60919002
Groundwater level (m SL)
Groundwater salinity (mg/L TSS)
Thousands
105
100
95
90
85
80
5
4
3
2
1
0
14/09/88
02/04/89
19/10/89
07/05/90
23/11/90
11/06/91
28/12/91
15/07/92
31/01/93
Date

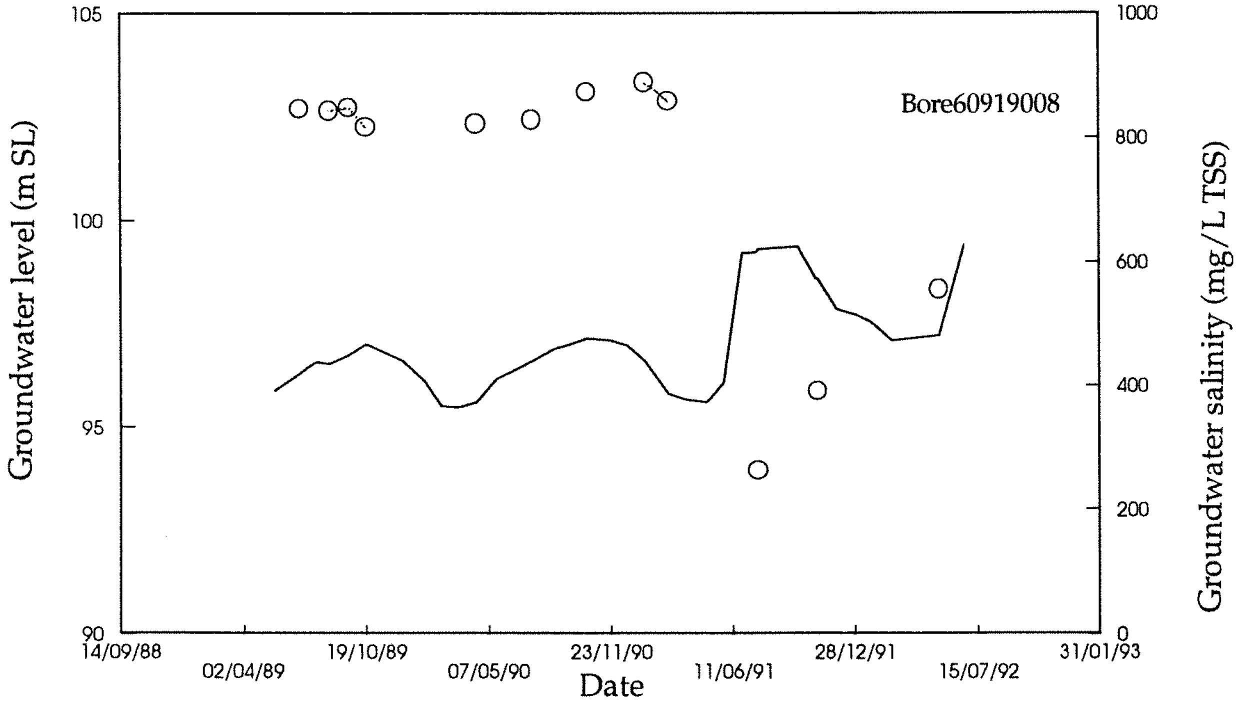

Bore60919003
Groundwater level
Groundwater salinity
Groundwater level (m SL)
Groundwater salinity (mg/L TSS)
Thousands
105
100
95
90
85
80
5
4
3
2
1
0
14/09/88
02/04/89
19/10/89
07/05/90
23/11/90
11/06/91
28/12/91
15/07/92
31/01/93
Date

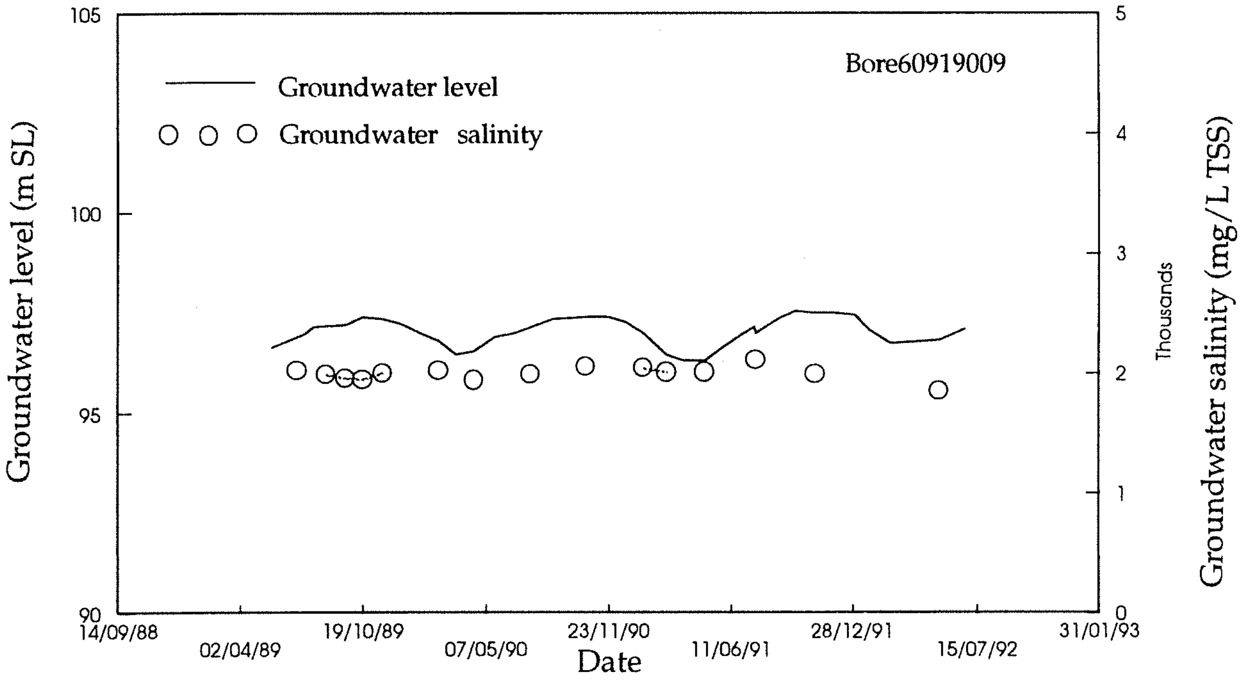

Bore60919004
Groundwater level (m SL)
Groundwater salinity (mg/L TSS)
Thousands
105
100
95
90
85
80
5
4
3
2
1
0
14/09/88
02/04/89
19/10/89
07/05/90
23/11/90
11/06/91
28/12/91
15/07/92
31/01/93
Date

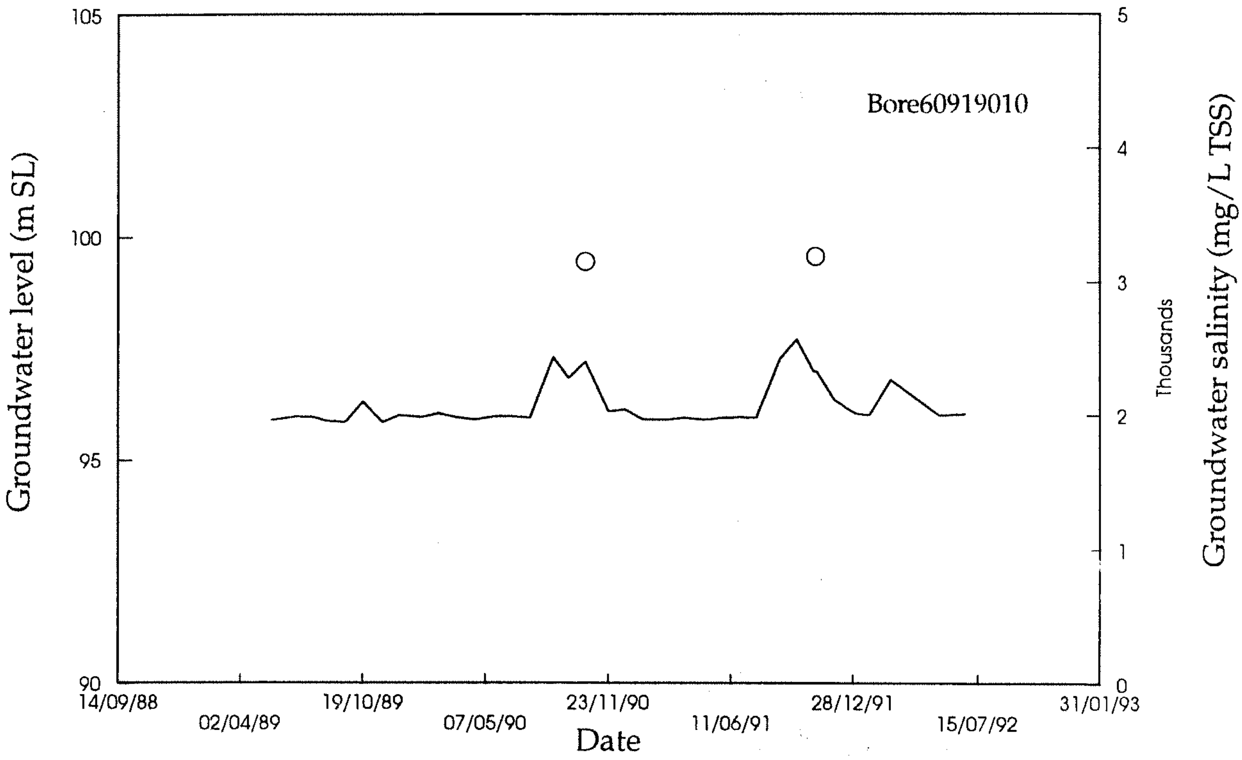

Groundwater level
Groundwater salinity
Bore60919005
Groundwater level (m SL)
Groundwater salinity (mg/L TSS)
Thousands
105
100
95
90
85
80
5
4
3
2
1
0
14/09/88
02/04/89
19/10/89
07/05/90
23/11/90
11/06/91
28/12/91
15/07/92
31/01/93
Date

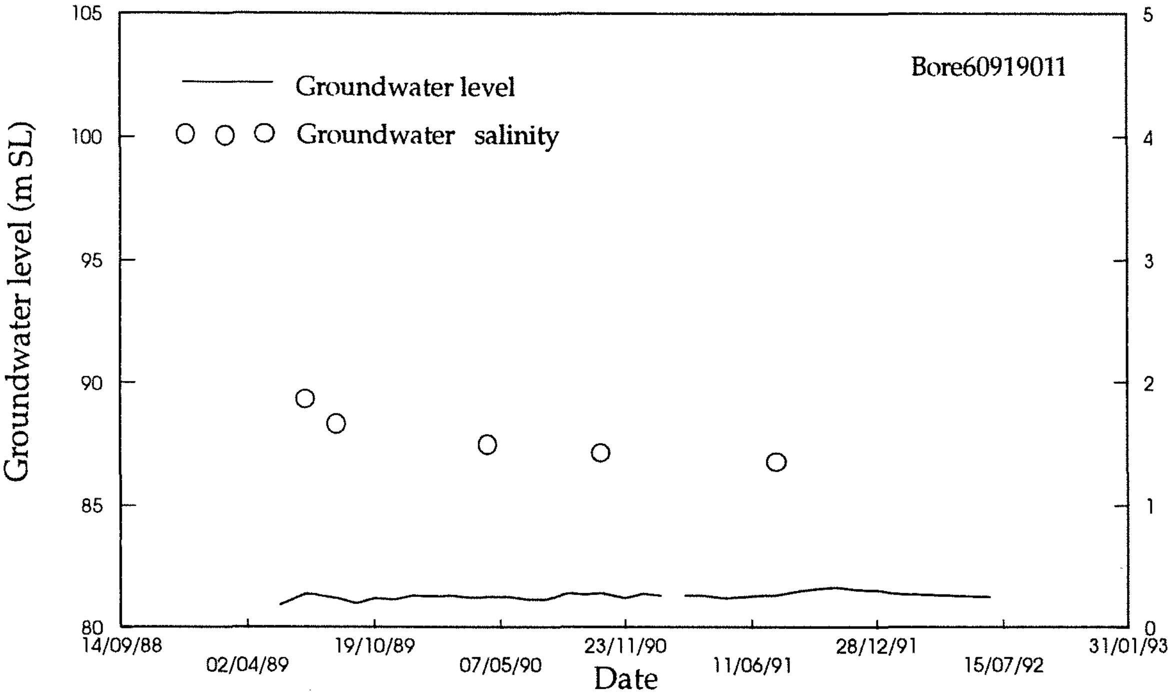

Bore60919006
Groundwater level (m SL)
Groundwater salinity (mg/L TSS)
Thousands
105
100
95
90
5
4
3
2
1
0
14/09/88
02/04/89
19/10/89
07/05/90
23/11/90
11/06/91
28/12/91
15/07/92
31/01/93
Date

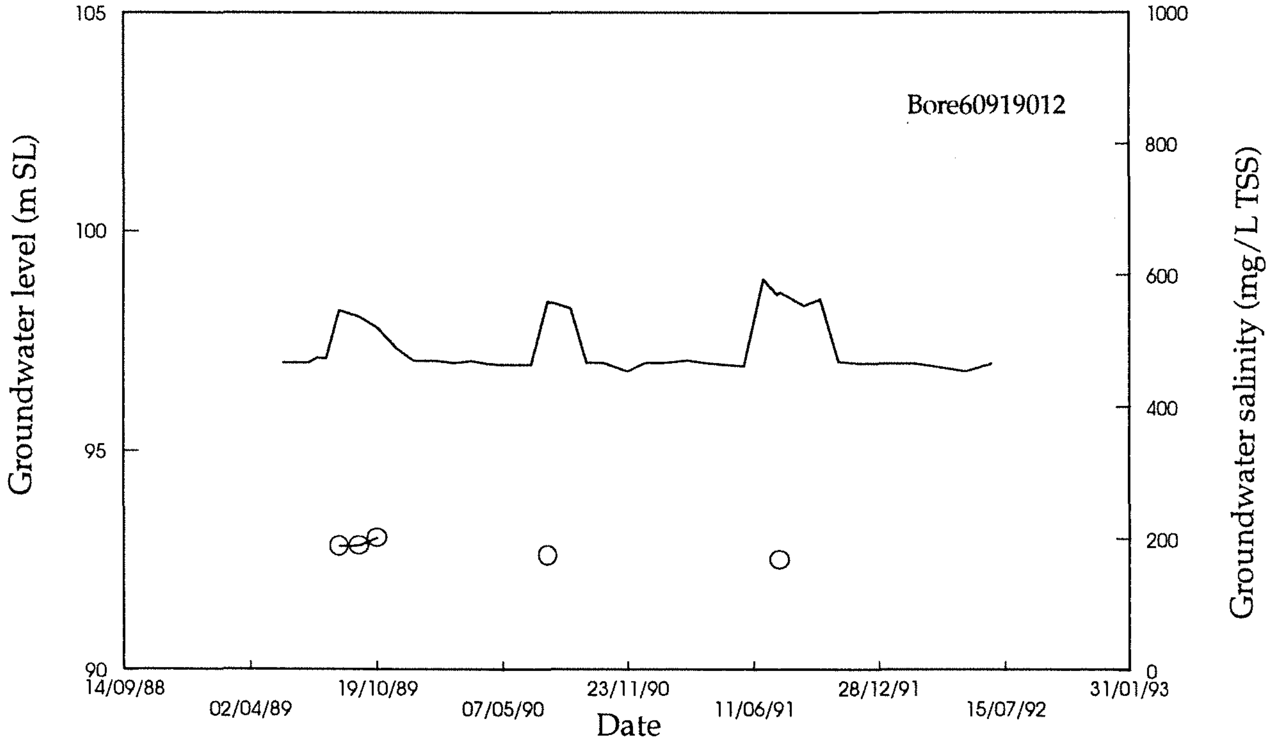

Bore60919007
Groundwater level
Groundwater salinity
Groundwater level (m SL)
Groundwater salinity (mg/L TSS)
Thousands
105
100
95
90
5
4
3
2
1
0
14/09/88
02/04/89
19/10/89
07/05/90
23/11/90
11/06/91
28/12/91
15/07/92
31/01/93
Date

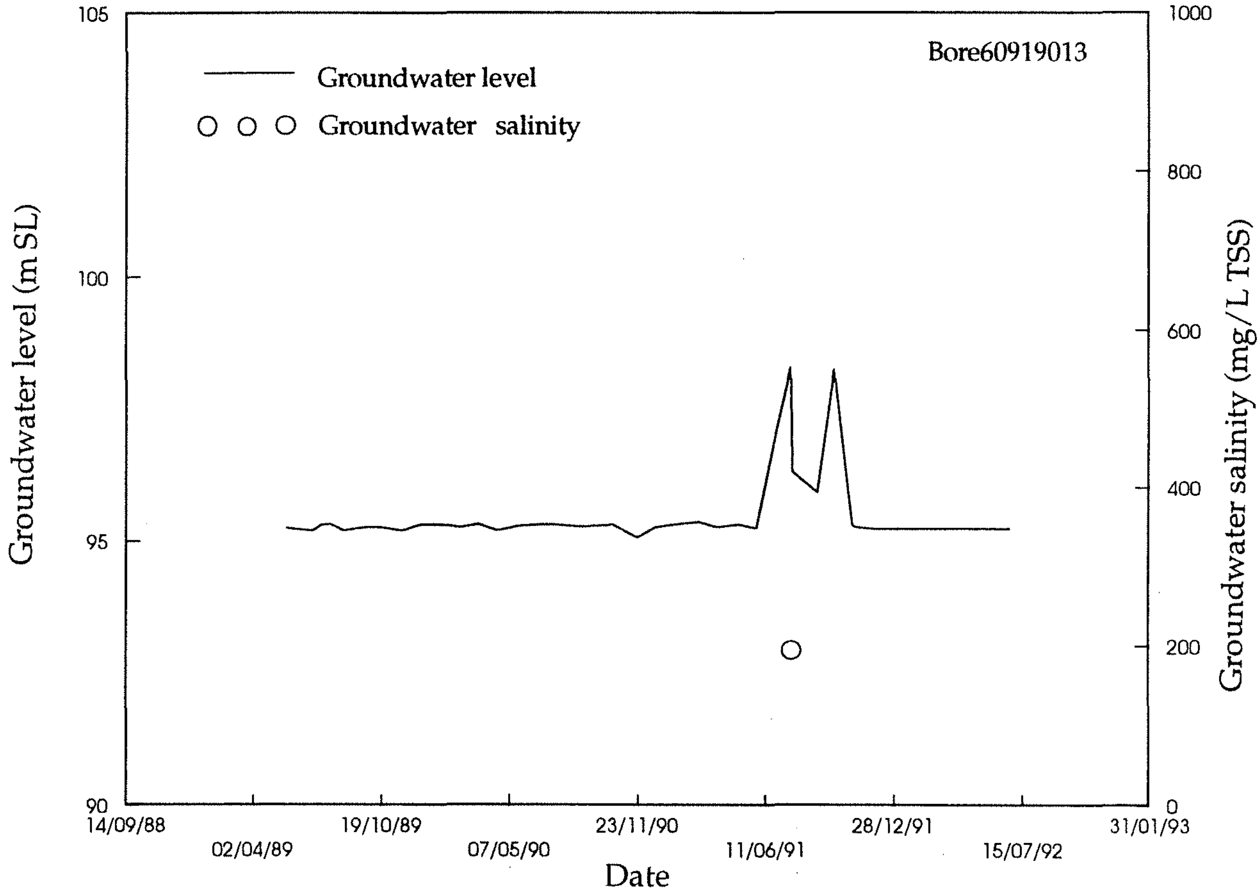

Bore60919008
Groundwater level (m SL)
Groundwater salinity (mg/L TSS)
105
100
95
90
1000
800
600
400
200
0
14/09/88
02/04/89
19/10/89
07/05/90
23/11/90
11/06/91
28/12/91
15/07/92
31/01/93
Date


105
100
95
90
5
4
3
2
1
0
Bore60919009
Groundwater level
Groundwater salinity
Groundwater level (m SL)
Groundwater salinity (mg/L TSS)
Thousands
14/09/88
02/04/89
19/10/89
07/05/90
23/11/90
11/06/91
28/12/91
15/07/92
31/01/93
Date


105
100
95
90
5
4
3
2
1
0
Bore60919010
Groundwater level (m SL)
Groundwater salinity (mg/L TSS)
Thousands
14/09/88
02/04/89
19/10/89
07/05/90
23/11/90
11/06/91
28/12/91
15/07/92
31/01/93
Date

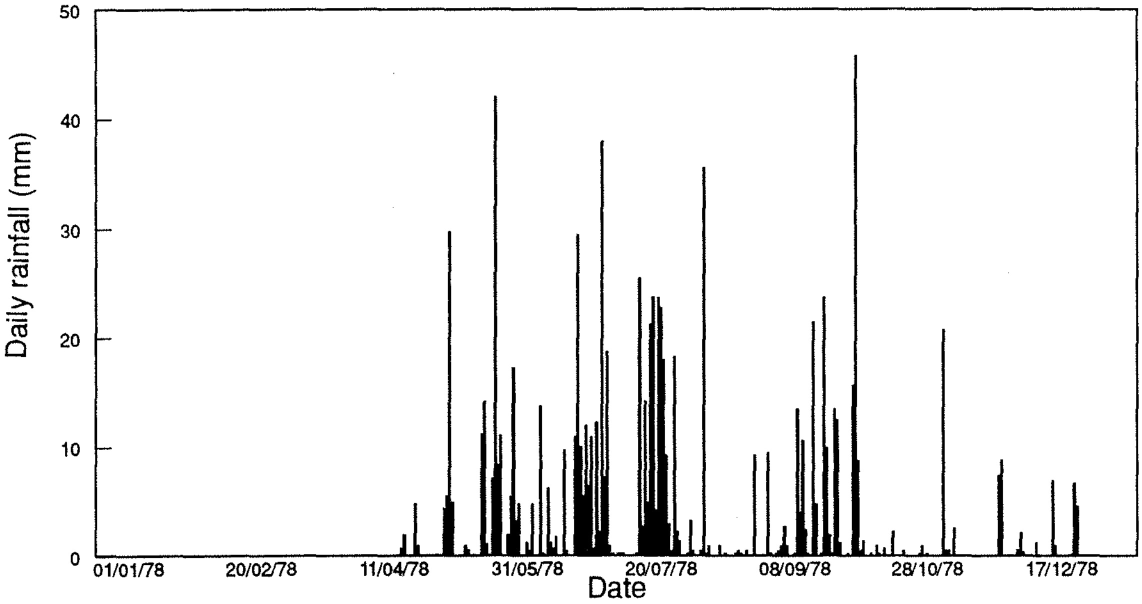

Groundwater level
Groundwater salinity
Bore60919011
Groundwater level (m SL)
Groundwater salinity (mg/L TSS)
Thousands
105
100
95
90
85
80
5
4
3
2
1
0
14/09/88
02/04/89
19/10/89
07/05/90
23/11/90
11/06/91
28/12/91
15/07/92
31/01/93
Date

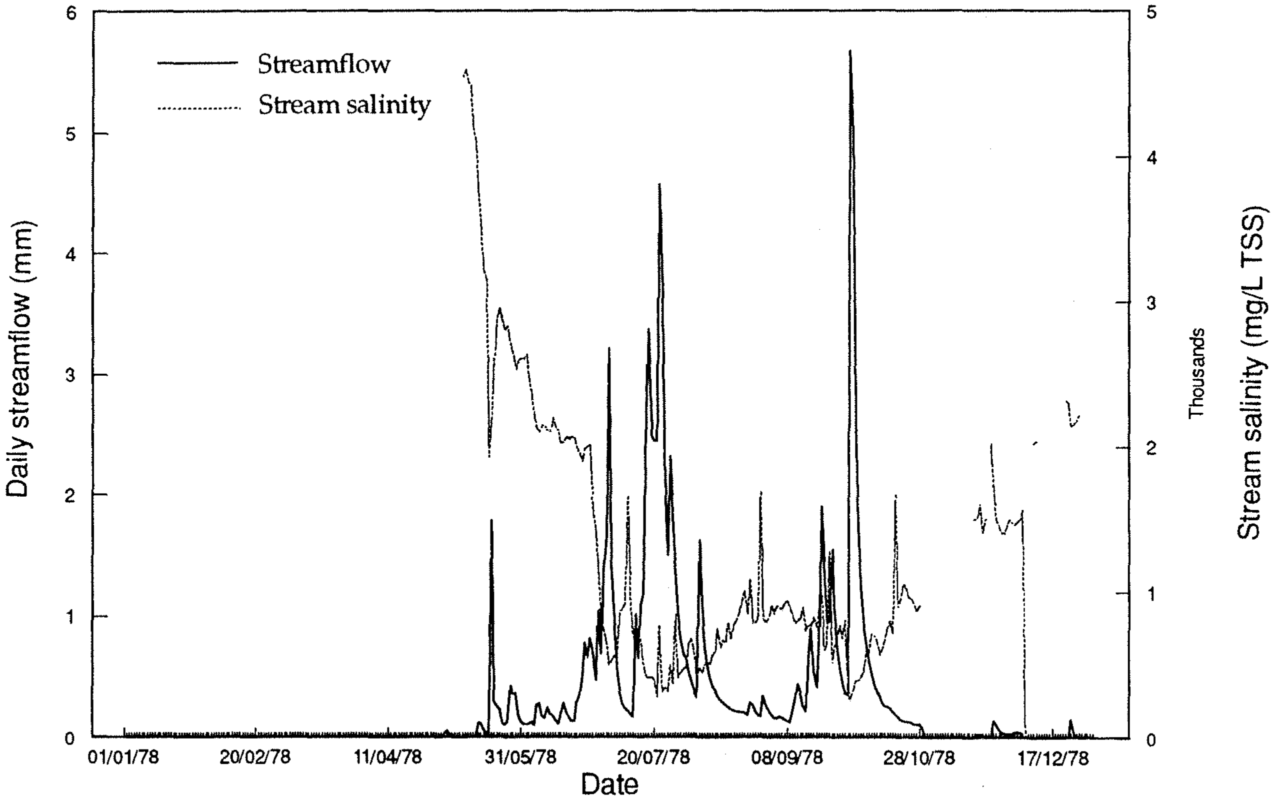

Bore60919012
Groundwater level (m SL)
Groundwater salinity (mg/L TSS)
105
100
95
90
1000
800
600
400
200
0
14/09/88
02/04/89
19/10/89
07/05/90
23/11/90
11/06/91
28/12/91
15/07/92
31/01/93
Date

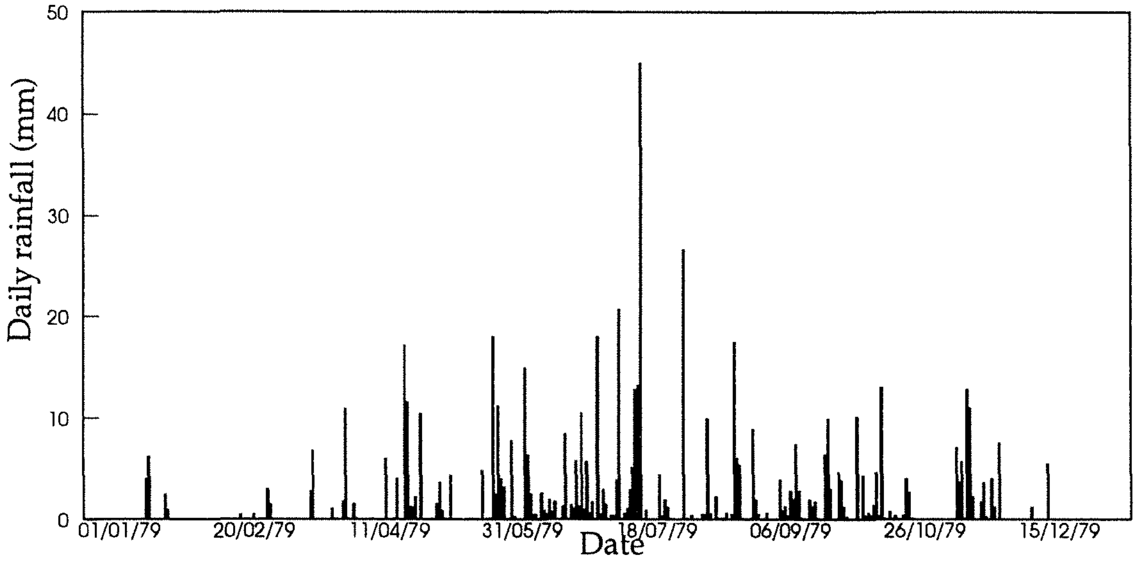

Bore60919013
Groundwater level
○ ○ ○ Groundwater salinity
Groundwater level (m SL)
Groundwater salinity (mg/L TSS)
105
100
95
90
1000
800
600
400
200
0
14/09/88
02/04/89
19/10/89
07/05/90
23/11/90
11/06/91
28/12/91
15/07/92
31/01/93
Date

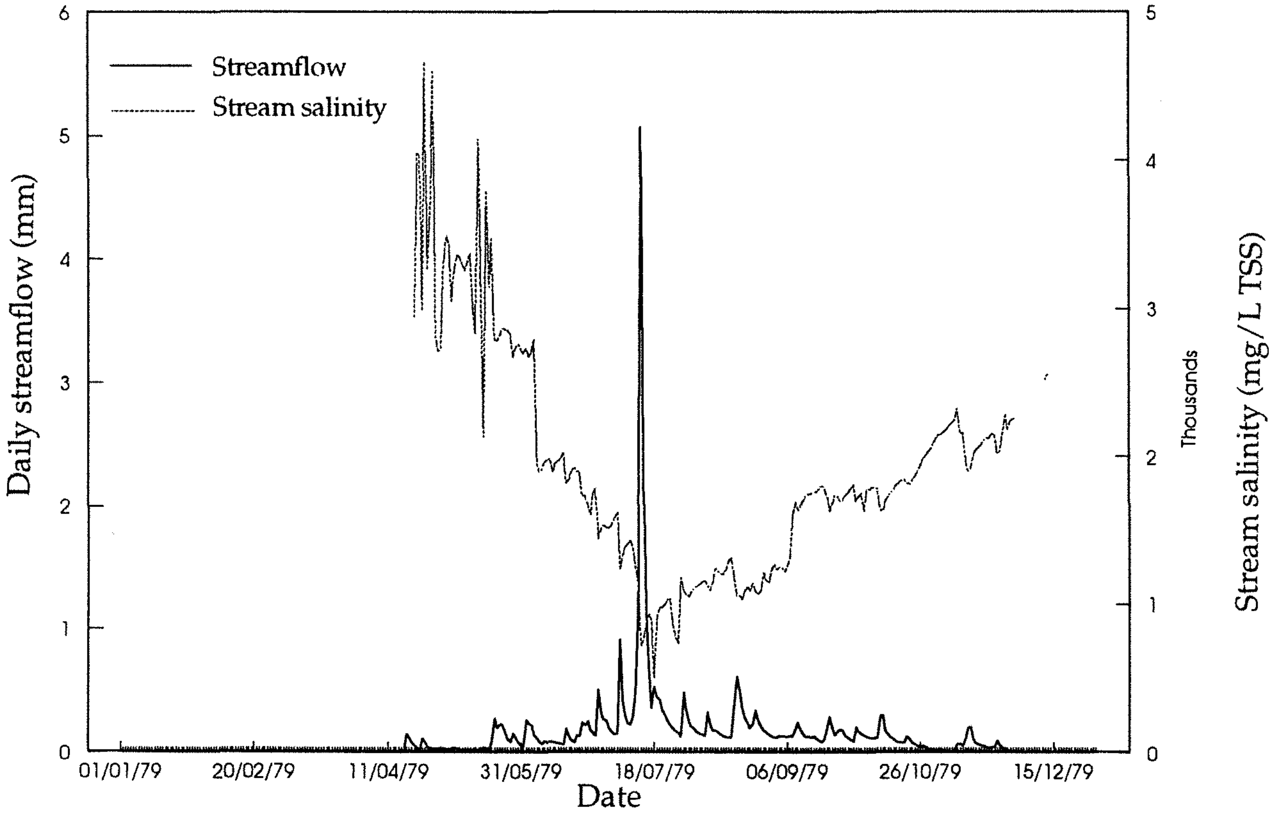
APPENDIX B

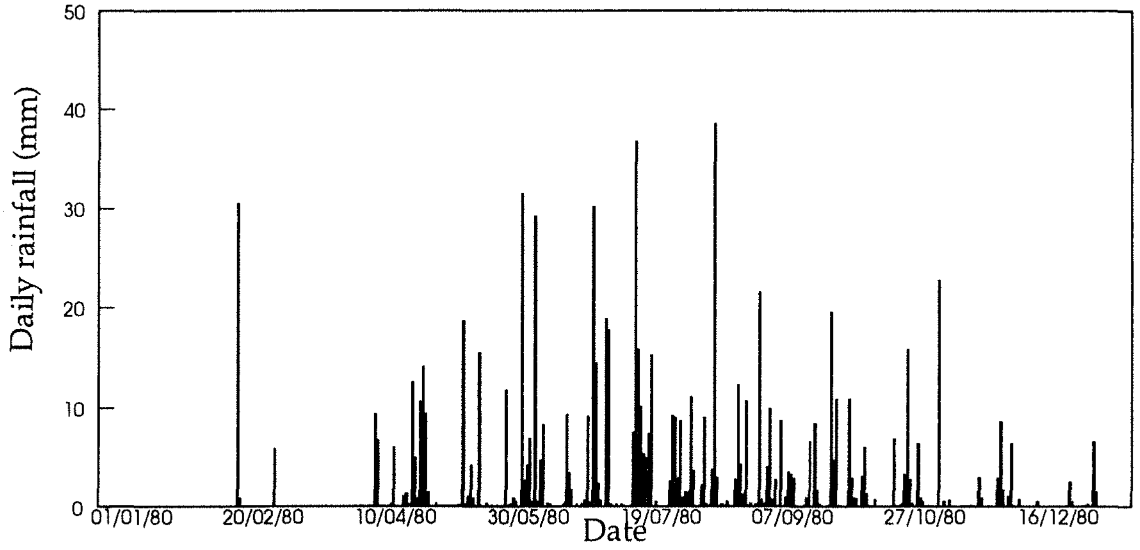
Streamflow and salinity graphs between 1978 and 1991

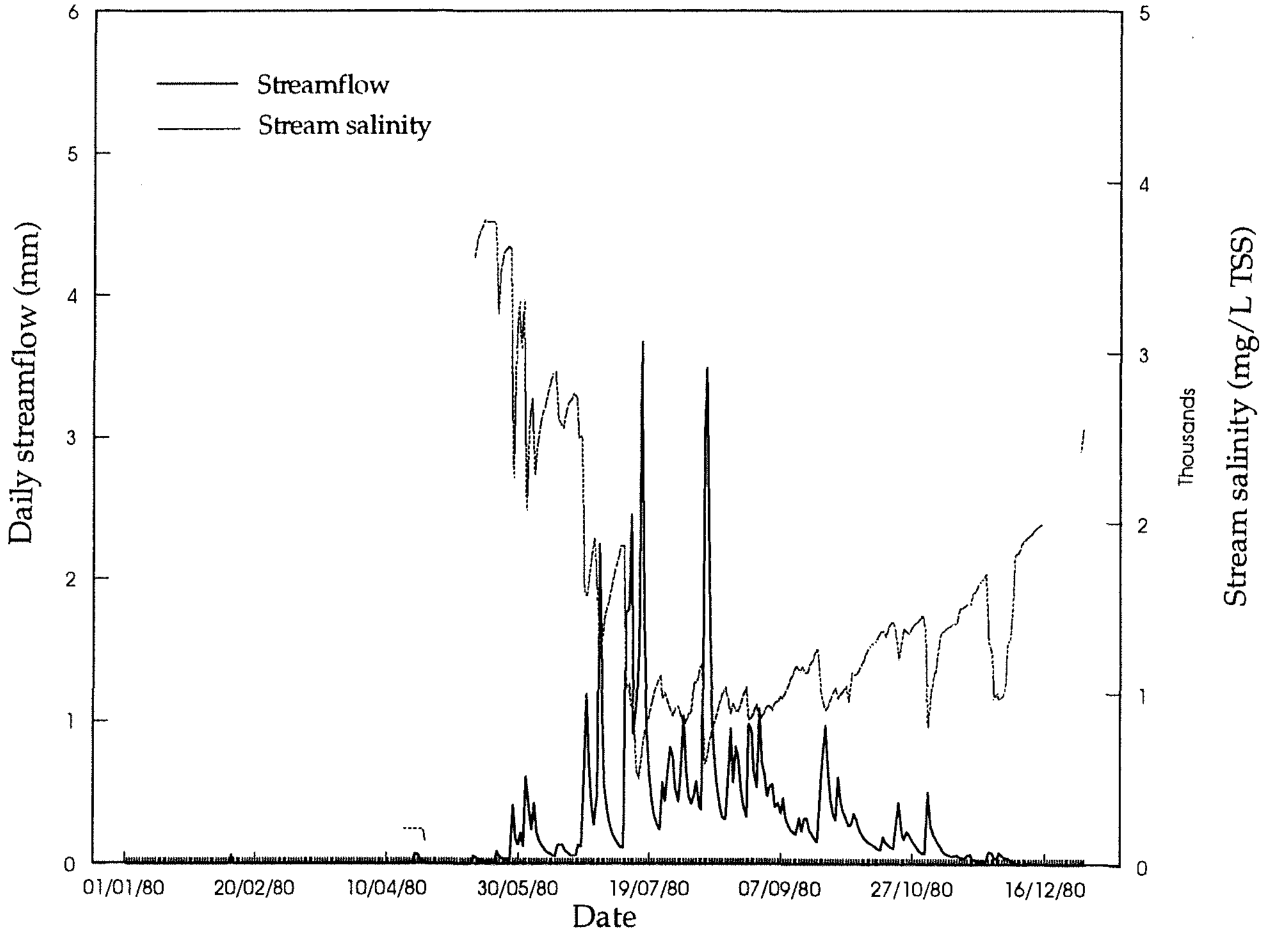

Daily rainfall (mm)
50
40
30
20
10
0
01/01/78
20/02/78
11/04/78
31/05/78
20/07/78
08/09/78
28/10/78
17/12/78
Date

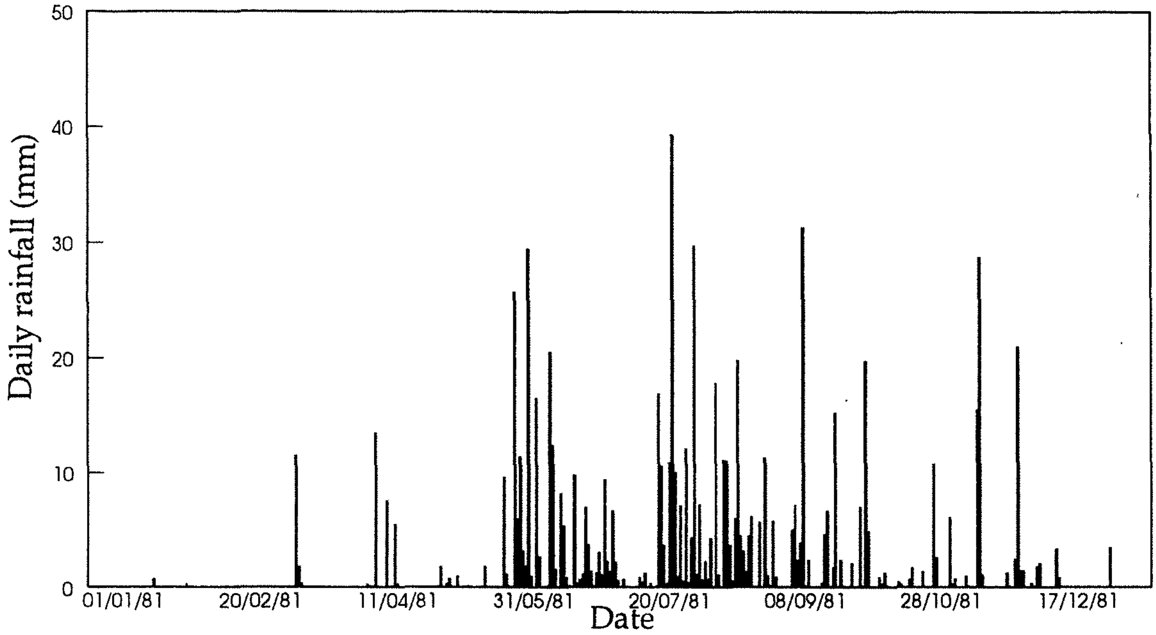

Streamflow
Stream salinity
Daily streamflow (mm)
6
5
4
3
2
1
0
Stream salinity (mg/L TSS)
Thousands
5
4
3
2
1
0
01/01/78
20/02/78
11/04/78
31/05/78
20/07/78
08/09/78
28/10/78
17/12/78
Date


Daily rainfall (mm)
50
40
30
20
10
0
01/01/79
20/02/79
11/04/79
31/05/79
18/07/79
06/09/79
26/10/79
15/12/79
Date

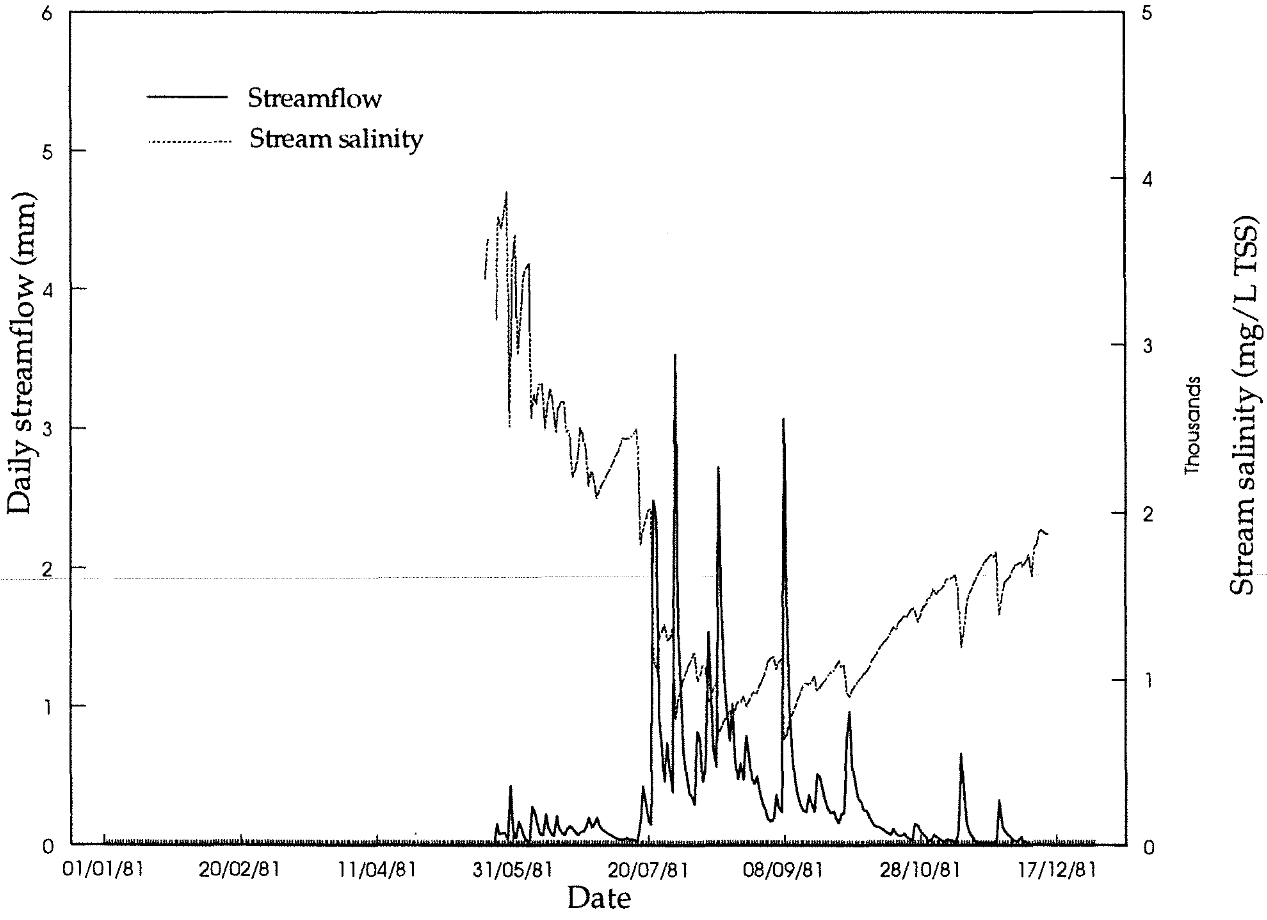

Streamflow
Stream salinity
Daily streamflow (mm)
6
5
4
3
2
1
0
Stream salinity (mg/L TSS)
Thousands
5
4
3
2
1
0
01/01/79
20/02/79
11/04/79
31/05/79
18/07/79
06/09/79
26/10/79
15/12/79
Date


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

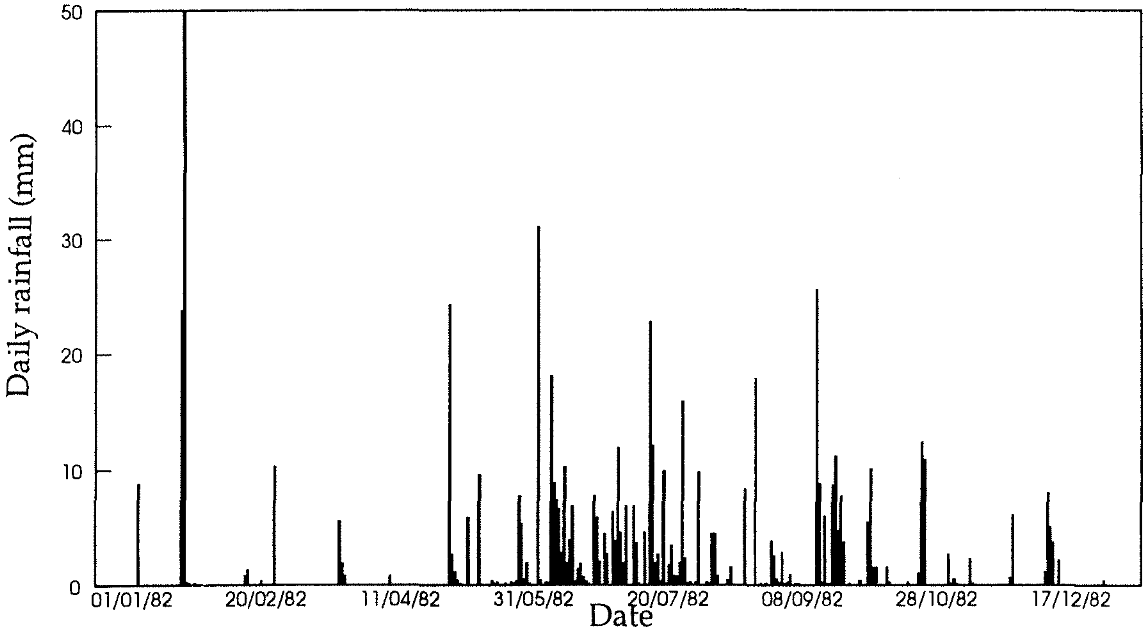

Streamflow
Stream salinity
Daily streamflow (mm)
6
5
4
3
2
1
0
Stream salinity (mg/L TSS)
Thousands
5
4
3
2
1
0
01/01/80
20/02/80
10/04/80
30/05/80
19/07/80
07/09/80
27/10/80
16/12/80
Date

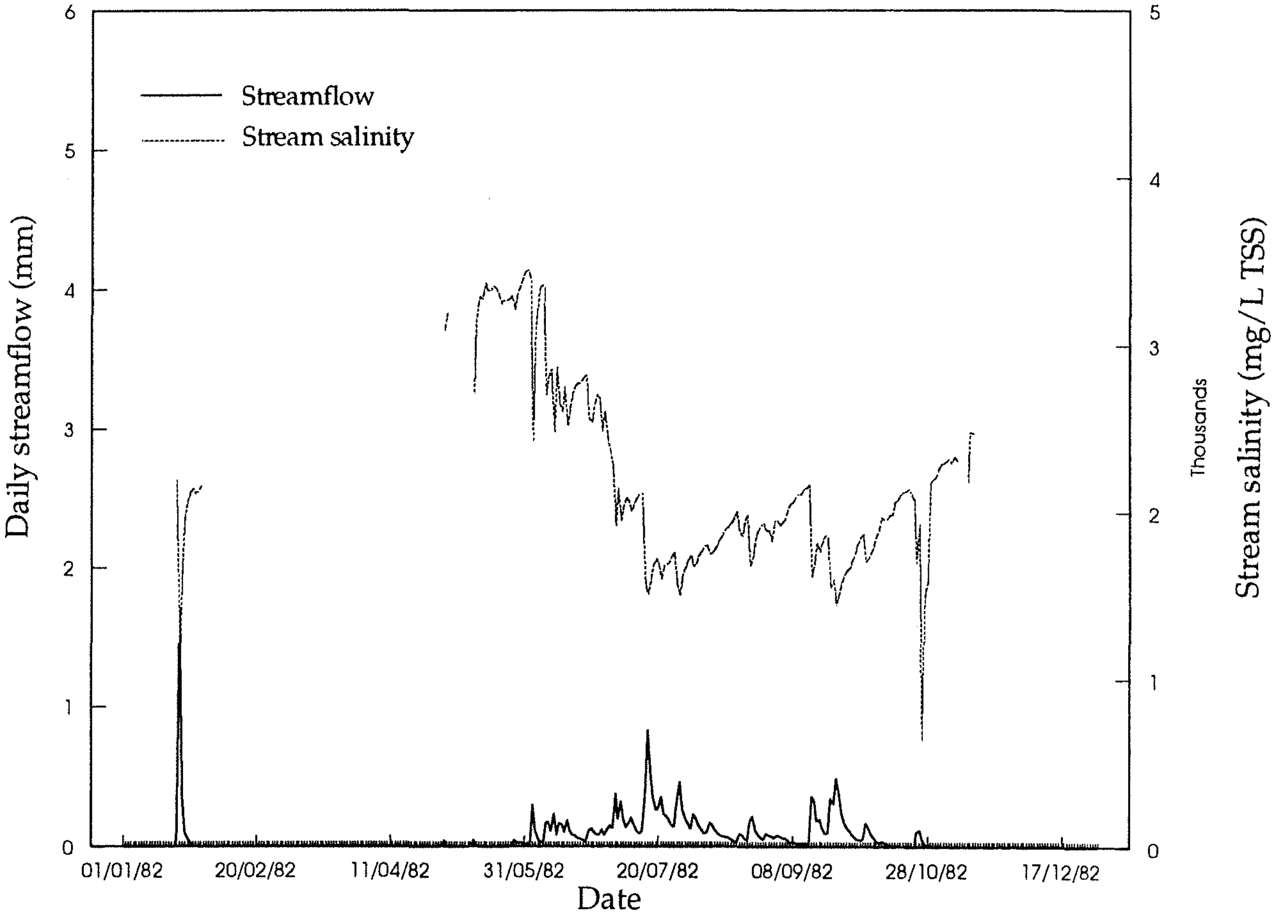


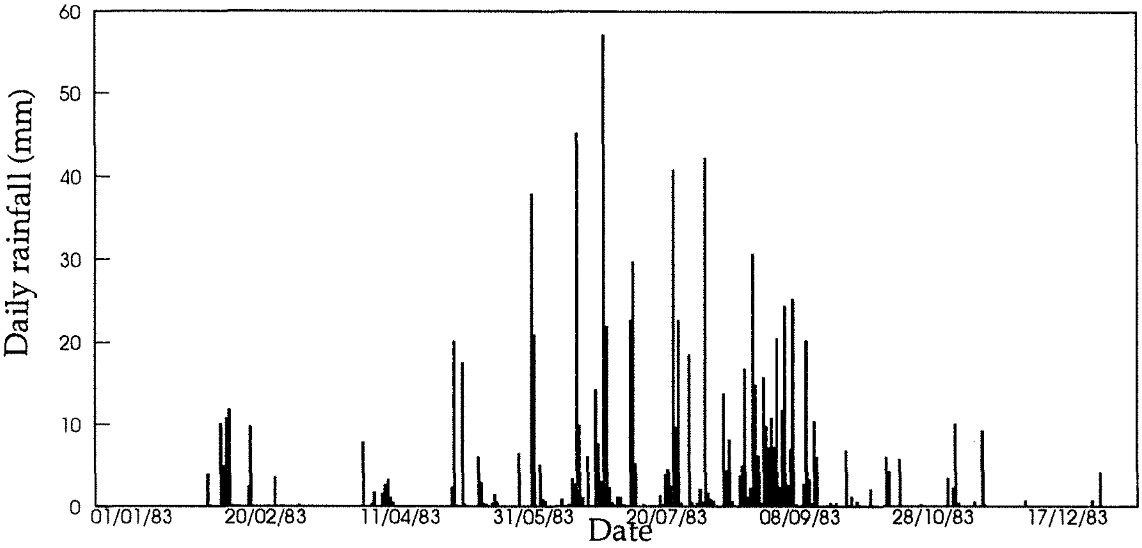
Daily rainfall (mm)
50
40
30
20
10
0
01/01/81
20/02/81
11/04/81
31/05/81
20/07/81
08/09/81
28/10/81
17/12/81
Date

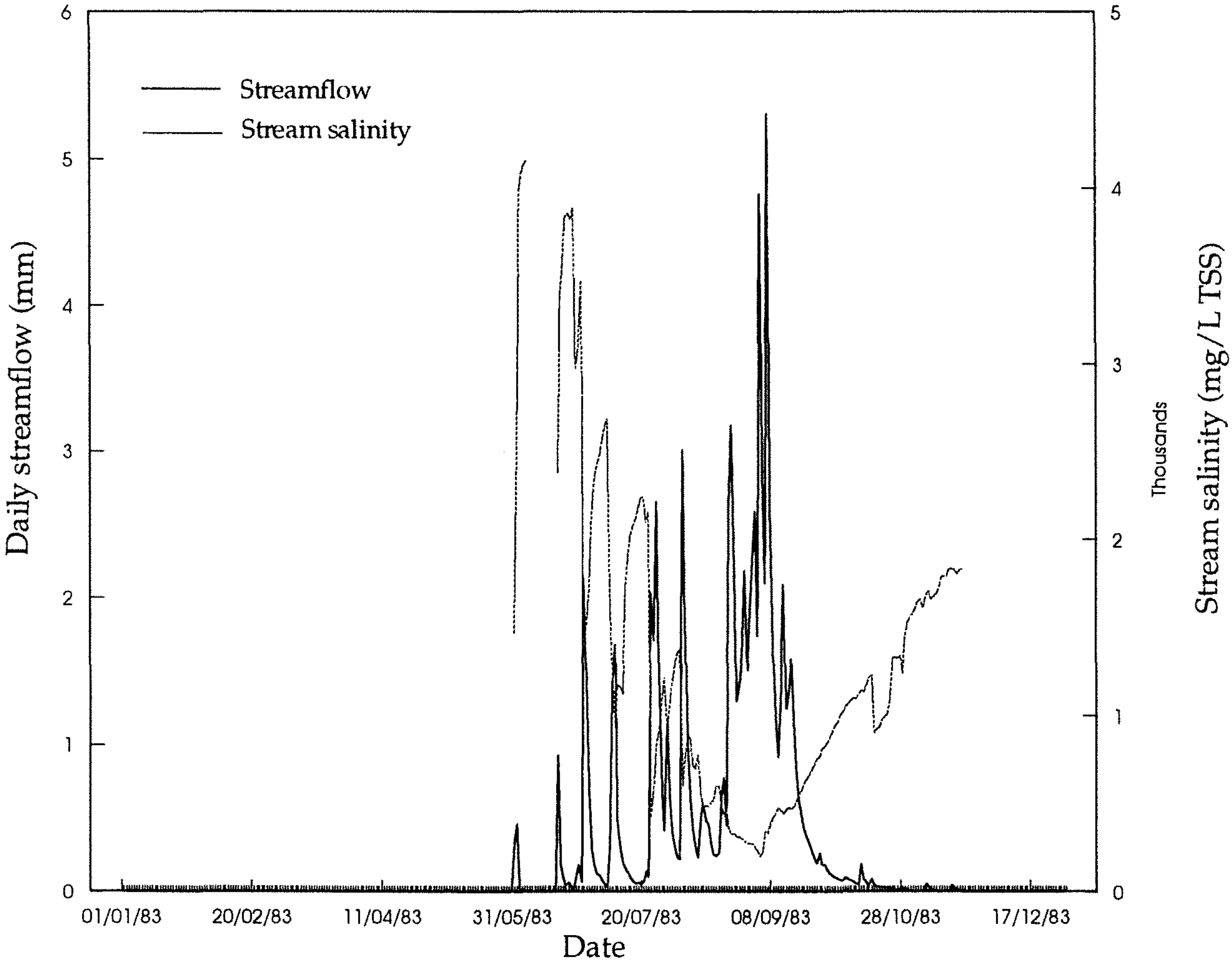


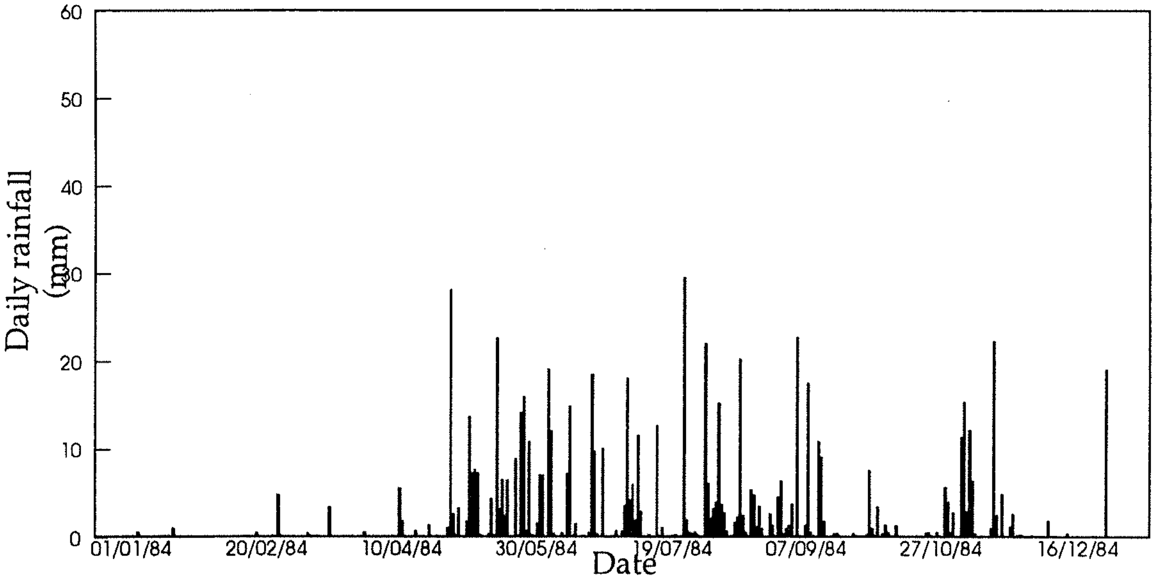
Streamflow
Stream salinity
Daily streamflow (mm)
6
5
4
3
2
1
0
Stream salinity (mg/L TSS)
Thousands
5
4
3
2
1
0
01/01/81
20/02/81
11/04/81
31/05/81
20/07/81
08/09/81
28/10/81
17/12/81
Date

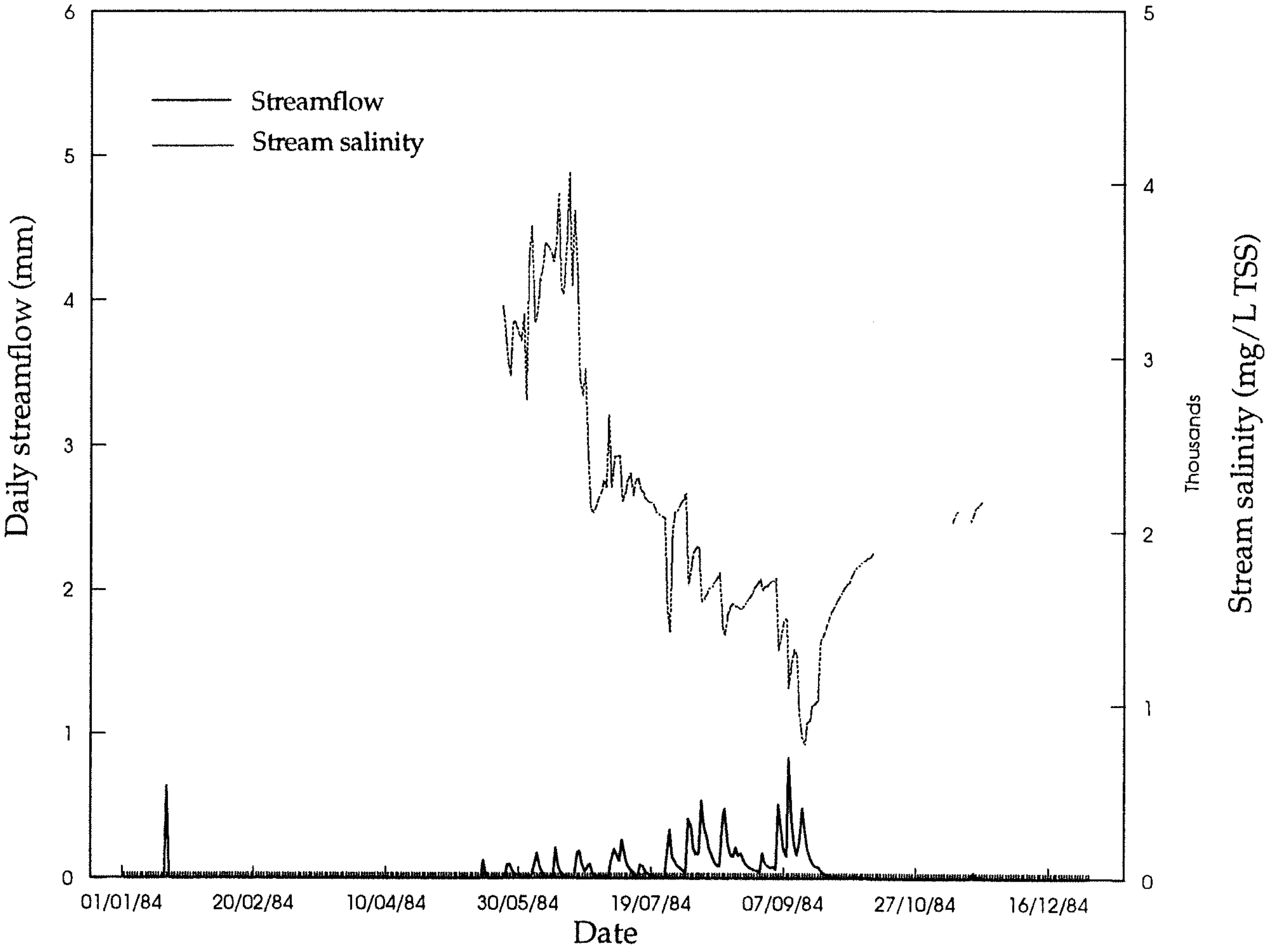

Daily rainfall (mm)
50
40
30
20
10
0
01/01/82
20/02/82
11/04/82
31/05/82
20/07/82
08/09/82
28/10/82
17/12/82
Date

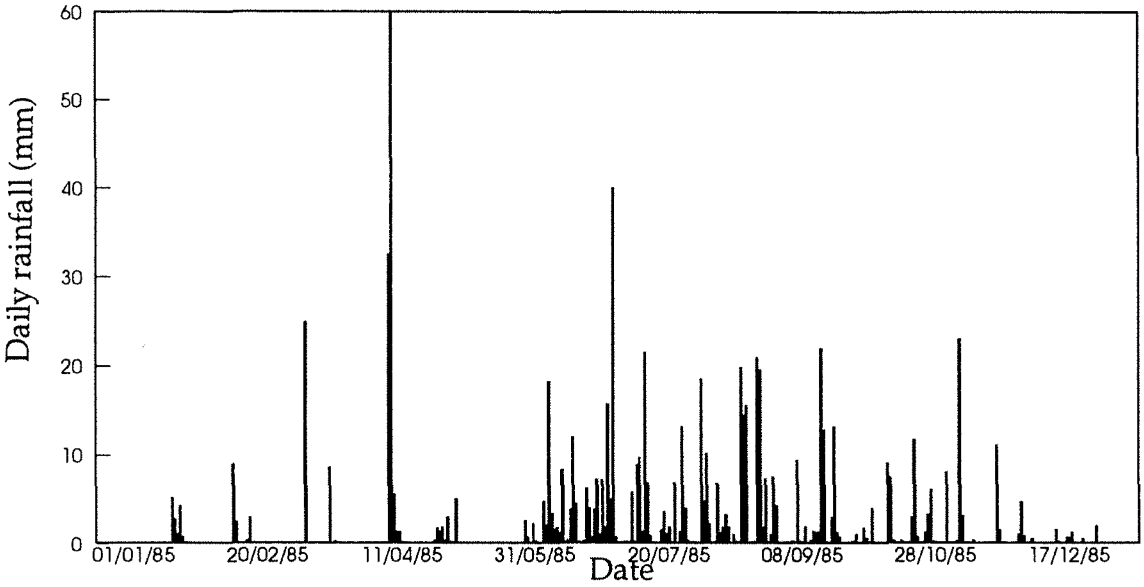

Streamflow
Stream salinity
Daily streamflow (mm)
6
5
4
3
2
1
0
Stream salinity (mg/L TSS)
Thousands
5
4
3
2
1
0
01/01/82
20/02/82
11/04/82
31/05/82
20/07/82
08/09/82
28/10/82
17/12/82
Date

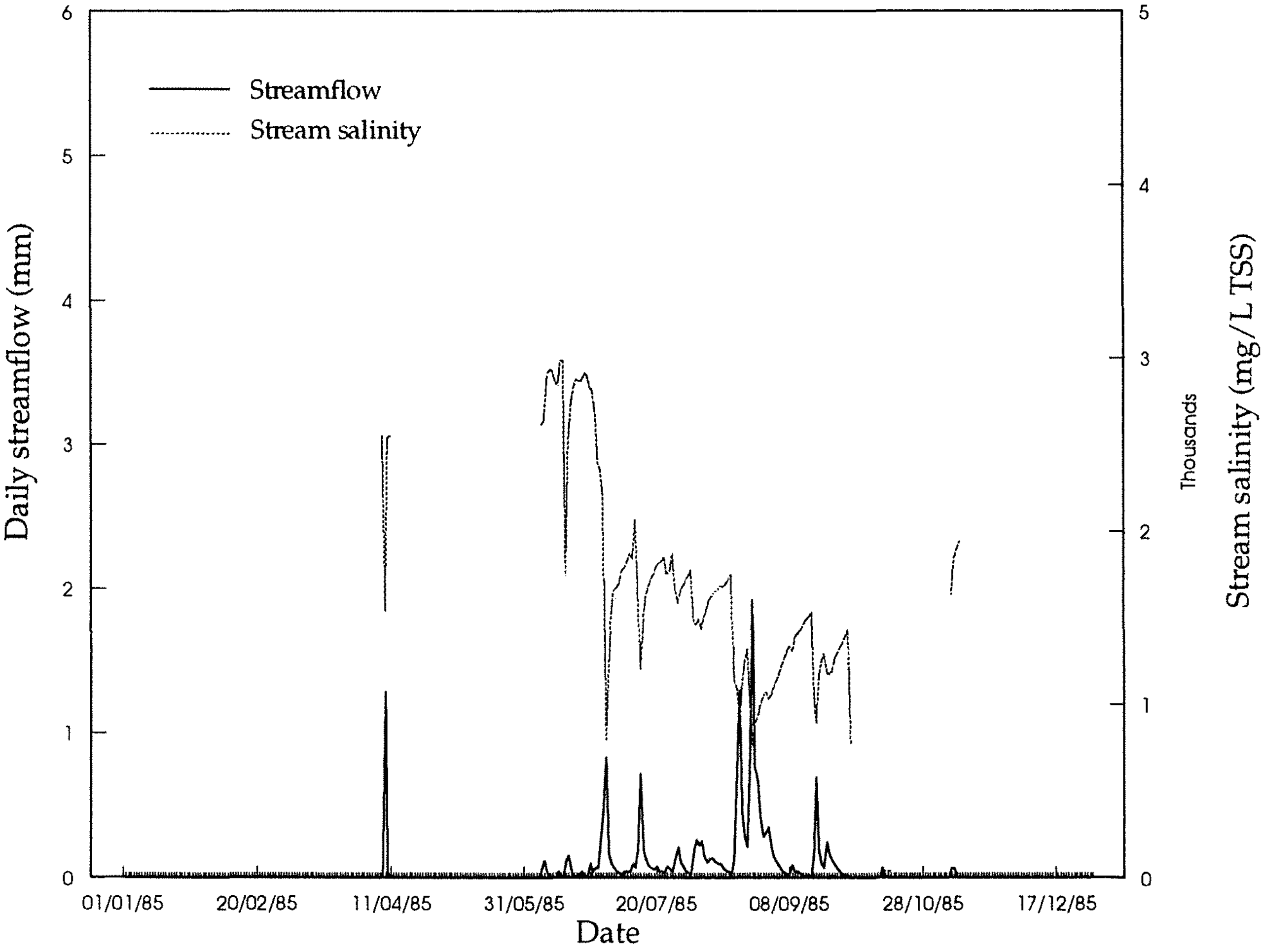

Daily rainfall (mm)
60
50
40
30
20
10
0
01/01/83
20/02/83
11/04/83
31/05/83
20/07/83
08/09/83
28/10/83
17/12/83
Date

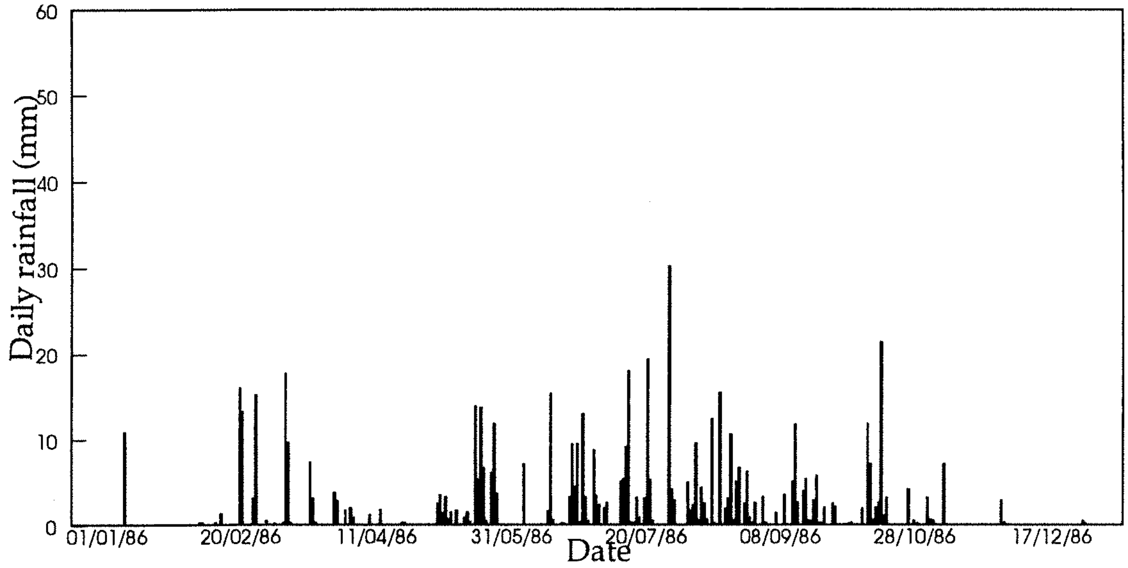

Streamflow
Stream salinity
Daily streamflow (mm)
6
5
4
3
2
1
0
Stream salinity (mg/L TSS)
Thousands
5
4
3
2
1
0
01/01/83
20/02/83
11/04/83
31/05/83
20/07/83
08/09/83
28/10/83
17/12/83
Date

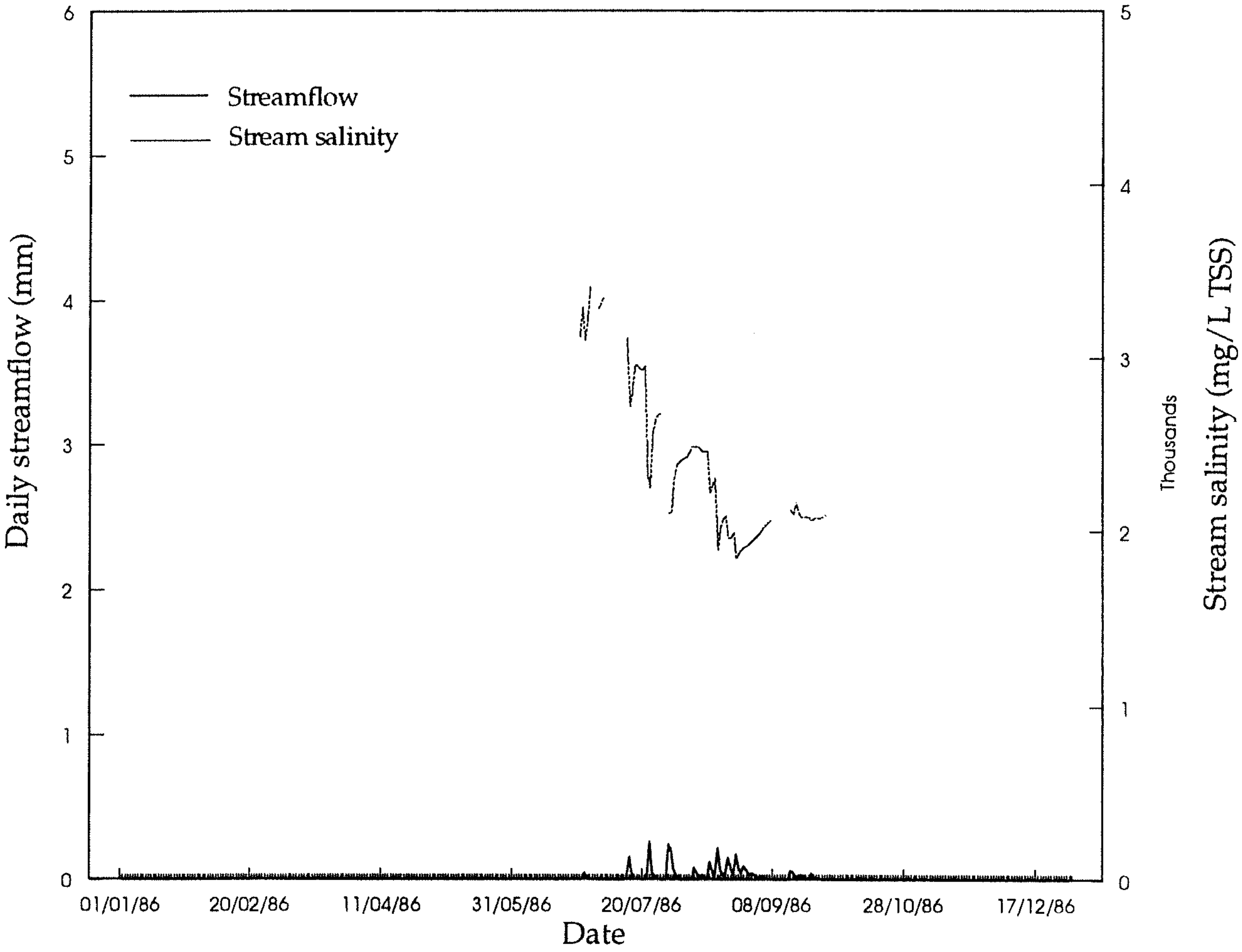

Daily rainfall (mm)
60
50
40
30
20
10
0
01/01/84
20/02/84
10/04/84
30/05/84
19/07/84
07/09/84
27/10/84
16/12/84
Date


Streamflow
Stream salinity
Daily streamflow (mm)
6
5
4
3
2
1
0
Stream salinity (mg/L TSS)
Thousands
5
4
3
2
1
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

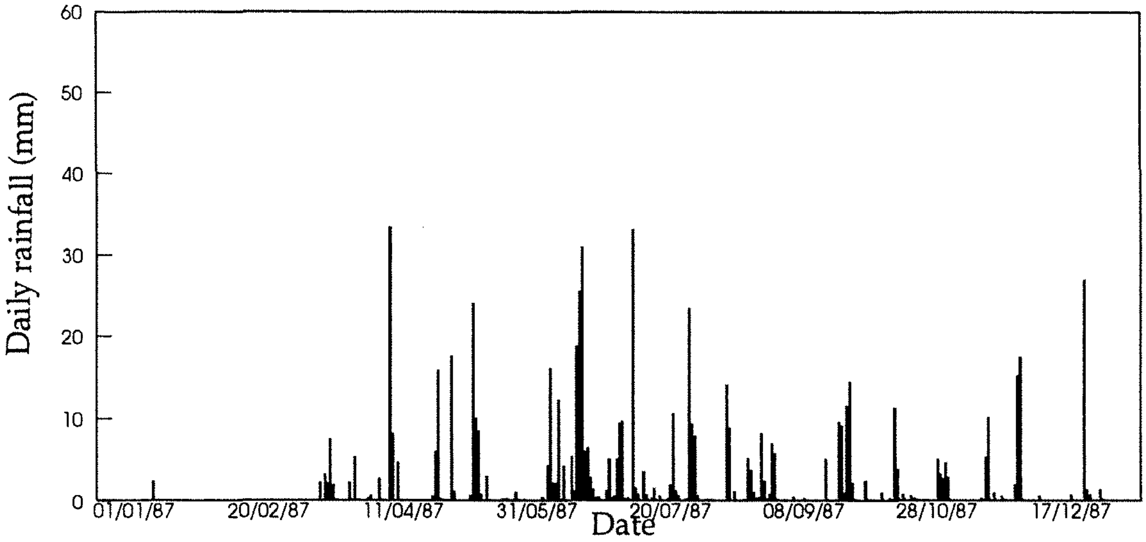

Daily rainfall (mm)
60
50
40
30
20
10
0
01/01/85
20/02/85
11/04/85
31/05/85
20/07/85
08/09/85
28/10/85
17/12/85
Date

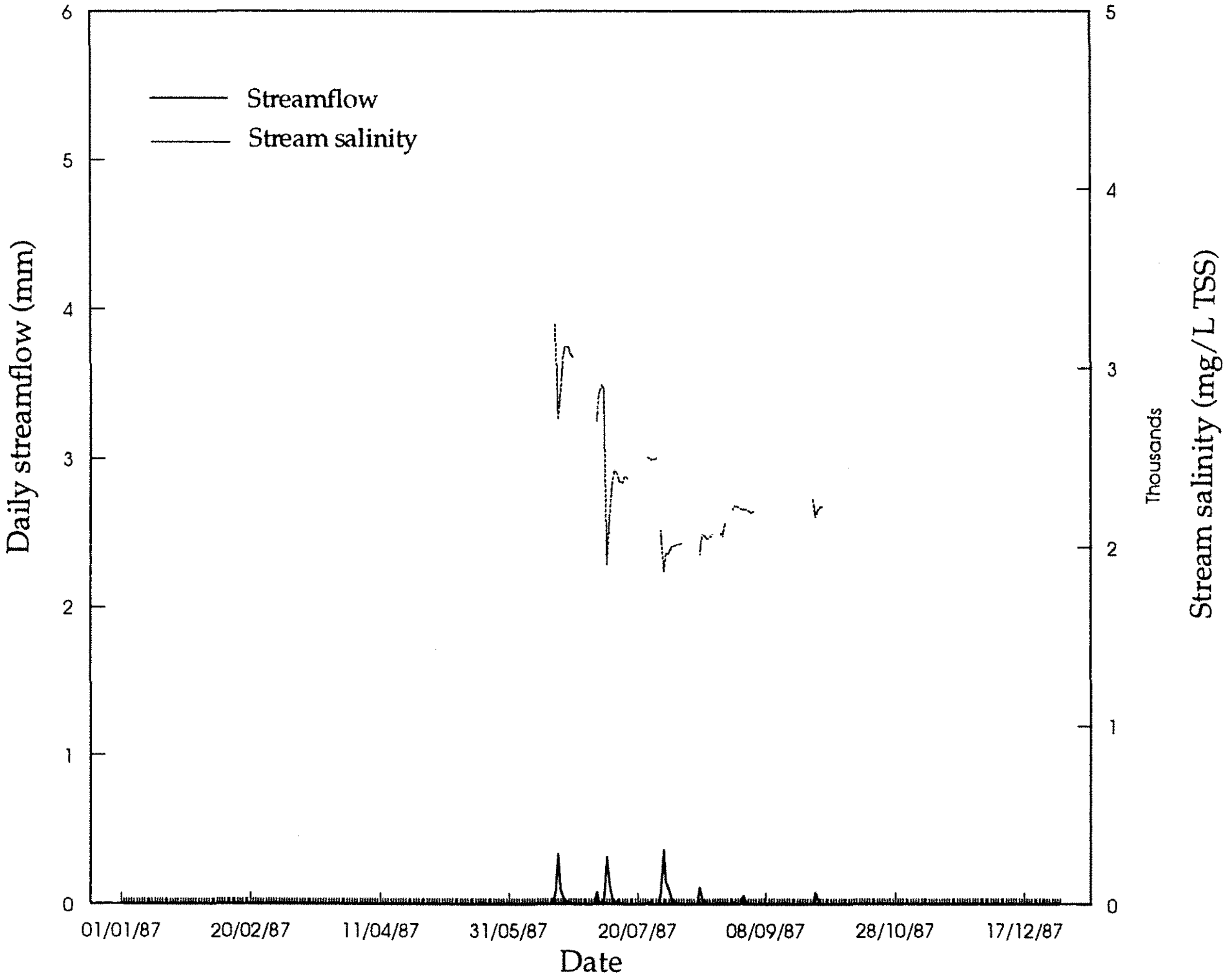

Streamflow
Stream salinity
Daily streamflow (mm)
6
5
4
3
2
1
0
Stream salinity (mg/L TSS)
Thousands
5
4
3
2
1
0
01/01/85
20/02/85
11/04/85
31/05/85
20/07/85
08/09/85
28/10/85
17/12/85
Date

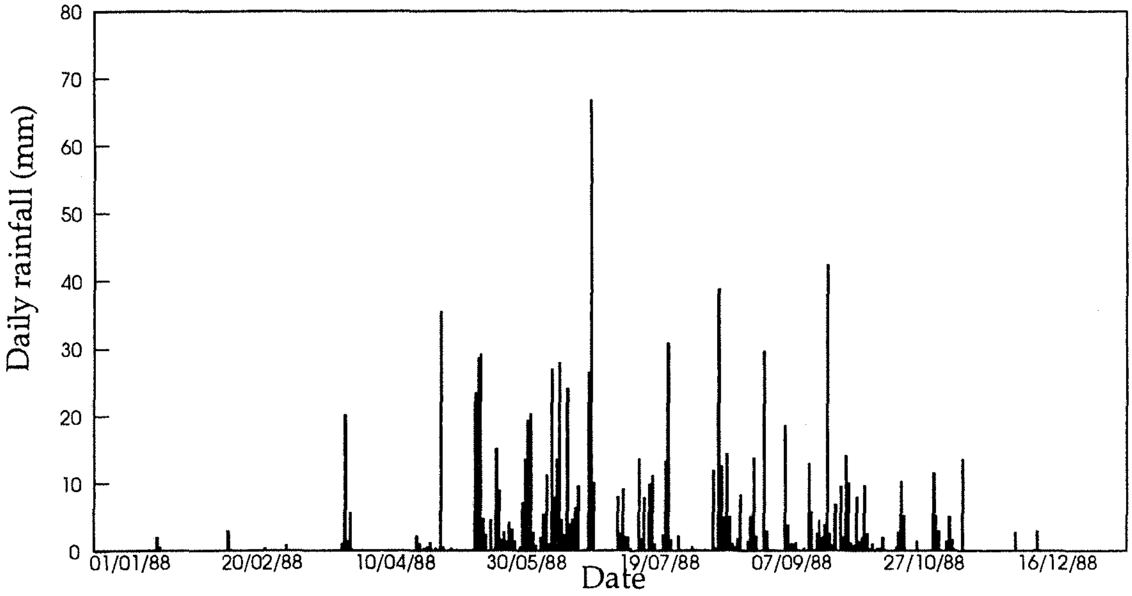

60
50
40
30
20
10
0
Daily rainfall (mm)
01/01/86
20/02/86
11/04/86
31/05/86
20/07/86
08/09/86
28/10/86
17/12/86
Date

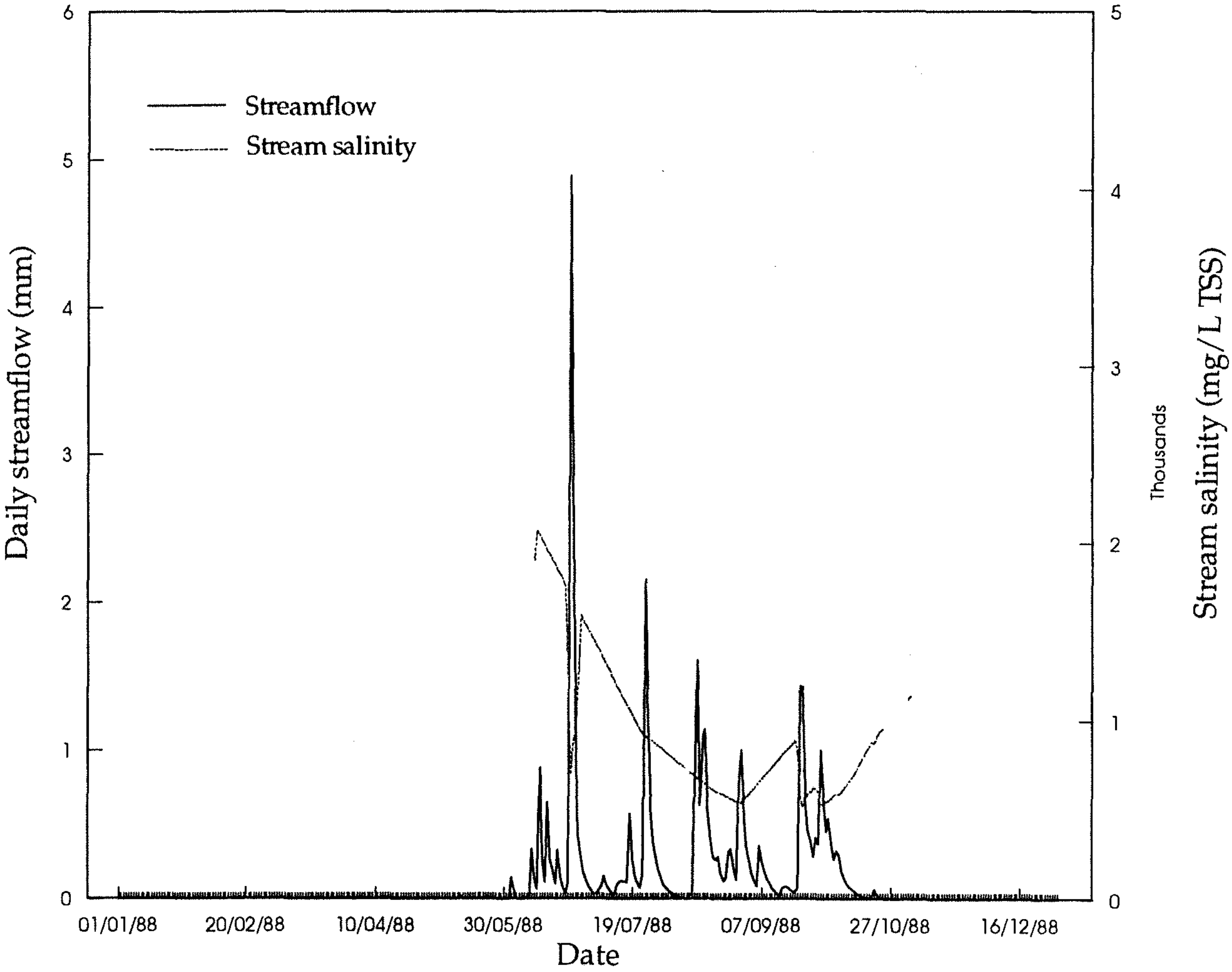

Streamflow
Stream salinity
6
5
4
3
2
1
0
Daily streamflow (mm)
5
4
3
2
1
0
Thousands
Stream salinity (mg/L TSS)
01/01/86
20/02/86
11/04/86
31/05/86
20/07/86
08/09/86
28/10/86
17/12/86
Date

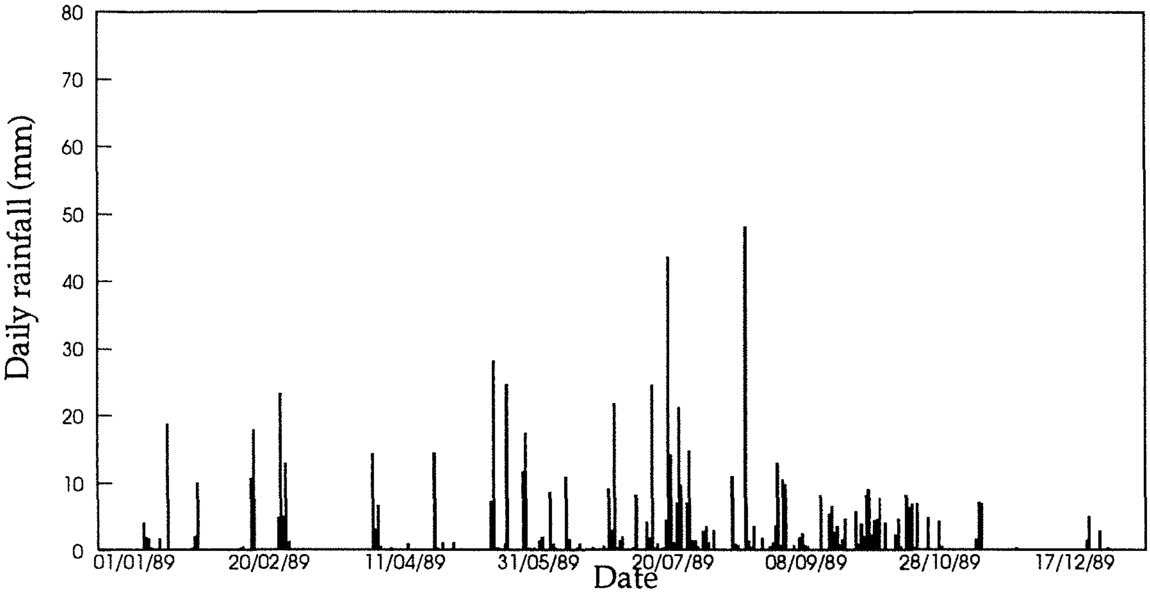
51

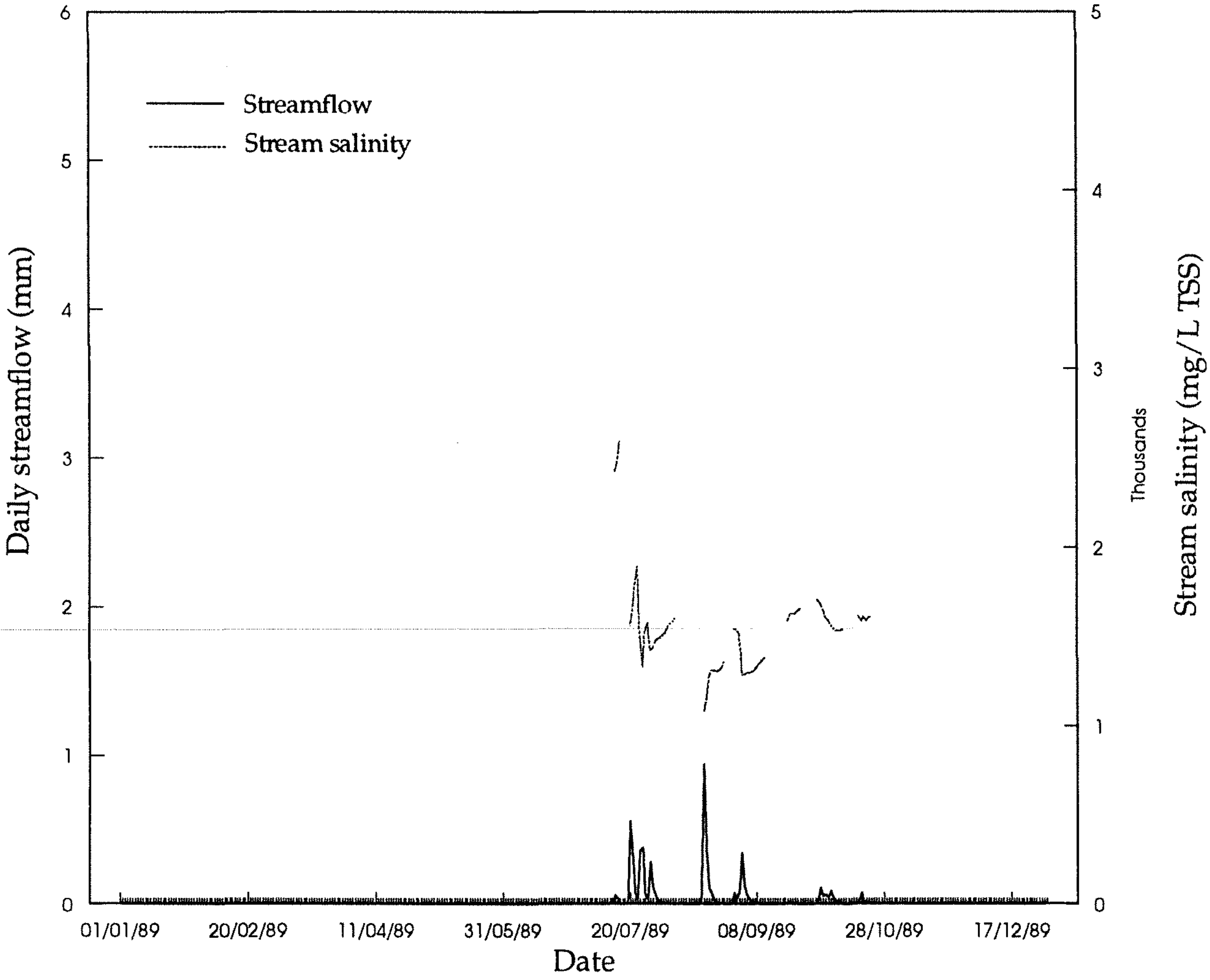

Daily rainfall (mm)
60
50
40
30
20
10
0
01/01/87
20/02/87
11/04/87
31/05/87
20/07/87
08/09/87
28/10/87
17/12/87
Date

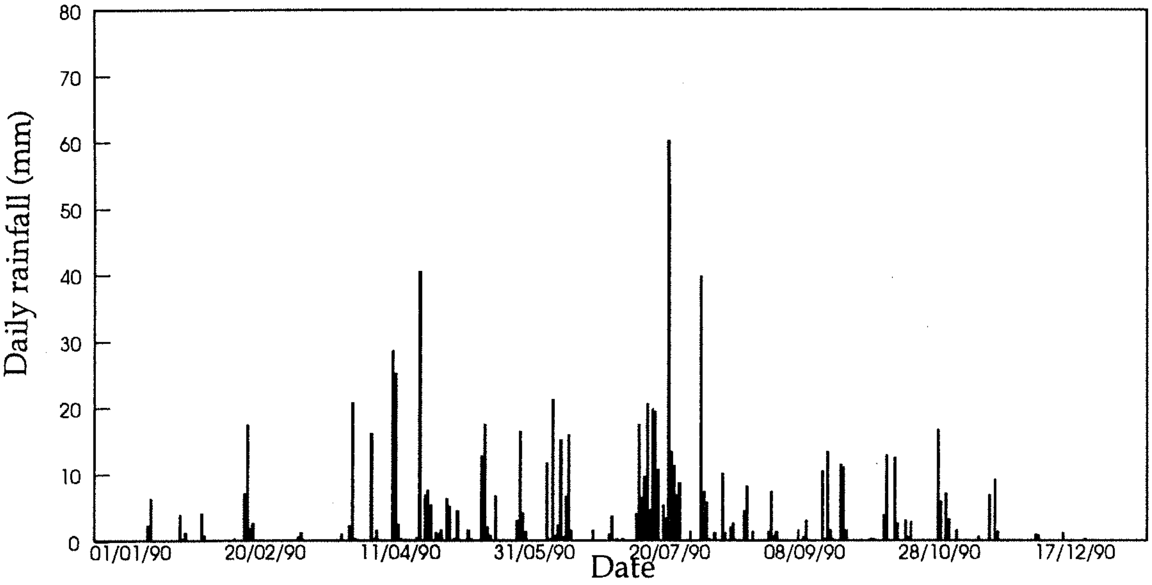

Streamflow
Stream salinity
Daily streamflow (mm)
6
5
4
3
2
1
0
Stream salinity (mg/L TSS)
Thousands
5
4
3
2
1
0
01/01/87
20/02/87
11/04/87
31/05/87
20/07/87
08/09/87
28/10/87
17/12/87
Date

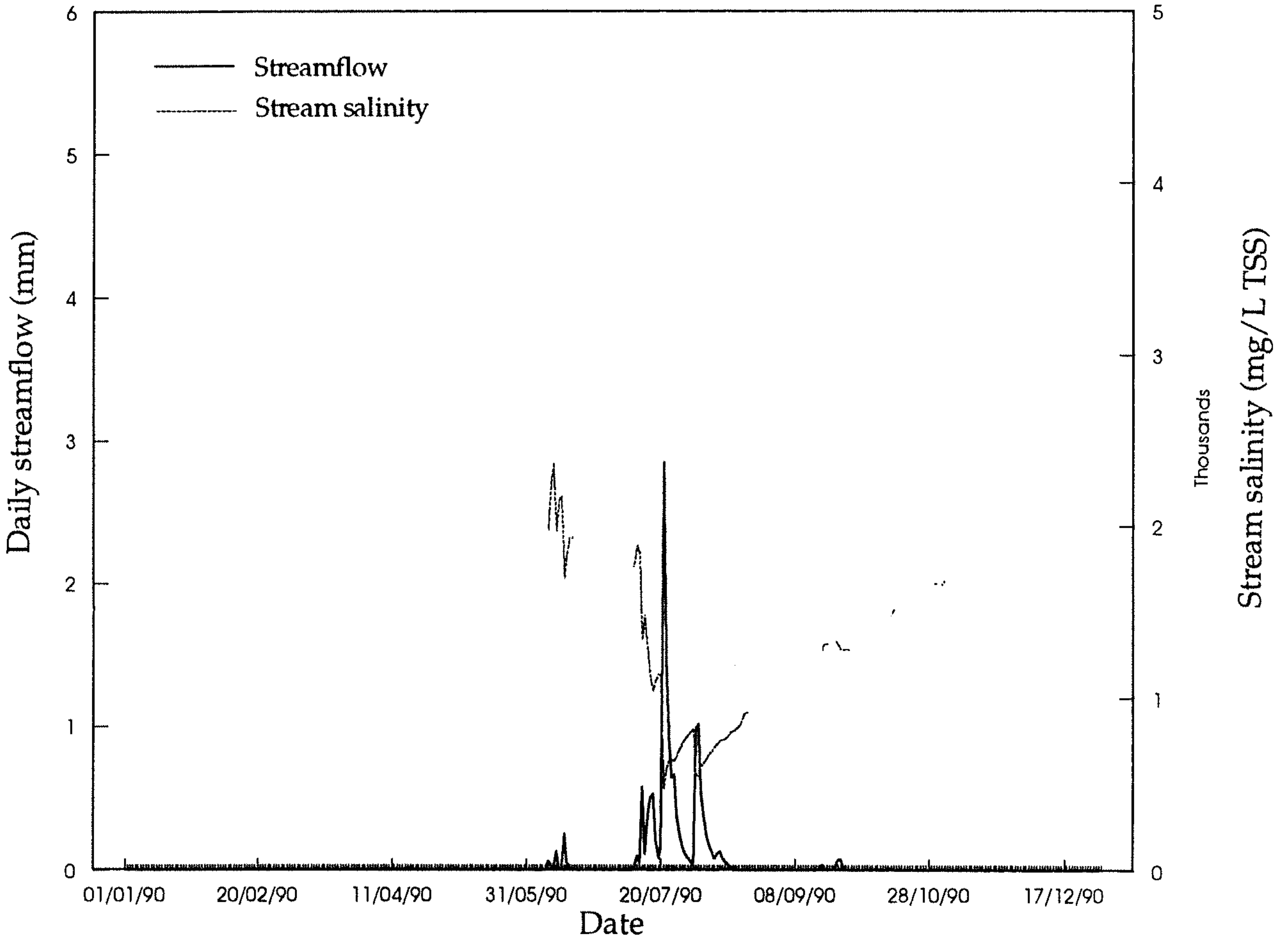

Daily rainfall (mm)
80
70
60
50
40
30
20
10
0
01/01/88
20/02/88
10/04/88
30/05/88
19/07/88
07/09/88
27/10/88
16/12/88
Date

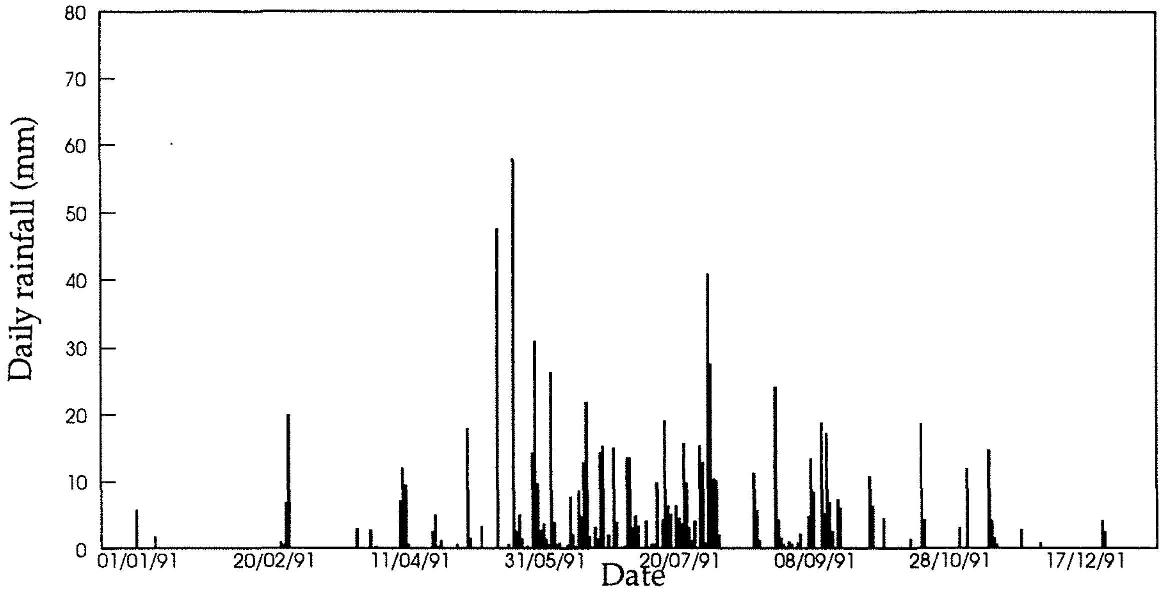

Streamflow
Stream salinity
Daily streamflow (mm)
6
5
4
3
2
1
0
Stream salinity (mg/L TSS)
Thousands
5
4
3
2
1
0
01/01/88
20/02/88
10/04/88
30/05/88
19/07/88
07/09/88
27/10/88
16/12/88
Date

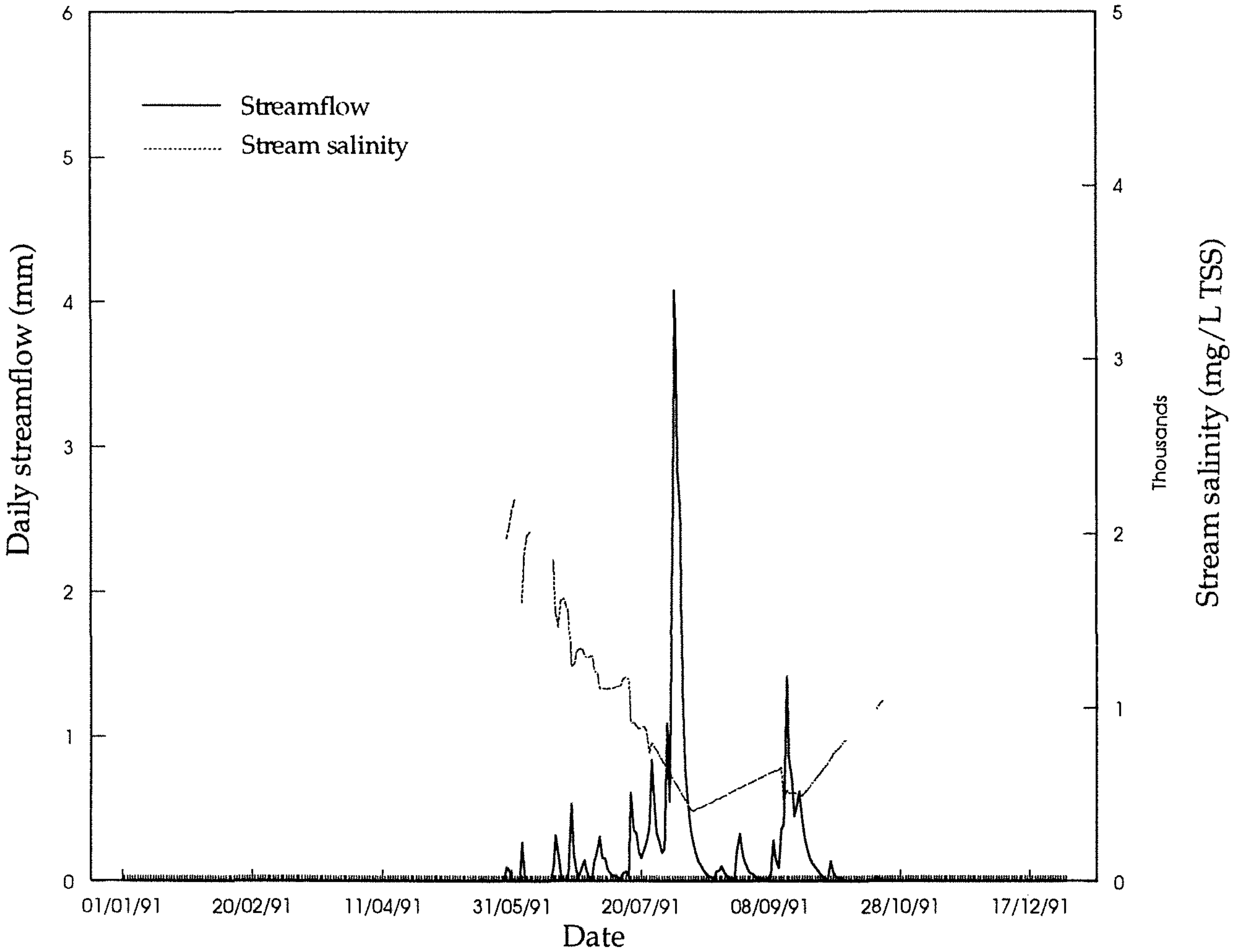

Daily rainfall (mm)
80
70
60
50
40
30
20
10
0
01/01/89
20/02/89
11/04/89
31/05/89
20/07/89
08/09/89
28/10/89
17/12/89
Date


Streamflow
Stream salinity
Daily streamflow (mm)
6
5
4
3
2
1
0
Stream salinity (mg/L TSS)
Thousands
5
4
3
2
1
0
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


Streamflow
Stream salinity
Daily streamflow (mm)
0
1
2
3
4
5
6
Stream salinity (mg/L TSS)
Thousands
0
1
2
3
4
5
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


Daily rainfall (mm)
80
70
60
50
40
30
20
10
0
01/01/91
20/02/91
11/04/91
31/05/91
20/07/91
08/09/91
28/10/91
17/12/91
Date


Streamflow
Stream salinity
Daily streamflow (mm)
6
5
4
3
2
1
0
Stream salinity (mg/L TSS)
Thousands
5
4
3
2
1
0
01/01/91
20/02/91
11/04/91
31/05/91
20/07/91
08/09/91
28/10/91
17/12/91
Date

APPENDIX C

Computer programme

```
C      THIS PROGRAM IS WRITTEN TO DETERMINE STREAM SALINITY,
C      STREAM SALT LOAD AND STREAM FLOW COMPONENTS
C      calander year
      DIMENSION FLOWMR(20,15),
     + FLOWMB(20,15), FLOWMT(20,15), SALTMT(20,15),
     + RANM(20,15),
     + RANM1(15), RAIN(9000), TSST(9000), SALTT(9000),FLOWT(9000),
     + FLOWB(9000), FLOWR(9000),IMNTH(9000),
     + IYEAR(9000),
     + FLOWDB(9000),
     + IDAY(9000) ,sflowmt(20),sflowmr(20),flowpk(20),
     + sflowmb(20),ssaltmt(20),tssct(20),
     + iyer(20),sranmt(20)
      data a/0.65/
      CHARACTER*80 DUMMY
      CHARACTER*60 FILNAM1
      CHARACTER*60 FILNAM2
 110  CONTINUE
      WRITE(*,210)
 210  FORMAT(1X,'*********************************************',/,
     +       1X,'WHAT IS THE NAME OF THE FLOW   INTPUT FILE  ',/,
     +       1X,'----------------------------------------',/)
      READ(*,*,ERR=110) FILNAM1
      OPEN(UNIT=11,FILE=FILNAM1, STATUS='OLD')
 510  CONTINUE
      WRITE(*,610)
 610  FORMAT(1X,'*********************************************',/,
     +       1X,'WHAT IS THE CATCHMENT AREA (HA)              ',/,
     +       1X,'----------------------------------------',/)
      READ(*,*,ERR=510) area
      area=area/100
 310  CONTINUE
      WRITE(*,410)
 410  FORMAT(1X,'*********************************************',/,
     +       1X,'WHAT IS THE NAME OF THE OUTPUT FILE  ',/,
     +       1X,'----------------------------------------',/)
      READ(*,*,ERR=310) FILNAM2
      OPEN(UNIT=21,FILE=FILNAM2, STATUS='NEW')
C
C
      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
       IYEAR(J)=1900+IYEAR(J)
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.0.0009) FLOWR(J)=0.0
       FLOWB(J)=FLOWT(J)-FLOWR(J)
C
111    FORMAT(3I5,12F10.2)
       GO TO 60
 70    CONTINUE
       FLOWR(J)=0.0
       FLOWB(J)=FLOWT(J)
60      CONTINUE
C
C
C      get monthly values
C      NK=0
       kky=1
c      iyear1=iyear(1)
       dumypk=flowt(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(flowt(i).gt.dumypk) dumypk=flowt(i)
C        SUM UP MONTHLY VALUES
```

```
C
       IF(IDIFF.EQ.0) THEN
       SUMSALTD=SUMSALTD+SALTT(I)
       SUMFLOWD=SUMFLOWD+FLOWT(I)
       SUMFLWDb= SUMFLWDb+ FLOWb(I)
       SUMFLWDR= SUMFLWDR+ FLOWR(I)
       SUMRAIND=SUMRAIND+RAIN(I)
       else
c       if(imnth1.le.3) imnt1=imnth1+12
        imnt1=imnth1
c      WRITE(21,71) nK, imnt1
       SALTMT(kky,IMNT1)=SUMSALTD
       FLOWMT(kky,IMNT1)=SUMFLOWD
       FLOWMR(kky,IMNT1) = SUMFLWDR
       FLOWMb(kky,IMNT1) = SUMFLWDb
       RANM(kky,IMNT1) =SUMRAIND
61      FORMAT(10X,2I10, 10F10.4//)
       SUMSALTD=SALTT(I)
       SUMFLOWD=FLOWT(I)
       SUMFLWDR=FLOWR(I)
       SUMFLWDb=FLOWb(I)
       SUMRAIND=RAIN(I)
C         SMFLTSY=SUMFLTSS
       SUMFLTSS=FLOWT(I)*TSST(I)/1000.0
       IMNT   = IMNTH1
       IYER(kky) = IYEAR1
       IMNTH1 = IMNTH(I)
       IYEAR1 = IYEAR(I)
      ENDIF
      IF(IDIFY.EQ.0) GO TO 100
      flowpk(kky)=dumypk/area
      dumypk=0.0
      nk=0
      kky=kky+1
100    continue
c     ky=ky-1
C      SUM UP ALL MONTHLY VALUES
C
      do 200 ky=1, kky
c     WRITE(21,71) kKy, imnt1
      NK=0
      SFLOWMT1=0.0
      SFLOWMR1=0.0
      SFLOWMb1=0.0
      SSALTMT1=0.0
      SRANMT1 =0.0
      SUMFLTSY1=0.0
```

```
      DO 30 II=1, 12
      flowmt(ky,ii)=flowmt(ky,ii)/area
      flowmr(ky,ii)=flowmr(ky,ii)/area
      saltmt(ky,ii)=saltmt(ky,ii)*10/area
      flowmb(ky,ii)=flowmb(ky,ii)/area
      SFLOWMT1 = SFLOWMT1+ FLOWMT(ky,II)
      SFLOWMR1 = SFLOWMR1+ FLOWMR(ky,II)
      SFLOWMb1 = SFLOWMb1+ FLOWMb(ky,II)
      SSALTMT1 = SSALTMT1+ SALTMT(ky,II)
      SRANMT1 = SRANMT1+ RANM(ky,II)
30     CONTINUE
c
c
c      DO 80 II=1, 3
c      SFLOWMT1 = SFLOWMT1+ FLOWMT(ky+1,II)/area
c      SFLOWMR1 = SFLOWMR1+ FLOWMR(ky+1,II)/area
c      SFLOWMb1 = SFLOWMb1+ FLOWMb(ky+1,II)/area
c      SSALTMT1 = SSALTMT1+ SALTMT(ky+1,II)*10/area
c      SRANMT1 = SRANMT1+ RANM(ky+1,II)
80      CONTINUE
      SFLOWMT(ky) = SFLOWMT1
      SFLOWMT(ky) = SFLOWMT1
      SFLOWMR(ky) = SFLOWMR1
      SFLOWMb(ky) = SFLOWMb1
      SSALTMT(ky) = SSALTMT1
      SRANMT(ky) = SRANMT1
      IYEAR1=IYEAR(I)
c     ky=ky+1
c     IMNTH1=IMNTH(I)
200    CONTINUE
71     FORMAT(1X, 2I10, 12F10.2)
       do 300 i=1,kky-1
       if(sflowmt(i).ne.0.0) then
        tssct(i)=ssaltmt(i)*100.0/sflowmt(i)
       else
        tssct(i)=0.0
       endif
       WRITE(21,71) i,IYER(i), sranmt(i), SFLOWMT(i),sflowmr(i)
     +  , sflowmb(i), ssaltmt(i),tssct(i),flowpk(i)
       smrn=smrn+sranmt(i)
       smft=smft+sflowmt(i)
       smfr=smfr+sflowmr(i)
       smfb=smfb+sflowmb(i)
       smst=smst+ssaltmt(i)
300     continue
       write(21,81)
81      format(//)
```

```
      write(21,91) smrn,smft,smfr,smfb,smst
91     format(21x, 12f10.2)
c
c      call write1(iyer,flowmt,kky)
c
c      call write1(iyer,flowmr,kky)
c
c      call write1(iyer,flowmb,kky)
c
c      call write1(iyer,saltmt,kky)
c
      STOP
      END
c
c     new subroutine
c
      subroutine write1(iyer,flowmr,kky)
c
      dimension iyer(20), flowmr(20,15), sum(20)
c
      write(21,121)
121    format(//)
      do 20 i=1,12
         sum1=0.0
         do 30 j=1, kky-1
         sum1=sum1+flowmr(j,i)
30     continue
      sum(i)=sum1
      sum1=0.0
20     continue
      do 10 i=1,kky-1
      write(21,111) iyer(i),( flowmr(i,j),j=1,12)
111    format(1x, i10, 12f8.2)
10     continue
      write(21,121) (sum(i),i=1,12)
131    format(11x,12f8.2)
      return
      end
```