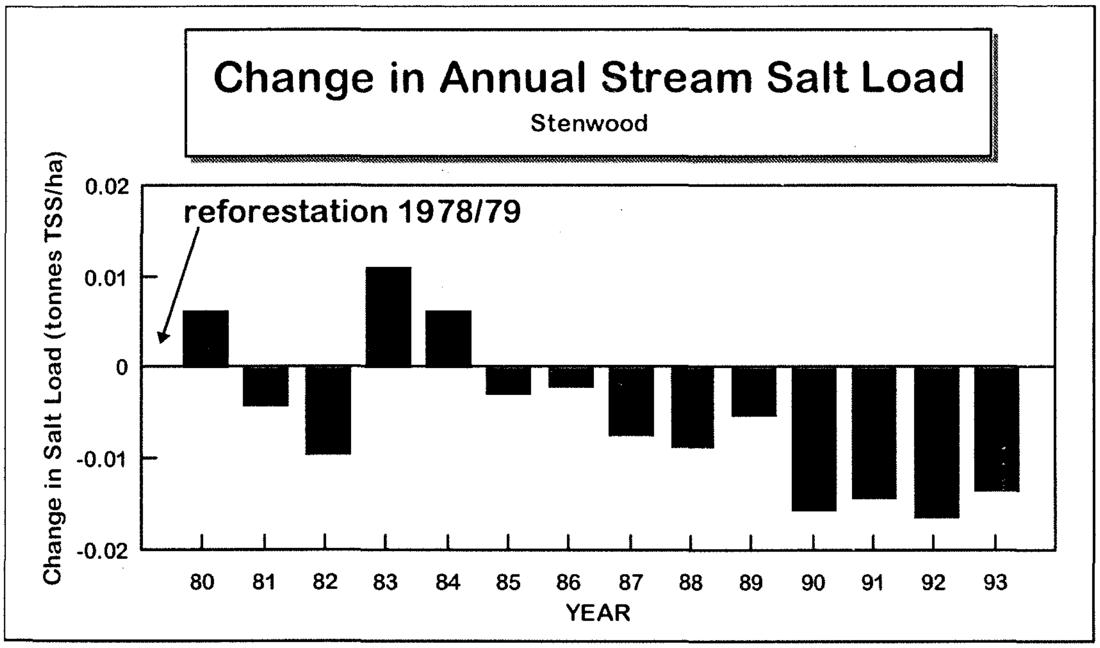
Water Authority
of Western Australia

WELLINGTON RESERVOIR CATCHMENT

STREAMFLOW AND SALINITY

REVIEW



Report WS 151
March, 1995

Water Authority
of Western Australia

Water Resources Directorate
Surface Water Branch

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STREAMFLOW AND SALINITY

REVIEW

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EXECUTIVE SUMMARY

INTRODUCTION

Wellington Reservoir is located on the Collie River some 200 km south-west of Perth. Formerly, the water supplied to the Great Southern Towns Water Supply Scheme (GSTWS) and the Collie River Irrigation District was drawn directly from the Wellington Reservoir. Wellington Reservoir has a storage capacity of 186×10^6 m^3 at full supply level.

The Wellington Reservoir has a catchment area of 2448 km^2 excluding the catchment area of Harris Reservoir which is about 382 km^2. Clearing of the catchment area to Mungalup Tower gauging station was 24% at 1976. **The inflow salinity to Wellington Reservoir for a median flow year has increased from 280 mgL^{-1} TSS in 1945 to approximately 1030 mgL^{-1} TSS in the 1991/92 water year.** This increase is attributed to agricultural development within the catchment. Concern over the increasing salinity led to the enactment of Catchment Clearing Control legislation in 1976 which has resulted in a stabilisation of the area of land cleared. Management programmes have also been developed to stabilise the catchment salinity.

This report presents the current state of the catchment in terms of its potential use as a water resource and proposes future investigation relevant to the management requirements.

CATCHMENT DESCRIPTION

The catchment area has a Mediterranean type climate with cool, wet winters and hot, dry summers. Annual rainfall varies from approximately 600 $mmyr^{-1}$ in the eastern part of the catchment increasing westward to about 1200 $mmyr^{-1}$ at the Wellington Reservoir. The Collie River originates in the low rainfall eastern part of the catchment and drains westward through increasingly incised valleys and higher rainfall areas. A basement of Archaean granitic and metamorphic rock underlies the lateritic soil profiles of the region with the exception of the Collie Coal Basin (area, 230 km^2). The dominant forest type throughout the Wellington Reservoir catchment is open forest of jarrah (*Eucalyptus marginata*) and marri (*E. calophylla*). Much of the cleared area is a result of agricultural development but a significant proportion can be attributed to the activities of coal mining and the generation and distribution of electrical power.

This study used streamflow data from eleven selected gauged catchments (Table 1). Much of the agricultural clearing is in the eastern parts of the catchment. The extent of clearing combined with the low rainfall of the eastern sub-catchments results in them having high salinity risk.

Table 1 - Wellington Reservoir catchment clearing (source: 1991 Landsat images)

Sub-catchment	Gauging station	Pasture (km^2)	Total (km^2)	Forest (km^2)	Pasture (%)
Coolangatta Farm	s612001	186.75	1299.85	1113.10	14.4
Mungalup Tower	s612002	-	2550	-	24 (1976)
Lemon	s612009	1.2	3.46	2.26	34.6
Wights	s612010	0.94	0.94	0.00	100.0
Palmer- Bingham River	s612014	10.92	366.55	355.63	3.0
Maxon Farm - Batalling Creek	s612016	4.18	16.4	12.22	25.5
James Crossing - Collie R. (East)	s612230	53.35	184.2	126.68	31.2
Stenwood - Bingham River	s612021	1.12	55.4	54.28	2.0
Maringee	s612026	3.78	12.75	9.22	29.1
James Well	s612025	44.83	173	128.17	25.9
South Branch	s612034	106.56	612.5	505.94	17.4

A partial reforestation scheme was commenced in 1979/80 to reduce the inflow salinity to Wellington Reservoir in the long term. The area reforested by the Water Authority of W. A. was 6743 ha at 1994. Much of the reforestation is in the 600-700 $mmyr^{-1}$ rainfall zone of the catchment.

RESULTS AND DISCUSSION

Rainfall during the period 1975-90 was about 15% lower than the long term average. Under long term rainfall conditions, the groundwater rise under pasture would have been greater. Streamflow and stream salt load are also likely to have been greater had long term rainfall conditions prevailed. While the magnitude of changes is expected to have been greater under higher rainfall the direction of trends would still be the same.

Remnant Vegetation

In administering the Catchment Clearing Control legislation (1976) it was accepted that there would be limited use of areas of remnant vegetation left on farmland (remnants) for stock shelter and grazing. However, Pettit and Froend (1994) report that the majority of remnants in the Wellington Reservoir catchment are in poor condition. Their study showed that the effect of grazing resulted in a shift from a community dominated by native perennial species to one dominated by exotic annual species. In the long term the lack of recruitment of overstorey species will result in an insidious form of clearing as old trees die and are not replaced. The potential loss of these areas would negate the clearing ban and reduce the effectiveness of the reforestation programme. Therefore, management and protection of remnant vegetation is an important part of controlling the inflow salinity to Wellington Reservoir.

Groundwater Levels and Salinity

The behaviour of groundwater level and salinity was investigated at three partially reforested sub-catchments. **The most successful reforestation strategy was the extensive dense plantings at Stene's arboretum (70% of cleared area reforested) which substantially lowered the groundwater table across the valley floor. Groundwater levels were lowered by 7.3m (1979-93) and, relative to pasture, the decline was 8.0m. Thus, this planting strategy resulted in elimination of saline groundwater**

discharge to the stream. Bore transects from Stene's valley and agroforestry sites were also investigated and comparing the results of the three Stene's sites, reveals that **the extent to which the groundwater table was lowered is directly proportional to the percentage of cleared area reforested.** Groundwater levels at the Maringee and Batalling bore transects have declined in the reforested areas while the pastured (control) bores had rising groundwater levels.

Groundwater salinity under reforestation showed a small decline or no significant change. At the pastured control sites the reduction to groundwater salinity was much greater. For example, at Stene's arboretum groundwater salinity reduced 10% under reforestation (1980-89) and under pasture the reduction was 40%. As both groundwater salinity and groundwater levels have declined beneath reforestation this will result in reduced volume and salinity of saline groundwater discharge to the stream.

Streamflow and Salinity

Stream salinity in the eastern, low rainfall catchments remains very high (Table 2). Most of the catchments show trends of increasing stream yield, stream salinity and salt load (Table 2). The exceptions to this observation are catchments which are partially reforested. The effect of the reforestation has been to reduce groundwater levels with a small reduction to groundwater salinity. This would in turn result in reduction of both stream yield and saline groundwater discharge to the stream. As the reforestation programme commenced in 1979/80, and planting at Maringee was not till 1985, changes are only just beginning to become apparent. These changes to streamflow are manifest in there being no significant trend of increasing stream yield, salinity and salt load at the partially reforested catchments. This contrasts with the catchments with little or no reforestation which still possess increasing trends of stream yield, salinity and salt load.

Stenwood catchment is so far the only catchment to exhibit a significant decreasing trend of stream salinity and salt load. This is probably owing to the early date of reforestation and the extent of the reforestation. At 1976, Stenwood was less than 10% pasture and after reforestation only 2% remained as pasture at 1991.

Table 2 - Streamflow and salinity characteristics of Wellington Reservoir catchment (1982-91)

Sub-catchment	Flow (mm)	Load (tonnes TSS/ha)	Salinity (mg/L TSS)	Rainfall (mm)	Trend over period of record		
					Stream Yield	Salinity	TSS Load
Coolangatta Farm	36	0.57	2040	685	I	I	I
Mungalup Tower	50	0.44	1080	732	N+I	I	I
Lemon	47	0.27	400	717	I	I	I
Wights	422	2.14	530	974	I	I	I
Palmer- Bingham River	17	0.05	370	729	N+I	N	N
Maxon Farm - Batalling Creek	42	1.73	5370	624	N+D	N+I	N
Stenwood - Bingham River	11	0.04	600	668	N+D	D	D
James Well	38	0.77	2840	615	I	I	I
Maringee	44	1.66	6300	576	N+D	N+I	N+I
South Branch	49	0.39	960	695	I	I	I
James Crossing - Collie River (East)	51	2.30	5610	630	I	I	I

Significance level of trends tested by t-test with 95% confidence.

I	Increasing
D	Decreasing
N	No significant trend (often due to short period of record)
N+I	Increasing trend apparent but magnitude of changes not significant

The magnitude of stream salinity response to clearing is affected by the extent and location (*i.e.* rainfall of area) of clearing. **Together, James Well and James Crossing catchments produce only 11.6% of streamflow to Mungalup Tower but contribute 47% of stream salt load.** These catchments have low rainfall (<650mmyr^{-1}) and at 1976 were more than 50% cleared. As these two catchments are the main cause of the salinity problem they ought to be the focus of efforts to manage and reduce Collie River salinity.

Loh and Anson (1988) expected that inflow salinities to Wellington Reservoir would not reduce until the mid to late 1990s. **Reforestation is just beginning to have an effect on the stream yield, salinity and salt load at some of the partially reforested catchments on the eastern boundary of the Wellington Reservoir catchment.** These eastern catchments contribute much salt load but relatively little streamflow. As the stream salt load output from these partially reforested catchments reduces, the reduction will soon be sufficient to counteract the increasing salinity from the other but lower salinity hazard catchments. Thus, inflow salinity to Wellington Reservoir will cease its increasing trend and eventually decrease as stream salt load from the eastern catchments reduces further. The rate of inflow salinity improvement is dependent on the timing and extent of reforestation in the eastern catchments.

Base flow salinity

The baseflow salinity was determined at South Branch (1952-93), James Crossing (1966-93) and James Well (1982-92). The overall trend was for baseflow salinity to increase with time at these gauging stations. As the trend of increasing baseflow salinity at South Branch preceded the lower than average rainfall of 1975-90, this trend is deemed not to be a response to long term climate trends but rather a response to agricultural clearing.

At James Crossing baseflow salinity increased at an average rate of 300 mgL^{-1} TSS yr^{-1} between 1970 and 1993. This increasing trend may have ceased with the high baseflow salinity year of 1987 being of similar magnitude to the maximum groundwater salinity recorded at Maxon Farm (Batalling Creek). Stream salinity and salt load at both Maxon Farm and James Well do not have any significant trend. Therefore, it can be inferred that the volume of saline groundwater discharge is not increasing significantly with time. The five year backwards moving average of baseflow salinity at James Crossing appears to have reached a plateau. It is expected that the reforestation in the catchment will further reduce groundwater levels, reducing the volume and salinity of saline groundwater discharge to the stream.

CONCLUSIONS

- Rainfall in the Wellington Reservoir catchment was about 15% lower than the long term average during 1975-90.

- The catchment area to Mungalup Tower was 24% cleared in 1976 when clearing bans were imposed. The area cleared in 1960 was 12% and in the 1940s was 8%.

- A partial reforestation scheme commenced in 1979/80. Reforestation by the Water Authority amounted to 6743 hectares at 1994. Much of the reforestation is in the 600-700 $mmyr^{-1}$ rainfall zone of the catchment.

- The groundwater transects investigated are in the low rainfall, eastern part of the Wellington Reservoir catchment. Groundwater levels in pastured areas increased. Groundwater levels in the midst of reforestation had the greatest decline. As groundwater levels under reforestation declined relative to the pasture (control) sites, the changes are attributed to the reforestation rather than climatic effects.

- **The extensive high density reforestation at Stene's arboretum (70% of cleared area) resulted in a groundwater level reduction of 7.3m (1979-93), with a decline relative to pasture of 8.0m.** Compared to the other planting strategies, Stene's arboretum had the greatest reduction of groundwater level.

- **Stream yield was found to be increasing at all the selected sub-catchments apart from the partially reforested catchments - Maxon Farm, Stenwood and Maringee.** These three reforested areas had a decreasing trend in stream yield though the magnitude of the decreases was not significant.

- Coolangatta Farm, to which the eastern catchments drain, contributes 38% of the flow to Mungalup Tower but 67% of the salt load (ratio 1.8). Thus, the eastern catchments produce most of the salt load.

- The James Crossing catchment on average contributes 6.4% of the flow but about 33% of the salt load which is a ratio of 5.1.

- The James Well catchment on average contributes 5.2% of flow but 13.7% of salt load which is a ratio of 2.6.

- **Most of the gauged catchments recorded trends of increasing flow weighted annual stream salinity and salt load. Stenwood catchment had a significant decreasing trend (t-test, 95%) in stream salt load and salinity.**

- The inflow salinity to Wellington Reservoir for a median flow year has increased from 280 mgL^{-1} TSS in 1945 to approximately 1030 mgL^{-1} TSS in the 1991/92 water year. It is expected that the inflow salinity will decline and ultimately reach 950 mgL^{-1} TSS for a median flow year. Without reforestation it is estimated that inflow salinity would eventually reach 1150 mgL^{-1} TSS while without clearing controls it would have reached 1700 mgL^{-1} TSS (Loh and Anson, 1988).

- The baseflow salinity at South Branch (1952-93), James Crossing (1966-93) and James Well (1982-92) had an overall increasing trend with time.

RECOMMENDATIONS

- **James Well and James Crossing are identified as producing 47% of the stream salt load to Mungalup Tower but only 11.6% of the streamflow. These catchments are therefore of significance to managing the inflow salinity of Wellington Reservoir.** Maxon Farm is a sub-catchment of James Crossing and Maringee Farm a sub-catchment of James Well. Monitoring of the groundwater levels and salinity at these sites should be continued to further the understanding of the effect of reforestation on reducing groundwater levels and reducing saline groundwater discharge.

- **The hydrological monitoring programme should be continued at the present level. Continuous stream salinity data should be monitored at all gauging stations.**

- At Maringee Farm, data collection ought be continued and then analysed after a further 5 or more years. The aim of this future review would be to assess any changes or trends occurring in streamflow, stream salinity, groundwater levels and groundwater salinity as a consequence of the reforestation.

- An Integrated Catchment Management plan should be developed including consideration of remnant vegetation, reforestation, forest regeneration and high water use agricultural systems.

- A strategy for the protection and management of remnant vegetation should be implemented. This strategy would serve to protect existing remnants and allow degraded remnants to regenerate.

- It is suggested that the Wellington Reservoir catchment be computer modelled to determine what level of improvement in stream salinities may be possible from reforestation and other catchment management activities. This would have application in the development of catchment management plans.

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1 INTRODUCTION

1.1 Background

Agricultural clearing in south-west Western Australia has led to substantial increases in salinity of most rivers whose headwaters are in areas of less than 900 $mmyr^{-1}$ rainfall (Schofield *et al.*, 1989). Of the divertible water resources in south-west Western Australia at 1985, 48% were classified as fresh, 16% were marginal, 30% brackish and 6% saline (Schofield *et al.*, 1988). The marginal water resources will require active management of their catchments to minimise or reverse further deterioration (Select Committee, 1988).

Rising groundwater levels as a consequence of agricultural clearing have been shown to cause large increases in stream salinity in the Intermediate and Low Rainfall Zones (<1100 $mmyr^{-1}$) (Schofield *et al.*, 1988; Loh, 1988a). The magnitude of the stream salinity response to clearing is affected by the extent and location of agricultural clearing. The trend is for larger cleared areas to give greater increases in salinity. The rate of increase in salinity with area cleared is greater the lower the average rainfall (Collins and Fowlie, 1981; Schofield *et al.*, 1988).

Wellington Reservoir is located on the Collie River some 200 km south-west of Perth (Fig. 1). Formerly, the water supplied to the Great Southern Towns Water Supply Scheme (GSTWS) and the Collie River Irrigation District was drawn directly from the Wellington Reservoir. Wellington Reservoir has a storage capacity of $186x10^6$ m^3 at full supply level. In 1983/84 the total draw was $76x10^6$ m^3 of which 93% was supplied for irrigation and 7% for the GSTWS (Loh, 1988b).

The Wellington Reservoir has a catchment area of 2448 km^2 excluding the catchment area of Harris Reservoir which is about 382 km^2. Harris Reservoir catchment is virtually fully forested whereas about 30% of the Wellington Reservoir catchment area has been cleared. Much of this cleared area is a result of agricultural development but a significant portion can be attributed to the activities of coal mining and the generation and distribution of electrical power (Karafilis and Ruprecht, 1993).

Agricultural development within Wellington Reservoir catchment over the last 60-70 years has caused a deterioration in the inflow salinity (Hookey and Loh, 1985). In 1945, the salinity of the median annual inflow volume to the reservoir was only 280 mgL^{-1} TSS (TSS - Total Soluble Salts). Over the ensuing 45 years, however, this salinity has increased by about 700 mgL^{-1} TSS and in 1992 was considered to be approximately 980 mgL^{-1} TSS. Salinities of inflow in years of low flow are much higher. Consequently in the run of dry years in the late 1970's water drawn from storage for the GSTWS at times exceeded 1000 mgL^{-1} TSS (Hookey and Loh, 1985).

In terms of water resources, fresh water is defined as having salinity of less than 500 mgL^{-1} TSS whereas marginal water is 500-1000 mgL^{-1} TSS beyond which water is classified as brackish and saline if greater than 5000 mgL^{-1} TSS (Steering Committee, 1989). In reaction to the high salinities in the Wellington Reservoir, Harris Dam was constructed in 1989 to enable the salinity of supply to the GSTWS to be reduced to approximately 250 mgL^{-1} TSS. Harris Dam is smaller than Wellington Dam and is built on Harris River a tributary of Collie River (Fig. 1).

Catchment Clearing Control legislation for the Wellington Reservoir catchment was enacted in 1976 to protect the water resource from further deterioration. It was recognised that to achieve major improvements in supply salinities would require reduction of the inflow salinity. Active evaluations of remedial actions commenced in 1977 and considered diverting flow with up to 3 dams on saline tributaries and pumping the flow over the catchment divide in to the already saline Blackwood River. These saline storages were more expensive than the partial reforestation option and impacted significant agricultural land as well as posing significant environmental problems (Loh, 1988a). A partial reforestation scheme was commenced in 1979/80 to reduce the inflow salinity to Wellington Reservoir in the long term (Loh, 1988a). Much of the reforestation is in the 600-700 $mmyr^{-1}$ rainfall zone of the catchment. A significant proportion of the area in this rainfall zone has been cleared and much salt is stored in the landscape. About 50% of the salt load but less than 10% of the inflow to the Wellington Reservoir originates from this region (Bari, 1992a).

1.2 Study Objectives

Specific sub-catchments and bore transects have been chosen to illustrate the state of the catchment in different areas (*i.e.* rainfall zones) and at sites having different land uses. The streamflow, stream salinity and other related data are analysed particularly for their trends with time. The objectives of this analysis is to assess the effects of land use changes on streamflow, salinity and salt load and to quantify these changes.

2 CATCHMENT DESCRIPTION

2.1 Location

Wellington Reservoir is located on the Collie River in the south-west of Western Australia (Fig. 1). It is situated 35 km to the east of Bunbury and some 200 km south-west of Perth.

Wellington Dam Catchment

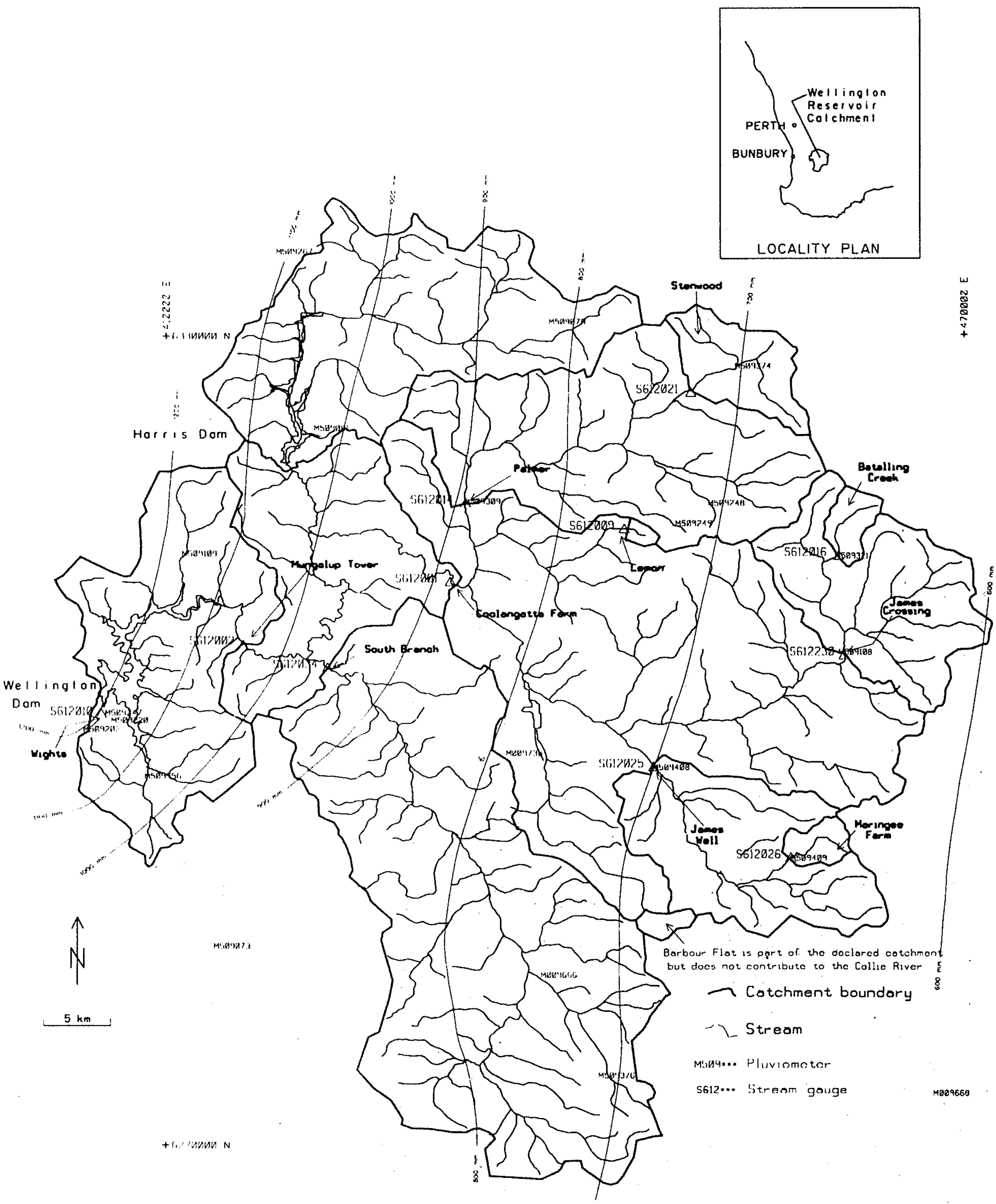

Figure 1 - Location and Instrumentation Set-up

2.2 Climate

Annual rainfall varies from approximately 600 $mmyr^{-1}$ in the eastern part of the catchment increasing westward to about 1200 $mmyr^{-1}$ at the Wellington Reservoir (Fig. 1). Climate is of the Mediterranean type with cool, wet winters and hot, dry summers. Evaporation averages 1500 $mmyr^{-1}$ at Mungalup Tower and ranges from 1650 to 1400 $mmyr^{-1}$ in the catchment area for this gauging station (Public Works Department, 1984).

2.3 Vegetation

Mungalup Tower is the last major gauging station on the Collie River before it enters the Wellington Reservoir (Fig. 1). As such it represents about 90% of the Wellington Reservoir catchment area. The catchment area to Mungalup Tower was 24% cleared in 1976 when clearing bans were imposed. The area cleared in 1960 was 12% and in the 1940s was 8%. In 1979 a partial reforestation programme was introduced with 6743 hectares being planted by the Water Authority of W. A. up to 1994 (G. Kikiros, *pers. comm.*). These plantings are in the eastern parts of the catchment. Clearing of individual sub-catchments at 1991 is detailed in Table 1. Figure 2 shows the distribution of clearing and reforestation in the Wellington catchment.

Since 1978, clearing licences have been issued for 89.7 km^2 of the Wellington Reservoir catchment while licences were refused for 139.7 km^2 of the area. The number of refusals of clearing licence applications has declined since 1978. Thus, demand for further clearing of the land has reduced.

Table 1 - Wellington Reservoir catchment clearing (source: 1991 Landsat images)

Gauging Station		Pasture (km^2)	Total (km^2)	Forest (km^2)	Pasture (%)
Coolangatta Farm	s612001	186.75	1299.85	1113.10	14.4
Mungalup Tower	s612002	-	2550	-	24 (1976)
Lemon	s612009	1.2	3.46	2.26	34.6
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James Well	s612025	44.83	173	128.17	25.9
South Branch	s612034	106.56	612.5	505.94	17.4

The dominant forest type throughout the Wellington Reservoir catchment is open forest of jarrah (*Eucalyptus marginata*) and marri (*E. calophylla*). Within the Mungalup Tower catchment area the jarrah-marri woodland comprises 85% of the natural vegetation (Public Works Department, 1984). In the very eastern part of the catchment, the low rainfall headwaters of the Collie River, the natural vegetation is an open woodland of marri (*E. calophylla*) and

Wellington Dam Catchment

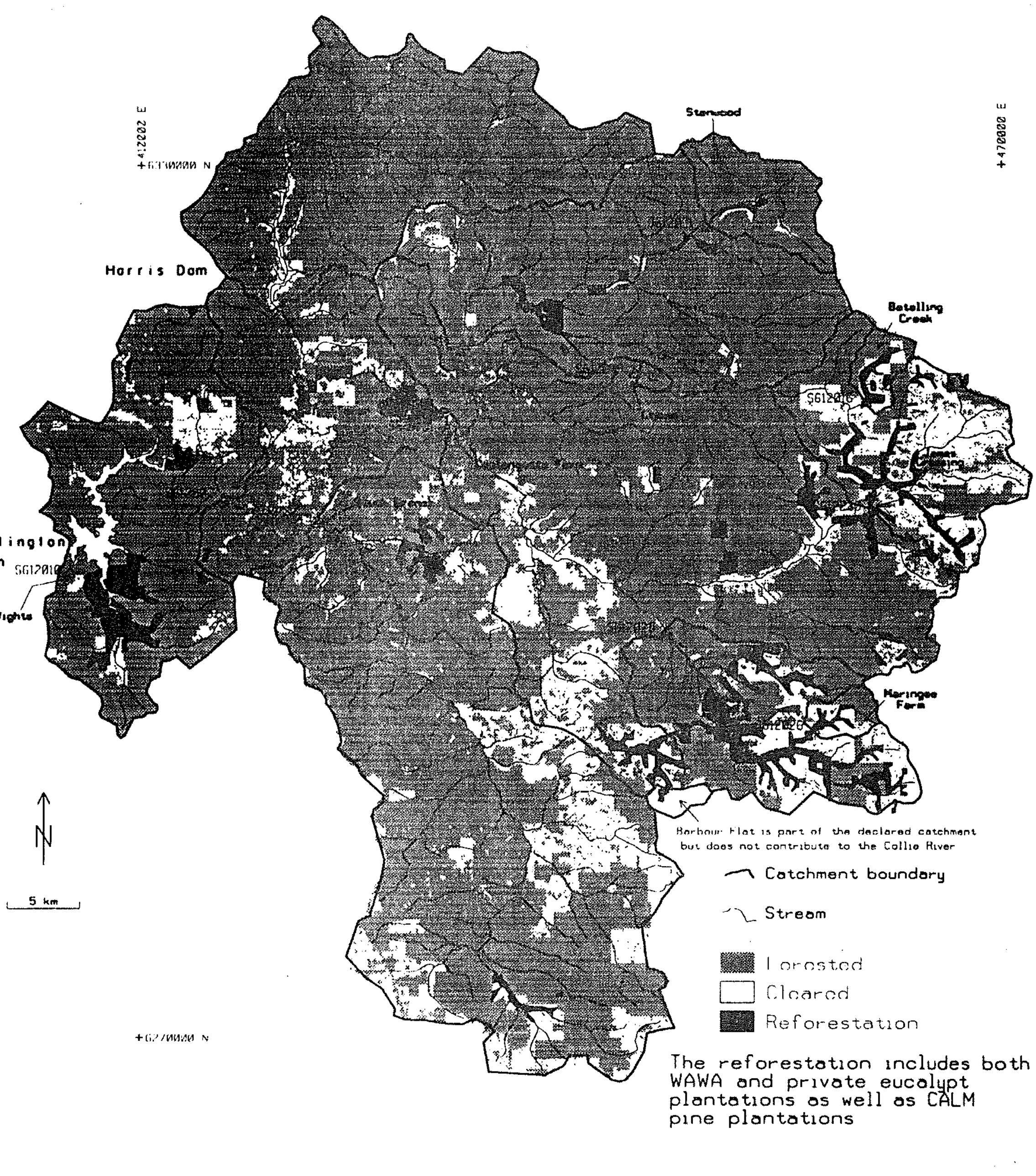


Figure 2 - Clearing at 1990

wandoo (*E. wandoo*) (Department of Conservation and the Environment, 1980).

2.4 Soils and Landforms

The Collie River rises in the dissected lateritic landscape of the Darling Range where the relief is gently undulating and relatively flat. It originates in the low rainfall eastern part of the catchment and drains westward through increasingly incised valleys and higher rainfall areas. The dominant landforms are Dwellingup laterite plateau (35% of the Mungalup Tower catchment) which occurs through most of the catchment except to the very south where the more sandy Wilga laterite plateau predominates. Together the Pindalup and Yarragil upland valley landforms account for 45% of the catchment area (Public Works Department, 1984). In the eastern part of the catchment the Pindalup valley landform occurs and is characterised by gravelly duplex soils on slopes with some rock outcrop, grey sands, duplex yellow soils and orange earths in broad valley floors. The Yarragil valley landforms occur in the western part of the catchment having sandy gravels on the slopes and orange earths in swampy floors (Department of Conservation and the Environment, 1980).

A basement of Archaean granitic and metamorphic rock underlies the lateritic soil profiles of the region (Public Works Department, 1984). Soil profiles are generally deep, typically being 20 m. The depth of weathering is variable but in the high rainfall areas (>1100 $mmyr^{-1}$) greater dissection occurs, slopes are steeper and bedrock frequently outcrops at the valley invert (Waugh, 1984). The Collie Coal Basin (area, 230 km^2) contains alternating sequences of Permian coal seams, shales and sandstones. Similar to the rest of the catchment, the basement of the Collie Coal Basin is comprised of crystalline rocks in the Archean shield (Ventriss, 1988).

3 RAINFALL

Four rainfall stations (Fig. 1) were selected to give an indication of trends in both long term rainfall and quantity of rainfall (Fig. 3) at different areas of the catchment. Rainfall measured at Collie Post Office and at Darkan was below the long term average during 1975-90 except in two years which were slightly above the long term average. Collie Post Office had rainfall 23% below long term average (Fig. 3b) and Darkan was 13% lower than average (Fig. 3d). Collie Post Office is located in the western part of the catchment while Darkan is situated east of the catchment. Between these two pluviometers lies much of the Wellington Reservoir catchment area. Thus, rainfall for the entire catchment is inferred to have had rainfall lower than the long term average during 1975-90. Observation of the 5 year back moving averages, at each of the four rain gauges, indicates a general trend of decreasing annual rainfall between 1965 and 1990.

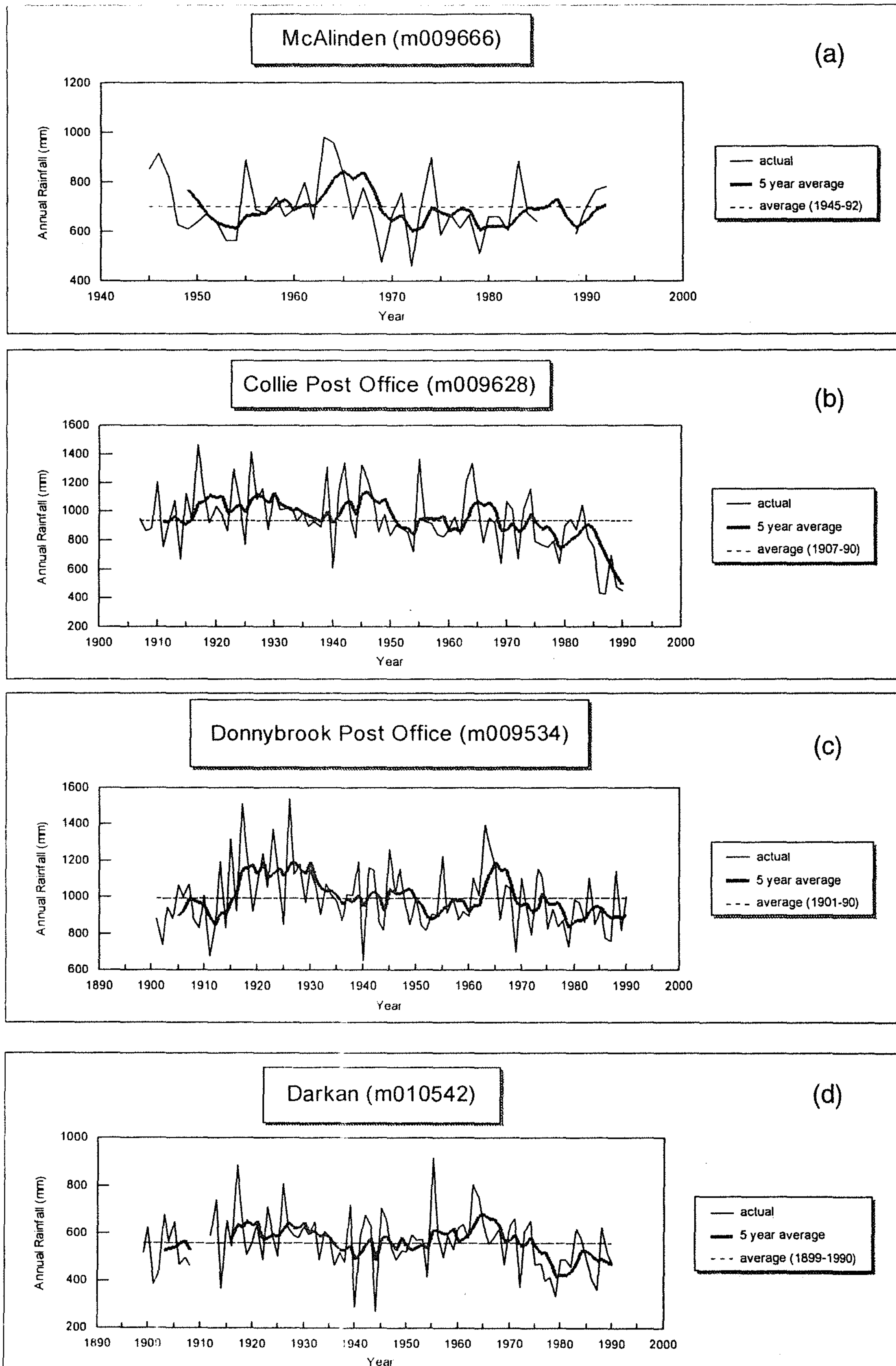


Figure 3 - Long term rainfall in and around the Wellington Reservoir catchment

Moving from west to east (heading inland) across the catchment the long term average rainfall decreases. Collie Post Office, in the west of the catchment, has an average rainfall of 939 mm (1907-90). Donnybrook Post Office average rainfall (1901-92) was 996 mm and McAlinden in the central south part of the catchment had 702 mm (1945-92). East of the catchment is Darkan with rainfall of 562 mm (1899-1990).

4 GROUNDWATER

Bore transects from three sub-catchments were analysed. These sites had been partially reforested and are located in the low rainfall, eastern part of the Wellington Reservoir catchment (Fig. 1). The objective was to determine the behaviour of groundwater levels and salinity in these areas.

4.1 Maringee Farm

Maringee Farm (Maringee) catchment has an area of 12.75 km^2 and is located on the eastern boundary of Wellington Reservoir catchment (Fig. 1). Mairdebing Creek flows through the Maringee catchment.

Progressive clearing for pasture development commenced in 1925 (Bari and Boyd, 1992). By 1976, 55% of the catchment was cleared and this was mainly on the lower slopes. Between 1981 and 1982, 180.8 ha was reforested on the lower slopes and the discharge zones of the valley. Some additional reforestation was planted in 1986. Tree survival was poor on water logged and salt affected plots. By 1990, the reforested area was 125.0 ha which is 9.8% of the total catchment area.

The groundwater level in the pasture bore rose 5.2m relative to the surface over the period 1982-93 (Fig. 4a). Those bores located adjacent to reforestation showed a small rise in groundwater level, up to 0.6m in the valley bores near the streamline or in the case of a mid-slope bore just above the reforestation section, the groundwater level declined 1.05m. The greatest decline was 1.15m from a bore located in the midst of the reforestation. This bore has declined 6.35m relative to pasture which is the difference in groundwater level that can be attributed to substituting trees for pasture.

Those bores, from the selected transect, located next to the stream line showed a slight rise over the period since planting (1982-93). However, aerial photographs taken at the onset of reforestation and again at 1990 show a reduction in size of the groundwater discharge area (Bari and Boyd, 1994). The evidence of the aerial photographs is assumed to be more representative of stream line groundwater levels than the selected transect. Thus, groundwater discharge to the stream has reduced below its 1982 level. The groundwater salinity data is highly variable.

At the bore locations near the streamline the groundwater salinity behaviour was different for each bore although generally the salinity is not much

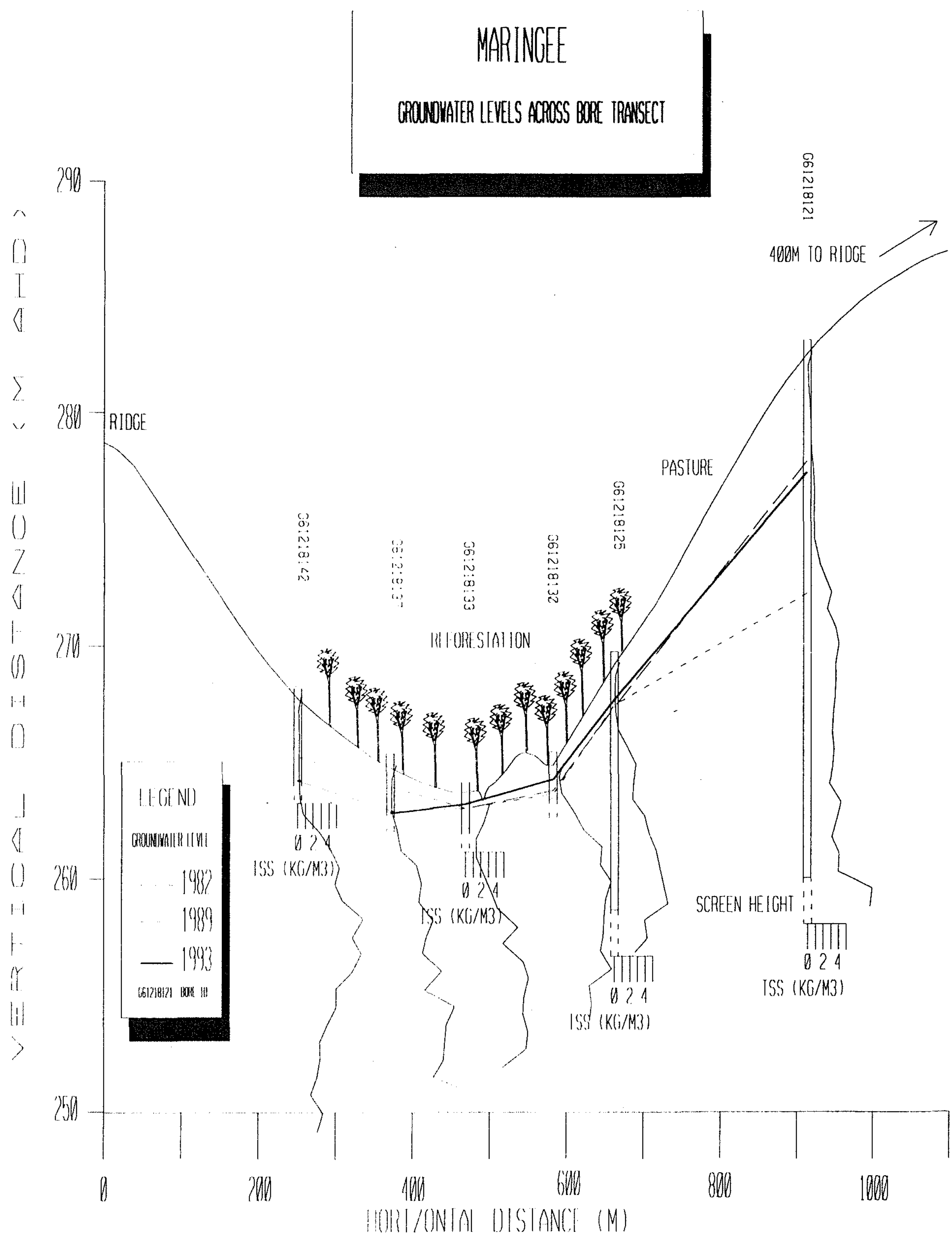


FIGURE 4A MARINGEE GROUNDWATER LEVELS

different in 1993 from 1982 (Appendix A). Thus, with the reduction in discharge area and only minor increases and decreases to salinity , the groundwater discharge for 1993 is expected to be slightly less than in 1982.

4.2 Stene's Farm

Several reforestation strategies were trialed at Stene's Farm (Fig. 1). These sites were investigations into valley reforestation, agroforestry and an arboretum.

4.2.1 Valley Reforestation

Clearing of native forest for pasture development at Stene's valley site took place in the 1950s. Clearing in this catchment is on the lower slopes. This catchment was 44% cleared, then in 1979 the reforestation was planted which covers 35% of this cleared area. A nearby site is used as a control. This site is 31% cleared and between 1976 and 1978, strip reforestation was carried out on the lower slopes. The bores used as a control are located in a mid-slope location between the strip reforestation and the native forest.

The groundwater level in the valley reforestation has declined about 1m between 1978 and 1993 (Fig. 4b). By comparison, the upslope bores in native forest showed little change in groundwater level (*i.e.* 0.14m rise from 1979-89). As the groundwater levels in native forest are only likely to respond to long term rainfall trends, it is apparent that the decline of groundwater level in the valley reforestation is likely to be an effect of the reforestation rather than climatic.

In the pastured mid-slope area the groundwater level rose 1.21m (1979-93). Lower in the mid-slope area the groundwater level rose by only 0.15m (1979-91) which may be due to being closer to the reforestation in the valley. These results are for single bores whereas at the pastured control site an average of 5 mid-slope bores gave a rise in groundwater level of 0.70m. Therefore, over the study period the minimum annual groundwater level beneath reforestation declined 1.12m relative to native forest and 1.68m relative to pasture at the control site.

Beneath the reforestation the groundwater salinity reduced by 30% (1980-89), under pasture the reduction was 41% and under native forest 13% (Appendix A).

4.2.2 Agroforestry

Agroforestry is a reforestation approach which involves planting trees in wide spaced rows with pasture or crops between the trees. The agroforestry site at Stene's Farm comprises farmland (pasture), native forest and reforestation. The clearing of native forest for pasture (25% of the area) took place in the

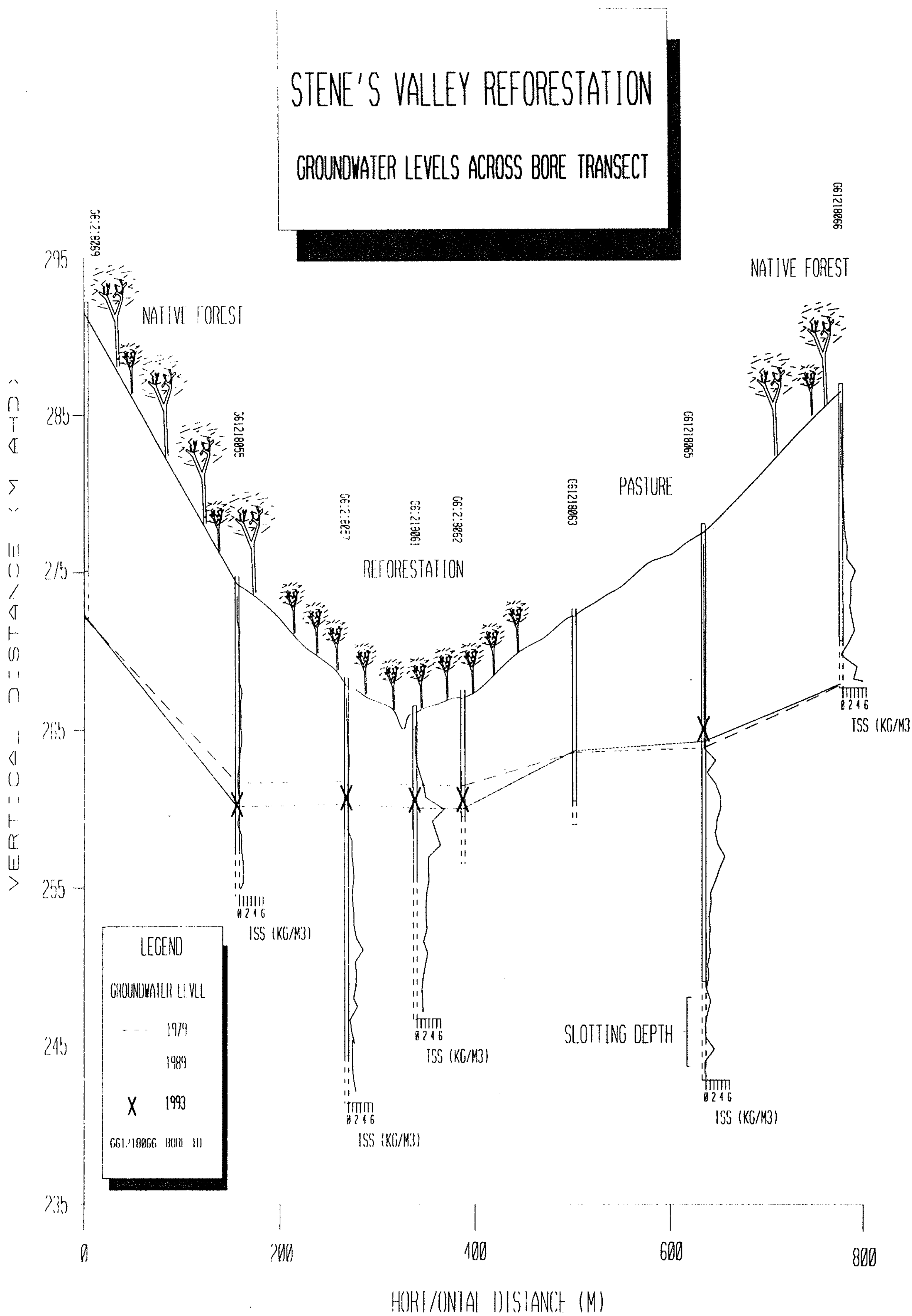


FIGURE 4B - STENE'S VALLEY GROUNDWATER LEVELS

1950s. Between 1976 and 1978 strip reforestation was carried out on the lower slopes covering about 14% of the catchment. The average minimum groundwater level declined 2.0m (1982-89) relative to a pasture control site while the absolute reduction was 1.7m (Bari *et. al*, 1991).

Groundwater salinity over 1982-89 was reduced by 5% under agroforestry and under pasture the reduction was 40% (Bari *et. al*, 1991). The combination of declining groundwater table and groundwater salinity will result in reduction of the volume and salinity of groundwater discharge to the stream (Bingham River).

4.2.3 Arboretum

Clearing took place on the lower slopes covering 35% of the catchment. The reforestation comprises 70% of the cleared area and consists of 63 species of *Eucalyptus* and two species of *Pinus*. This extensive high density reforestation has resulted in a reduction of groundwater level by 7.3m (1979-93) (Fig. 4c) and the decline relative to pasture was 8.0m.

Groundwater salinity reduced by 10% beneath the arboretum (1980-89) and under pasture the reduction was 40% (Appendix A).

4.3 Batalling

Batalling Creek catchment has an area of 16.6 km^2 (Fig. 1). Long term average rainfall is about 640 $mmyr^{-1}$ (Hayes and Garnaut, 1981). Progressive clearing commenced in the 1950s. By 1977, 51% of the area had been cleared mostly on the lower slopes. Eucalypt species were planted in plots along the stream lines in 1985 and 1986. Reforestation in 1986 was 20.5% of the catchment area. Tree survival was poor in water logged and salt affected areas so that by 1991 reforestation had reduced to 19.4% of the catchment area (Bari, 1992a).

In 1980, saline seeps were evident along the stream line. The permanent seep area had expanded to 19 ha by 1985 and in 1991 it was 20 ha. Groundwater modelling by Hookey (1985) predicted that the groundwater seep area would have doubled by 1990 in the absence of reforestation. As the seep area remained stable at around 20 ha it appears that the reforestation has halted the expansion of the saline seep area.

During 1978 to 1981, groundwater levels rose with the greatest rise being in the mid-slope area (0.35m) (Fig. 4d). Groundwater levels in 1993 had declined below their 1978 levels except in the valley seep area. The decline of groundwater level was 1.21m in the mid-slope area (1981-1993).

Bari (1992a) found an average reduction in groundwater salinity of 5% under reforestation while at the valley seep area the reduction was negligible.

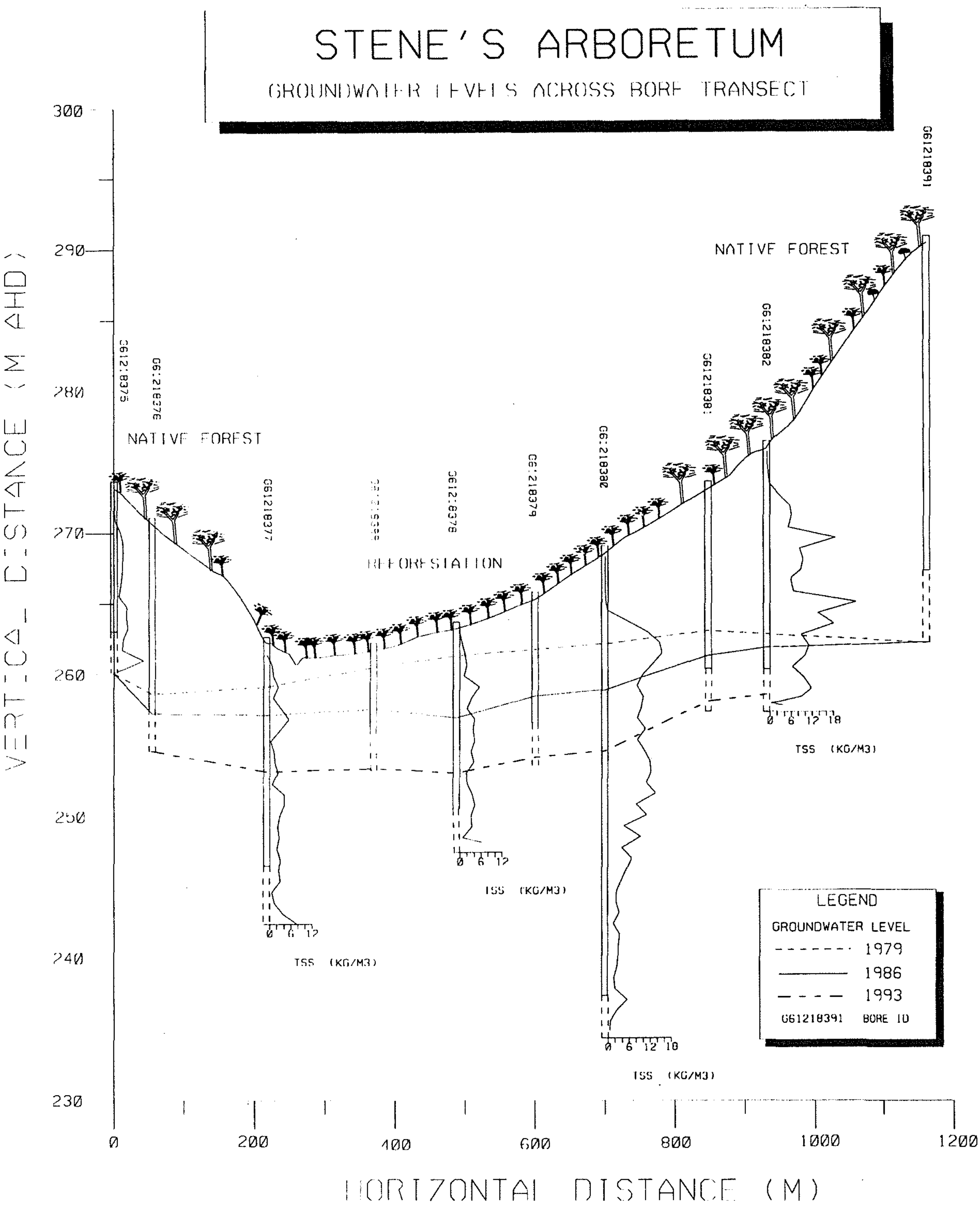


FIGURE 4C - STENE'S ARBORETUM GROUNDWATER LEVELS

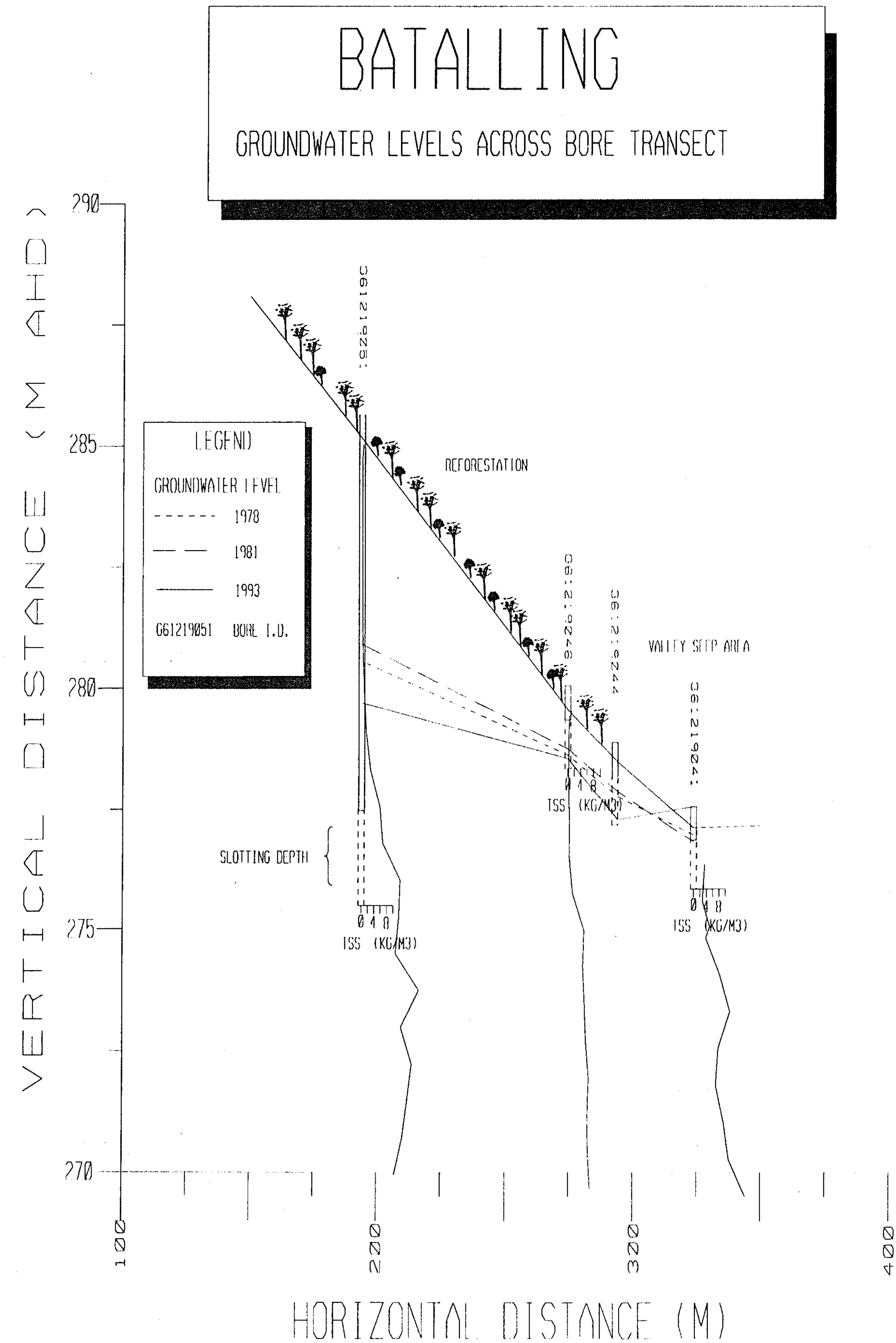


FIGURE 4D - BATALLING GROUNDWATER LEVELS

5 STREAMFLOW AND SALINITY

The inflow salinity to Wellington Reservoir for a median flow year has increased from 280 mgL^{-1} TSS in 1945 to approximately 1030 mgL^{-1} TSS in the 1991/92 water year (Fig. 5). This increase to the inflow salinity is an effect of clearing for agriculture in the Wellington Reservoir catchment. If the area of clearing was maintained at the 1976 level but with no reforestation it is estimated that the inflow salinity would reach 1150 mgL^{-1} TSS in a median inflow year (Loh and Anson, 1988). However, without clearing control legislation the inflow salinity would ultimately reach 1700 mgL^{-1} TSS (Loh and Anson, 1988).

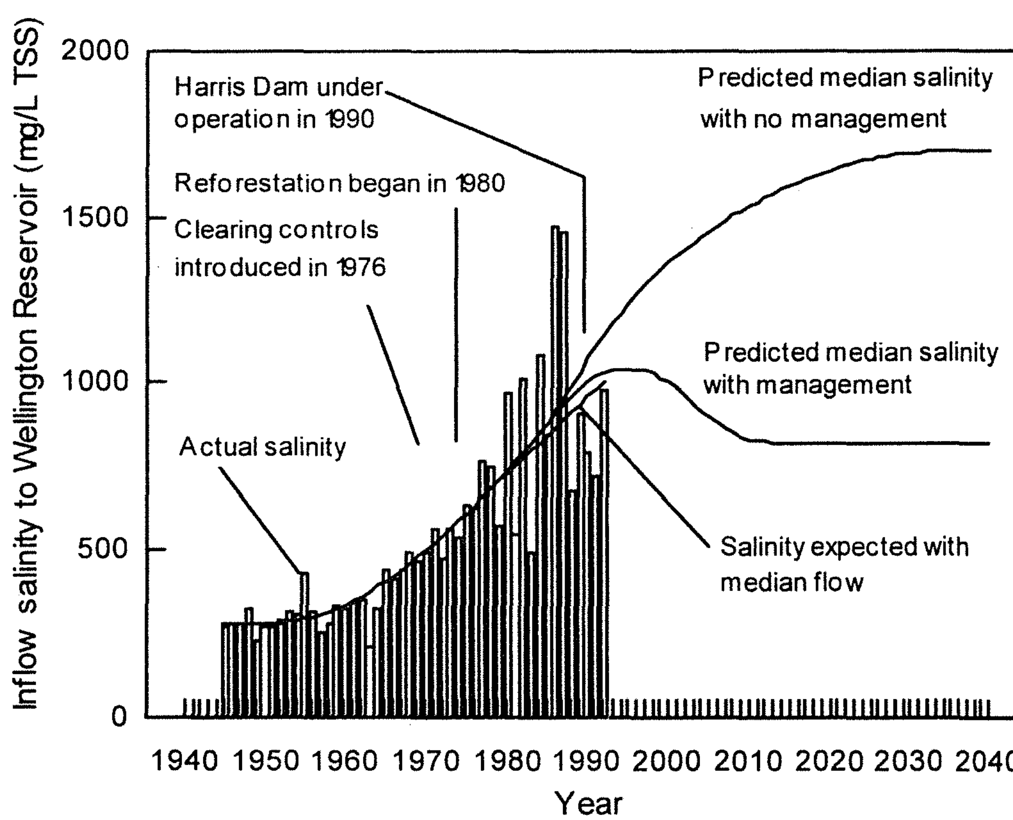


Figure 5 - Salinity trend of Wellington Reservoir Catchment

Analysis of the rate of deterioration in the inflow salinity reveals an acceleration in the rate of salinity increase. In the late 1940s the rate of change was for an increase of 1 mgL^{-1} TSS which by the end of the 1950s had become 10 mgL^{-1} TSS. Towards the end of the 1970s the rate of salinity increase was 25 mgL^{-1} TSS. The acceleration of the rate of increase appears to have ended as the annual rate of increase in salinity was about 23 mgL^{-1} TSS in the late 1980s. This observed end to the acceleration may be an effect of the clearing controls. Thus, the current trend of increasing salinity is attributed to past clearing.

The various sub-catchments that make up the Wellington Reservoir catchment differ in rainfall and extent of clearing (Fig. 1,2). A selection of these sub-catchments are analysed individually for their trends in streamflow and salinity. These selected gauging stations relate to each other on the river network as shown in figure 6. Table 2 shows the basic flow mechanism of the Wellington Reservoir catchment. Those catchments in the High Rainfall Zone produce greater streamflow but lower stream salinity relative to the catchments in the Intermediate and Low Rainfall Zone. The extent of clearing in a catchment is directly related to streamflow, stream salt load and salinity (Table 2).

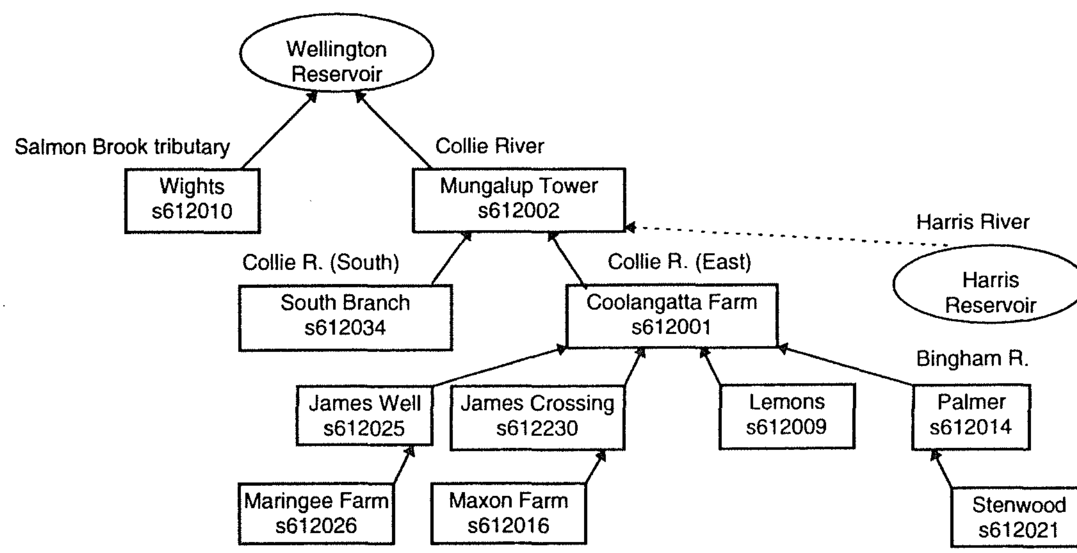


Figure 6 - Relation between selected gauging stations

Table 2 - Streamflow and salinity averages at selected gauging stations

Gauging Station	Period* (years)	Flow (mm)	Load (tonnes TSS/ha)	Salinity (mg/L TSS)	Rainfall (mm)
Coolangatta Farm	1982-91	36	0.57	2040	685
Mungalup Tower	1982-91	50	0.44	1080	732
Lemon	1982-91	47	0.27	400	717
Wights	1982-91	422	2.14	530	974
Palmer- Bingham River	1982-91	17	0.05	370	729
Maxon Farm - Batalling Creek	1982-91	42	1.73	5370	624
Stenwood - Bingham River	1982-91	11	0.04	600	668
James Well	1983-92	38	0.77	2840	615
Maringee	1983-92	44	1.66	6300	576
South Branch	1981-93	49	0.39	960	695
James Crossing - Collie River (East)	1982-92	51	2.30	5610	630

* averages calculated for the period 1982-91, or thereabouts depending on data availability for the particular gauging station.

5.1 Wights

Wights catchment is a tributary of Salmon Brook and is located near Wellington Dam (Fig. 1). During the summer 1976/77 this 0.938 km^2 catchment was completely cleared. The pre-clearing flow weighted annual salinity (1974-76) averaged 385 mgL^{-1} TSS (Appendix B). Thus, the streamflow from Wights catchment is inferred to have been fresh prior to clearing. This High Rainfall Zone catchment had stream yield of 9.1% in 1975 and 2.1% in 1976.

A regression equation relating streamflow to rainfall was used to estimate streamflow as though the catchment hydrology was in equilibrium. Actual flow data was compared to the estimate giving the calculated change in streamflow which has been expressed as a percentage of annual rainfall. The change to streamflow was for an increase of average 21.1% of annual rainfall (1981-92) (Fig. 7a). The trend of increasing stream yield was statistically significant (t-test, 95%) over the whole period of record (*i.e.* the Student's t-test for 95% confidence of a significant trend returned a true result). The annual rate of increase to stream yield was estimated to be 1.8%. Over the period 1981-92 the trend was for an insignificant increase (t-test, 95%) at an annual rate of 0.3%. The trend determined for 1981-92 was less significant than the trend for the whole period. This is because most of the increase to stream yield occurred in the first few years following clearing (Fig. 7a). Variation in annual rainfall affects the magnitude of the increase to streamflow with higher annual rainfall corresponding to a greater magnitude of increase (Appendix B). By 1984, the trend of increasing streamflow with time was masked by the yearly variation in rainfall (Fig. 7a). Although the analysis suggests a slowing of the rate of increase in the magnitude of the increases to stream yield (*i.e.* the slope of Fig. 7a levels out) it still remains that stream yield is increased relative to the regression equation.

Regression equations relating salt load and flow weighted salinity to annual streamflow were developed using data from 1974-79 (Appendix C). The change of stream salt load and salinity was an increase, relative to this regression equation, for all subsequent years (1980-93). Between 1980 and 1993 the increase to salt load averaged 1.234 tonnes TSS ha^{-1} which is greater than the maximum absolute value (1974-79) of 0.345 tonnes TSS ha^{-1} (Fig. 7b). Stream salt load increased at a significant annual rate (t-test, 95%) of 0.09 tonnes TSS ha^{-1} over the period 1974-93. The time trend of stream salinity was for a significant increase (t-test, 95%) at an average rate of 20 mgL^{-1} TSS.

Salt load is generally directly related to annual streamflow and flow weighted salinity inversely related. The magnitude of changes in salt load and stream salinity are similarly related to rainfall as rainfall is directly related to streamflow. The increasing trend with time of stream salt load and salinity (Fig. 7b,c) becomes masked by the yearly variation in rainfall by the mid 1980s.

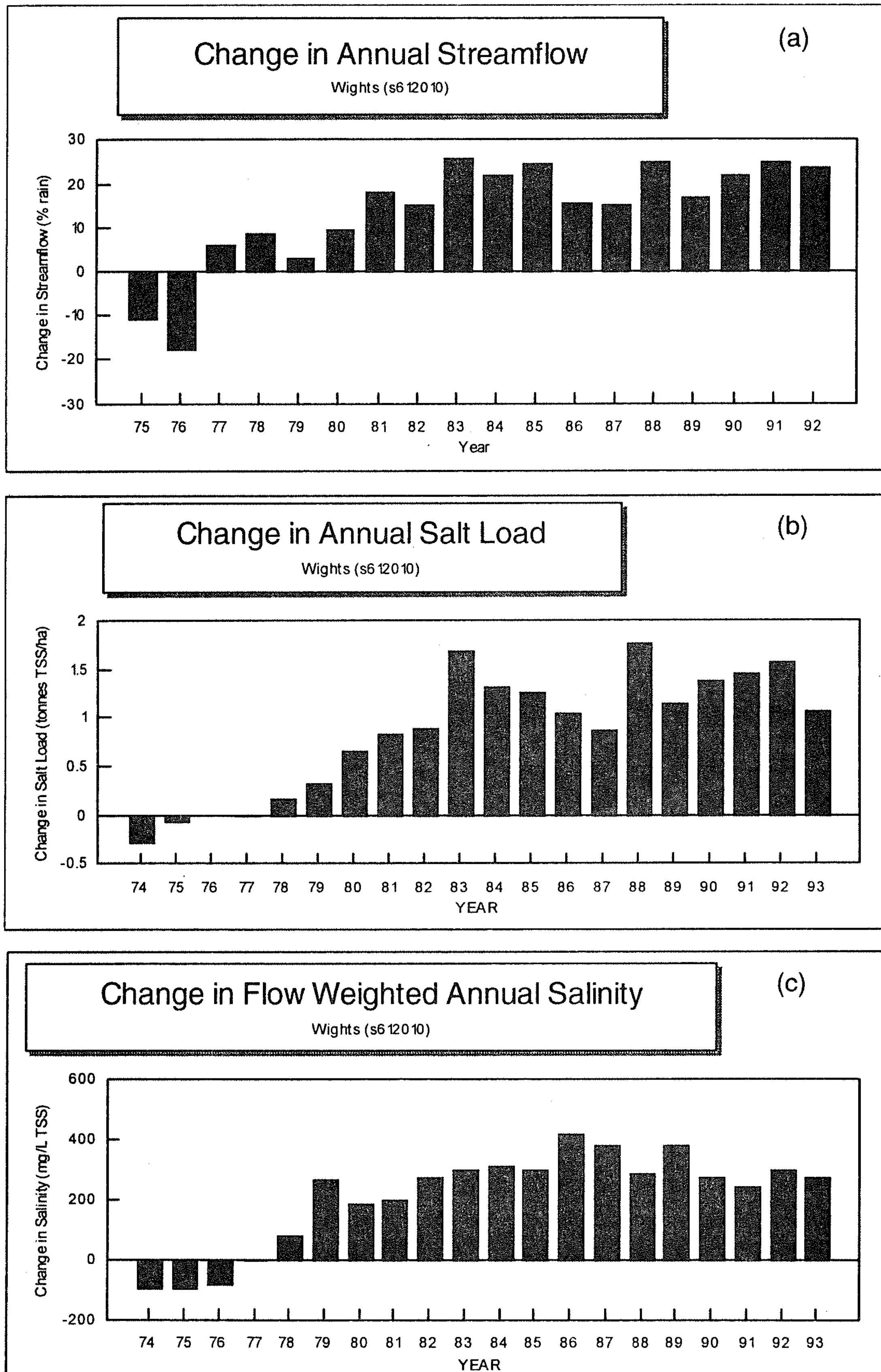


Figure 7 - Wights catchment changes in streamflow, salinity and salt load

5.2 Mungalup Tower

Mungalup Tower is the last major gauging station on the Collie River before it enters the Wellington Reservoir (Fig. 1,6). As such it is downstream of all the low rainfall (high salinity risk) agricultural areas in the east of the Collie River catchment. The catchment area is 2830 km^2 (2448 km^2 excluding the Harris tributary) and had been 24% cleared by 1976 (Table 1) when clearing control bans were imposed. The 1979-85 average of flow weighted annual salinity was 1045 mgL^{-1} TSS (Appendix B). As the streamflow is greater than 1000 mgL^{-1} TSS it is classified as a brackish water resource.

Streamflow data was related to annual rainfall by a regression equation developed for the period 1977-83 (Appendix C). The calculated changes in streamflow showed that all years 1984-92 had increased streamflow which averaged 1.8% of annual rainfall compared to the regression period (1977-83) which averaged 0.5% of annual rainfall (Fig. 8a). The increase in stream yield was not statistically significant (t-test, 95%) as the variance during the period used to calculate the regression was greater than any change to stream yield for 1984-92. The insignificant trend is partly owing to large maximum absolute value during the period in which the regression equation was calculated. This large maximum absolute value is due to high rainfall. Thus, to determine if the trend is significant would require further years of monitoring which include some high rainfall years.

Regression equations relating salt load and flow weighted salinity to annual streamflow were developed using data from 1977-84 (Appendix C). All years of data (1985-92) showed increased salt load and salinity relative to the relationships developed for 1977-84 (Fig. 8b,c). Although only some of the years show a significant increase (t-test, 95%), the consistent increases contrast with the 1977-84 data which varies from year to year between an increase or decrease relative to the regression equation. The trend of increasing stream salt load was significant (t-test, 95%) having an annual rate of 0.016 tonnes TSS ha^{-1}. Salinity had a significant increasing trend (t-test, 95%) over 1977-92 with an average annual rate of increase of 28 mgL^{-1} TSS.

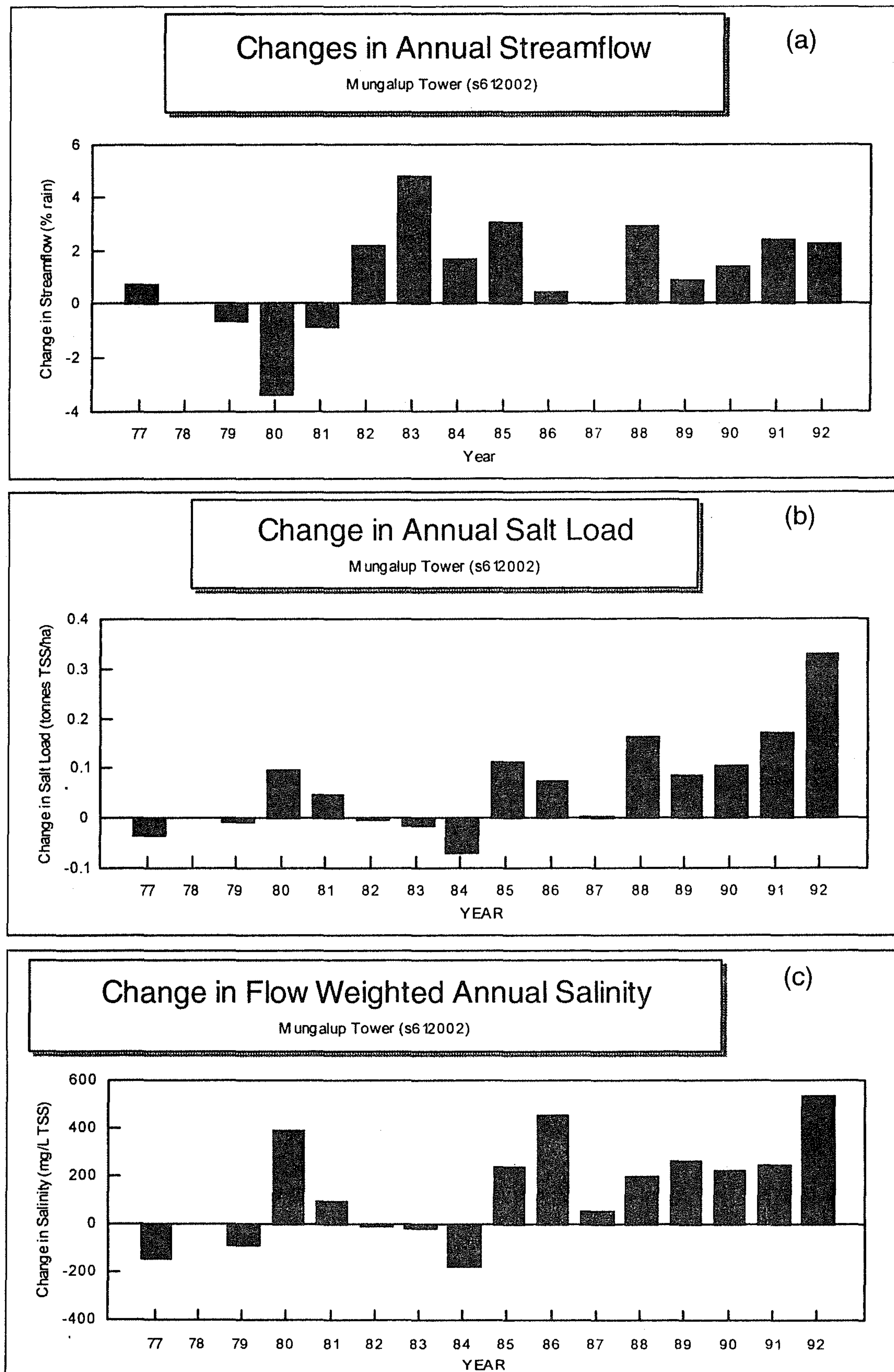


Figure 8 - Mungalup Tower catchment changes in streamflow, salinity and salt load

5.3 South Branch

The catchment area for the South Branch of Collie River is 612.5 km^2 (Fig. 1). State Forest reserve covers most of the catchment while the cleared areas are used for sheep and cattle grazing, some cereal production and orchards *etc.* (Public Works Department, 1984). The extent of clearing in the 1940s was 14%, 20% in 1966 and 27% in 1976. Stream salinity (1953-60) averaged 570 mgL^{-1} TSS (Appendix B) which is just above the limit for fresh water and is classified as marginal.

Streamflow produced for a given quantity of annual rainfall was estimated using a regression equation developed from 1974-79 data. Changes in streamflow showed a pattern of increase from 1983 onwards. The average increase (1980-92) was 1.4% of annual rainfall whereas the annual rate of increase, averaged for 1974-92, was 0.2% which is a significant trend (t-test, 95%). The trend of increasing stream yield is well illustrated in the plot of rainfall and stream yield against time (Appendix B).

Streamflow and salinity data was available for the period 1953-93. Regression equations relating stream salinity and salt load to streamflow were developed for the 1953-74 period (Appendix C). All years (1975-93) showed increased salinity and salt load relative to the predictions of the regression equation. The increase to salt load (1975-93) averaged 0.151 tonnes TSS ha^{-1} (Fig. 9b). Over the whole period (1953-93) the annual rate of increase to stream salt load averaged 0.006 tonnes TSS ha^{-1} which is a significant trend (t-test, 95%). Between 1975 and 1993 the magnitude of salt load increases had an insignificant trend of decrease (t-test, 95%). The increase to salinity (1975-93) averaged 500 mgL^{-1} TSS (Fig. 9c) and in some years the magnitude of the increases to salinity was significantly greater (t-test, 95%) than the regression period. Stream salinity increased at a significant (t-test, 95%) average annual rate of 16 mgL^{-1} TSS. During the period 1975-93, the magnitude of increases had a significant decline (t-test, 95%). As streamflow and stream yield had trends of increase during 1975-93, the trend of stream salinity and salt load no longer increasing but beginning to decrease is real and therefore more than a climatic response.

Baseflow salinity seemed to generally increase over the period 1952-93 (Appendix D). This increase was fairly steady up until the early 1980s and since then the baseflow salinity has not risen any further. During 1956 to 1993 the 5 year back moving average increased from approximately 540 mgL^{-1} TSS to 1010 mgL^{-1} TSS which equates to an average rate of increase of about 12 mgL^{-1} TSS per year.

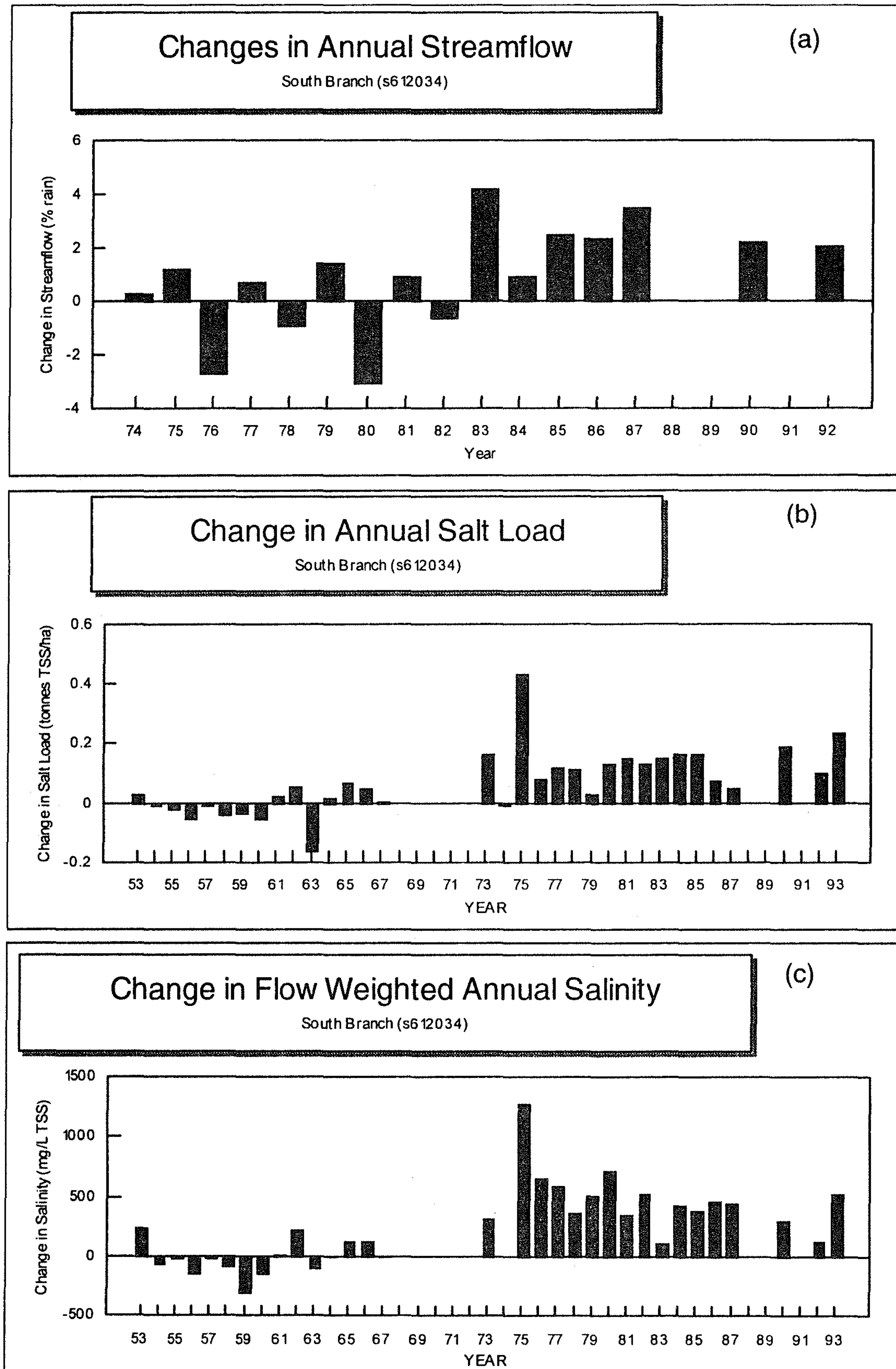


Figure 9 - South Branch catchment changes in streamflow, salinity and salt load

5.4 Eastern Catchments

5.4.1 Coolangatta Farm

The catchment area for this Collie River gauging station is 1340 km^2 (Fig. 1). Much of the catchment is State Forest reserve with the cleared areas being for sheep and cereal production with some beef (Public Works Department, 1984). The extent of clearing in the 1940s was 6.5%, 11.8% in 1960 and 27.5% in 1976. The 1970-80 average of flow weighted annual salinity was 2010 mgL^{-1} TSS. Therefore, at this location the Collie River is classified as a brackish water resource.

Streamflow and rainfall data from 1975-80 was used to develop a regression equation. Predictions based on this equation indicate increased streamflow though the magnitude of increase is directly related to rainfall (Appendix C). The average increase to stream yield was 1.7% of annual rainfall (Fig. 10a) while the trend of increase over 1975-91 was significant (t-test, 95%) with the annual rate of increase averaging 0.1%.

Stream salinity and salt load were related to streamflow using regression equations formed from the 1970-80 data (Appendix C). Estimates based on these equations showed that relative to 1970-80 the salt load (1981-91) had increased slightly (Fig. 10b). The change in salt load was in all years 1981-91 an increase. While the magnitude of these increases was not significant (t-test, 95%) the trend of increase over the whole period of record (1970-91) was statistically significant (t-test, 95%). The situation is similar for stream salinity which while consistently increased (1983-91) the magnitude of the increases were insignificant (t-test, 95%) whereas the trend of increase, at an annual rate of 47 mgL^{-1} TSS, was significant (t-test, 95%).

5.4.2 Lemons

Lemon catchment is a tributary of Pollard Brook and has an area of 3.44 km^2 (Fig. 1). The lower portion (34.6%) of the catchment, valley and slopes, was cleared during the summer 1976/77. Lemon catchment and the nearby forested control, Ernies catchment, were selected due to their potential to exhibit characteristics commonly associated with salinity problems which follow some years after clearing (Ruprecht and Schofield, 1991a). The 1975-80 average of flow weighted annual salinity was 110 mgL^{-1} TSS (Appendix B). Thus, the Lemon catchment is inferred to have had fresh streamflow prior to clearing.

The first year of complete streamflow data was 1974. Estimates of the change in streamflow for a given quantity of rainfall were made using a regression equation developed from 1974-79 data (Appendix C). Streamflow increased considerably and the magnitude of increase continued to increase to the end of the study period (1992) when the increase was 11.4% of annual

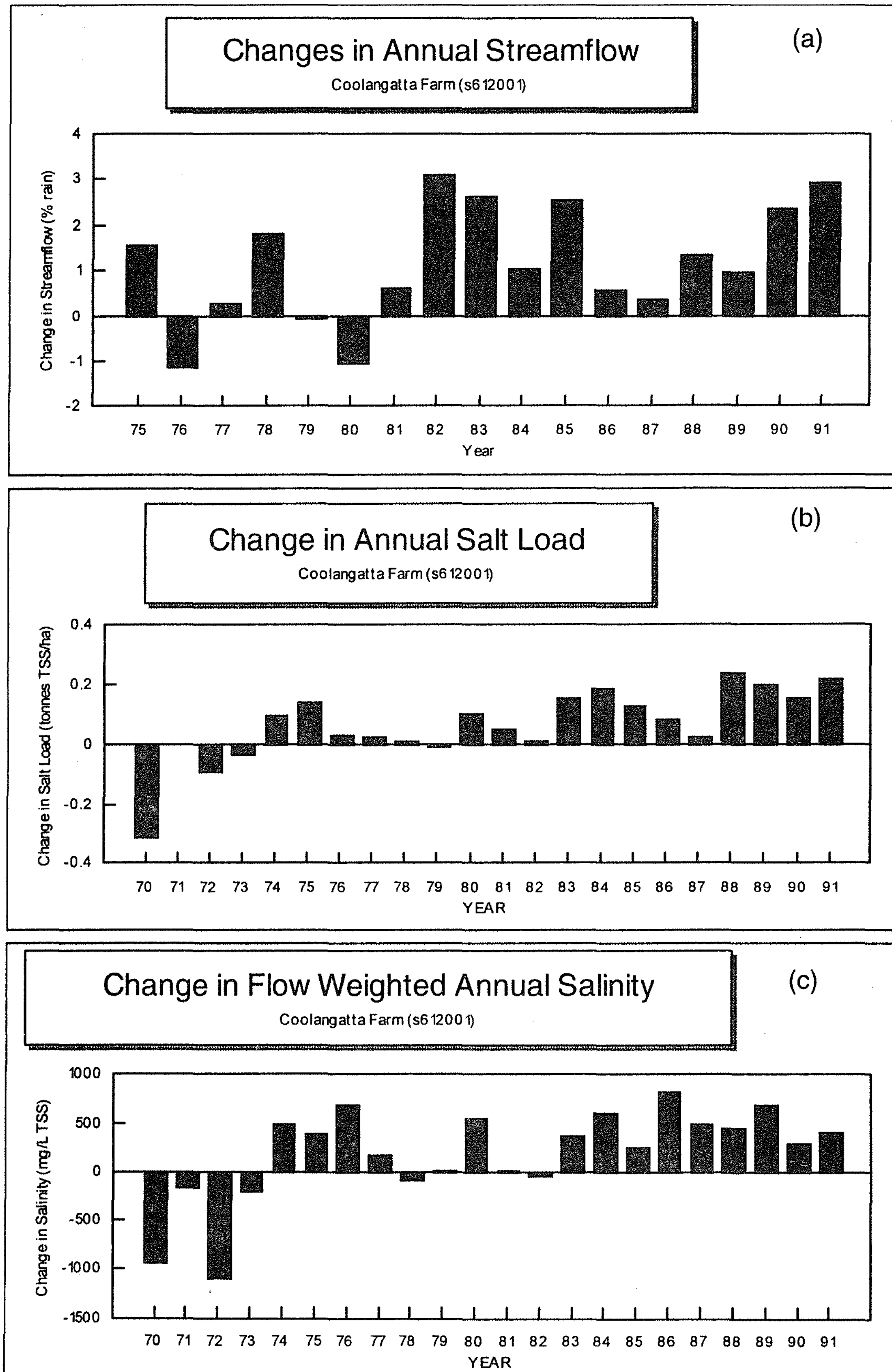


Figure 10 - Coolangatta Farm catchment changes in streamflow, salinity and salt load

rainfall (Fig. 11a). The magnitude of the increase to stream yield was significantly increased during 1990-92 (t-test, 95%) and the trend of increasing stream yield (1974-92) was also significant (t-test, 95%) with an annual rate of increase averaging 0.56%.

Regression equations relating stream salinity and salt load to streamflow were developed for the period 1975-87 (Appendix C). A small groundwater discharge area first appeared in 1988 (Ruprecht and Schofield, 1991a). From 1988 onwards the increase in salt load and stream salinity was dramatic (Fig. 11b,c). The average annual salt load 1975-87 was 0.024 tonnes TSS ha^{-1} and salinity was 120 mgL^{-1} TSS whereas by 1993 salt load had increased to 1.267 tonnes TSS ha^{-1} and salinity was 1515 mgL^{-1} TSS (Appendix B). Therefore, stream salinity has increased from being fresh prior to clearing to brackish 15 years after clearing. The trend of increasing stream salinity (1988-93) was highly significant (t-test, 95%) with an annual rate of increase of 240 mgL^{-1} TSS.

5.4.3 James Well

James Well has a catchment area of 173 km^2 (Fig. 1) of which 25.9% is cleared for agriculture (Fig. 2). Streamflow data was available for the period 1983-93. During the period 1983-87, the average flow weighted annual salinity was 3410 mgL^{-1} TSS (Appendix B) which is classified as brackish water. Regression equations were developed for the period 1983-87 which left only 6 further years of data. This limited period of data is too short to detect small changes as many years of data would be necessary to distinguish minor changes from yearly climatic variation. The trend over 1983-93 was for streamflow to have an insignificant trend (t-test, 95%) of decrease (Fig. 12a).

Stream salt load had an insignificant trend of increase (t-test, 95%) over the period 1983-92. While the trend of the change was not statistically significant the magnitude of the increases were significant (t-test, 95%) for 1988, 91 and 92 (Fig. 12b). The trend of changes to was for an insignificant decrease 1983-92. Further years of data are necessary to determine if there is any trend (albeit gradual) with time.

The overall trend for baseflow salinity (1982-92) and annual streamflow was to increase (Appendix D). As the volume of streamflow also increased (Appendix D), the increase to baseflow salinity was more than a climatic response. The increase in 5 year back moving average baseflow salinity was from 6500 mgL^{-1} TSS to 8900 mgL^{-1} TSS which is a rate of increase of about 340 mgL^{-1} TSS per year.

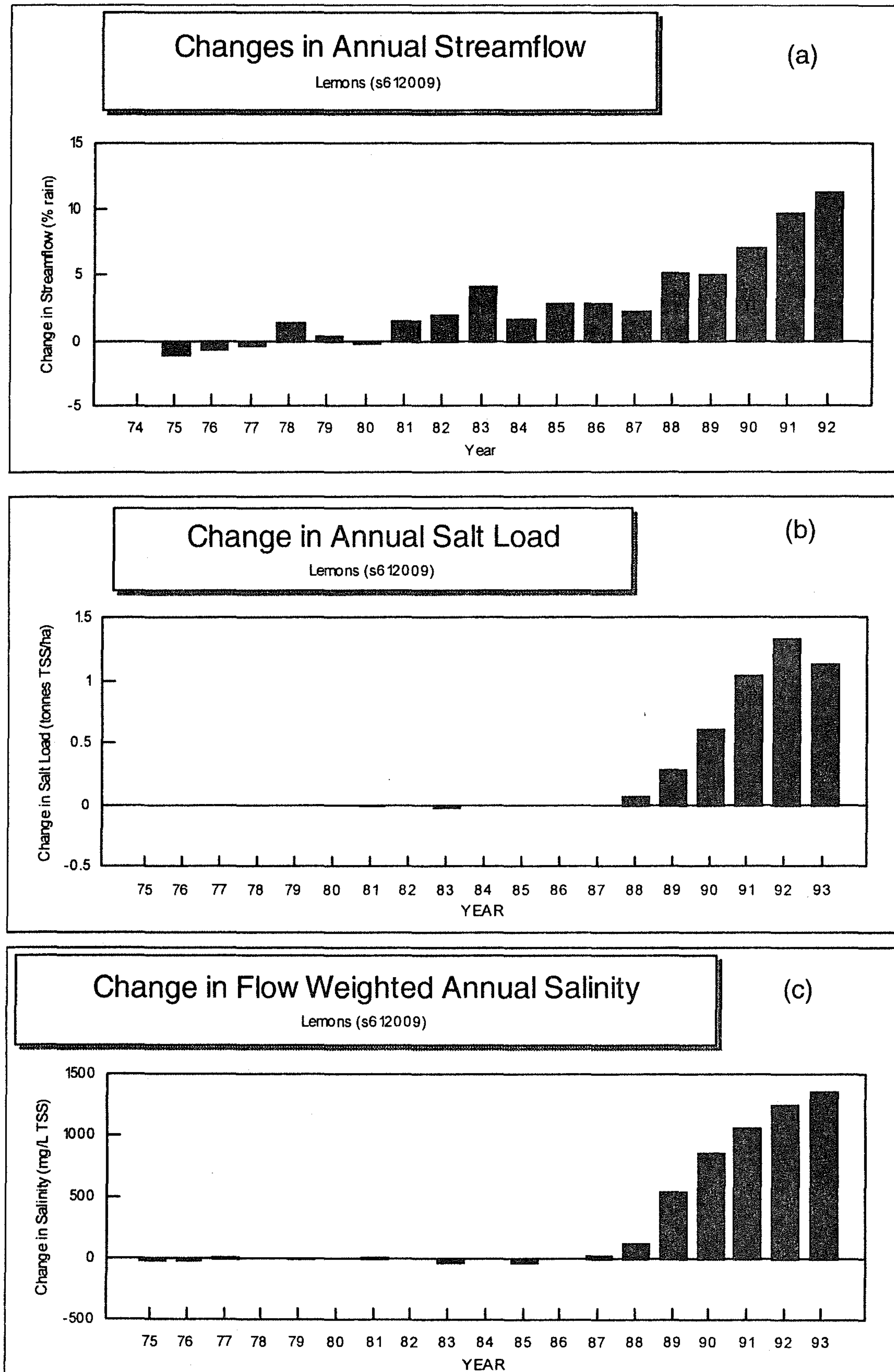


Figure 11 - Lemons catchment changes in streamflow, salinity and salt load

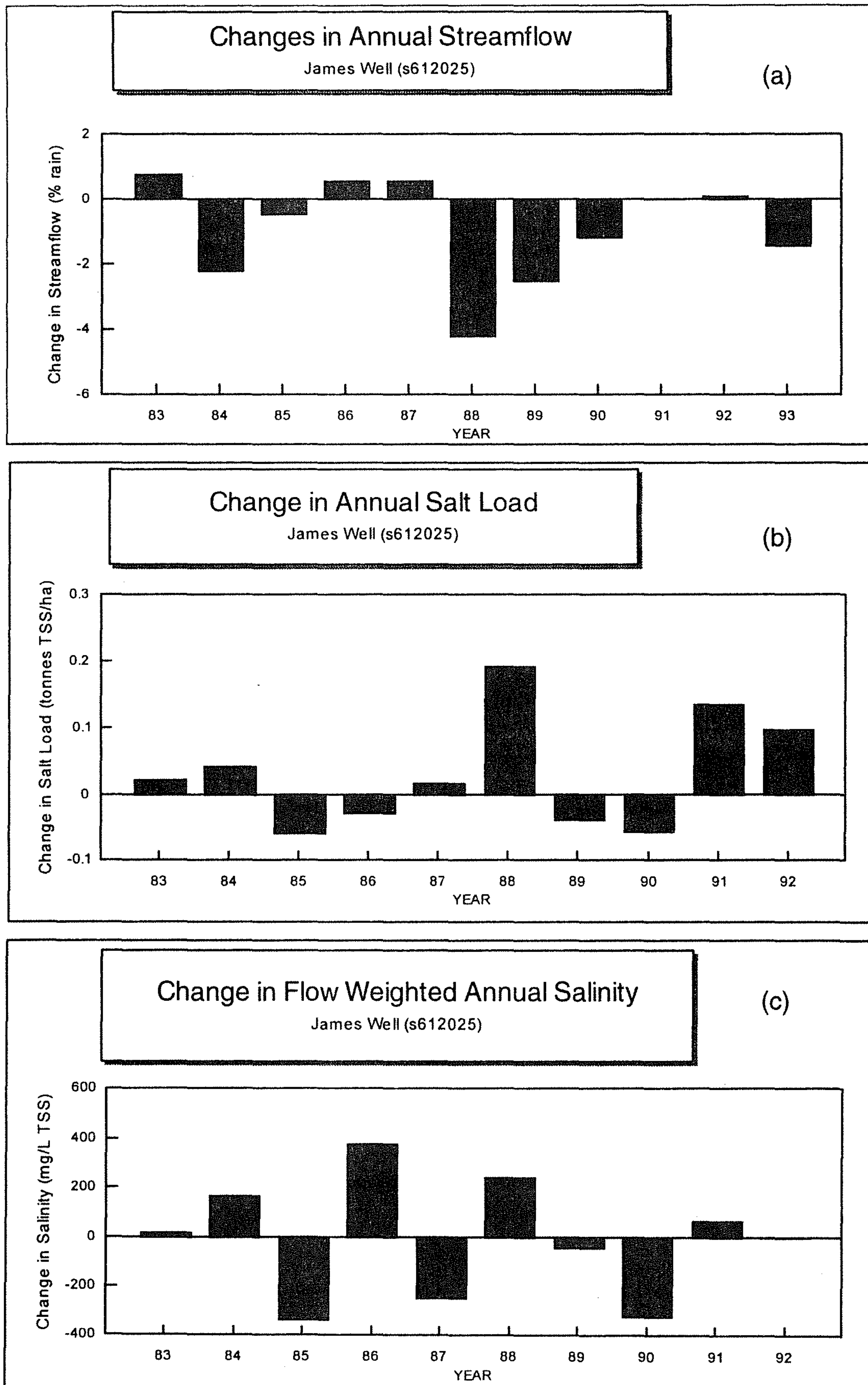


Figure 12 - James Well catchment changes in streamflow, salinity and salt load

5.4.4 Maringee

Maringee catchment is a sub-catchment of James Well catchment (Fig. 1,6). Mairdebing Creek flows through the catchment which has an area of 12.75 km^2. Clearing of Maringee farm began in 1925 and by 1976, 55% of the site had been cleared. Reforestation was conducted between 1981 and 1982 with some further planting in 1986 (Bari and Boyd, 1992). The reforestation consisted of eucalypts planted on the lower slopes and floor of the valley. According to calculations based on 1991 Landsat imagery, pasture constituted 29.1% of the catchment area.

Streamflow and salinity data was available for 1983-93. Regression equations were developed using 1983-87 (Appendix C). Stream yield had an insignificant trend (t-test, 95%) of decrease over 1983-93 (Fig. 13a). The years 1988 and 1989 had significantly decreased streamflow (t-test, 95%) while the remaining years were decreased but not significantly.

There was no significant change to the stream salt load (1988-93) relative to the regression period 1987-93 (Fig. 13b). The trend of the changes in salt load was for an insignificant increase (t-test, 95%). This insignificant trend is so small that it would be rounded to zero. The calculated changes in stream salinity were not significant (t-test, 95%) and the trend of the changes was for an insignificant increase (Fig. 13c).

5.4.5 Palmer

The Palmer gauging station measures the streamflow of Bingham River which is a tributary of Collie River - East Branch (Fig. 6). Palmer catchment has an area of 367 km^2 (Fig. 1) of which less than 10% was cleared, mainly along river terraces, by 1976. Reforestation has taken place so that, at 1991, about 3.0% of the catchment remained as pasture (Fig. 2). Streamflow and rainfall data from 1976-81 were used to develop a regression equation (Appendix C). The estimates from this equation indicated that on average streamflow had increased by 0.6% of annual rainfall (1982-92) (Fig. 14a). However, this is misleading as three high rainfall years (1983, 88 and 91) are largely responsible for this apparent increase. The regression equation was developed for a period in which the rainfall was less than the three high rainfall years and thus there is difficulty in accurately extrapolating the equation. The magnitudes of the increases to stream yield was not significant (t-test, 95%) and the trend with time was for an insignificant increase (t-test, 95%).

Regressions relating stream salinity and salt load to streamflow were developed for 1976-82 (Appendix C). The calculated changes in salt load indicate an insignificant trend of decrease (Fig. 14b). However, this trend in reality is likely to be even more insignificant but this is masked by the unsuitability of the regression equation to high rainfall/streamflow years. Stream salinity was determined to have an insignificant trend of decrease.

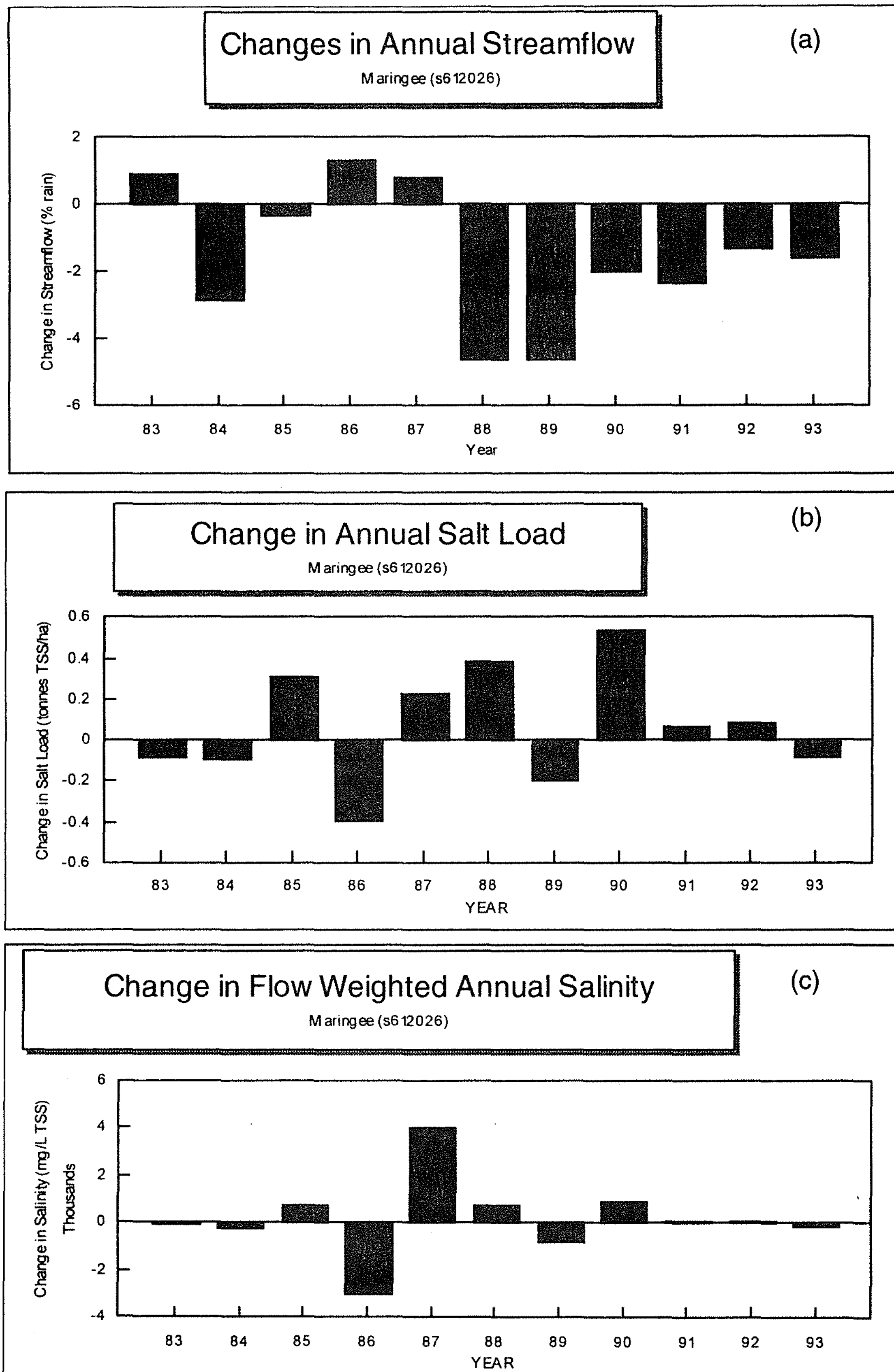


Figure 13 - Maringee catchment changes in streamflow, salinity and salt load

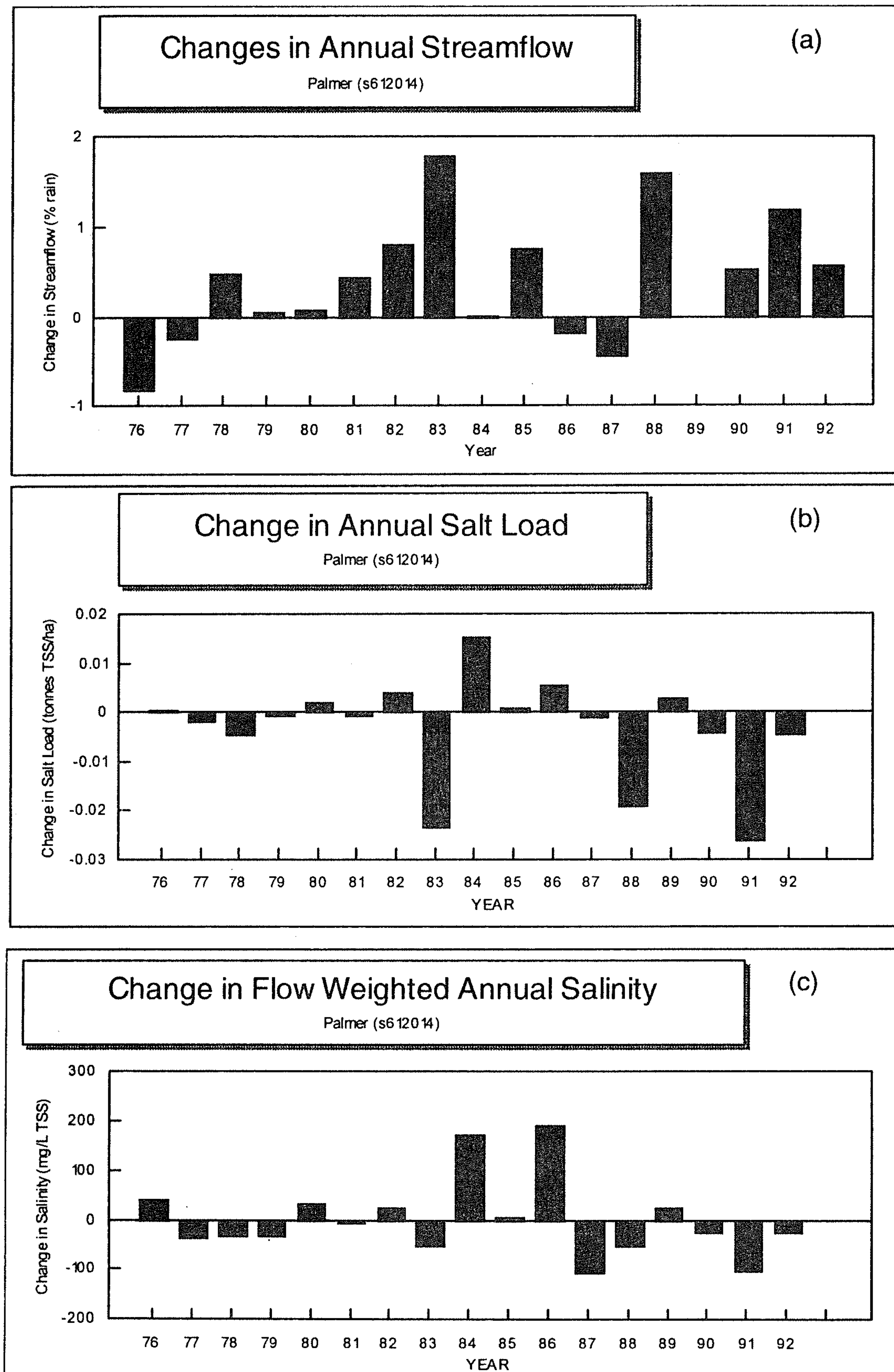


Figure 14 - Palmer catchment changes in streamflow, salinity and salt load

5.4.6 Stenwood

Stenwood catchment is a sub-catchment of the Palmer catchment and is a tributary of Bingham River (Fig. 1,6). Clearing of the 55.4 km^2 catchment is mainly along the river terraces which by 1976 were less than 10% cleared. Reforestation (1978/79) has taken place such that in 1991, calculations based on Landsat imagery determined that 2.0% of the catchment was pasture.

Regression equations were developed using 1980-83 streamflow and rainfall data (Appendix C). Between 1984 and 1987, stream yield had an increasing trend with time (Fig. 15a). Then, from 1988-92, stream yield had a decreasing trend with time. The trend of stream yield changes was analysed for the period 1984-93 and was found to be an insignificant decrease (t-test, 95%). At very least, it can be concluded that stream yield has stopped increasing. It is possible that the apparent increase in streamflow (relative to the regression equation), of the 1984-87 period, was a climatic effect due to low rainfall.

Regression equations (1980-83) relating stream salinity and salt load (Appendix C) to streamflow indicated a significant trend (t-test, 95%) with time of decreasing salt load (Fig. 15b). By 1990, the decrease in salt load was consistently greater than the regression period maximum absolute value. Stream salinity also showed a significant (t-test, 95%) decreasing trend with time (Fig. 15c).

5.4.7 James Crossing

James Crossing has a catchment area of 184.2 km^2 (Fig. 1) of which 31.2% is pasture for sheep and cattle grazing with some cereal production. This catchment has been partially reforested in valleys and lower slopes. Clearing at 1976/77 amounted to about 61% of the catchment area while at 1960 the extent of clearing was only 36% and during the 1940s about 16% had been cleared. Based on estimates made from a rainfall-streamflow regression equation (1975-80) (Appendix C), in some years streamflow was increased by statistically significant amounts (t-test, 95%). The greatest estimated increases were in high rainfall years. Over the period 1975-92 there was a significant trend (t-test, 95%) of increasing stream yield. Between 1981 and 1992, there was no significant trend (t-test, 95%) with time in the changes to stream yield other than response to the climatic (rainfall) variation. The average increase to streamflow (1981-92) was 2.9% of annual rainfall (Fig. 16a).

Stream salt load and salinity were related to streamflow by regression equation for 1967-74 (Appendix C). Estimates of stream salt load based on this equation show increased salt load with a significant (t-test, 95%) increasing trend with time during both 1967-92 (Fig. 16b) and 1975-92 (*i.e.* subsequent to the regression period). The average increase to salt load was 0.583 tonnes TSS ha^{-1} (1975-92) and since 1985 the increase has

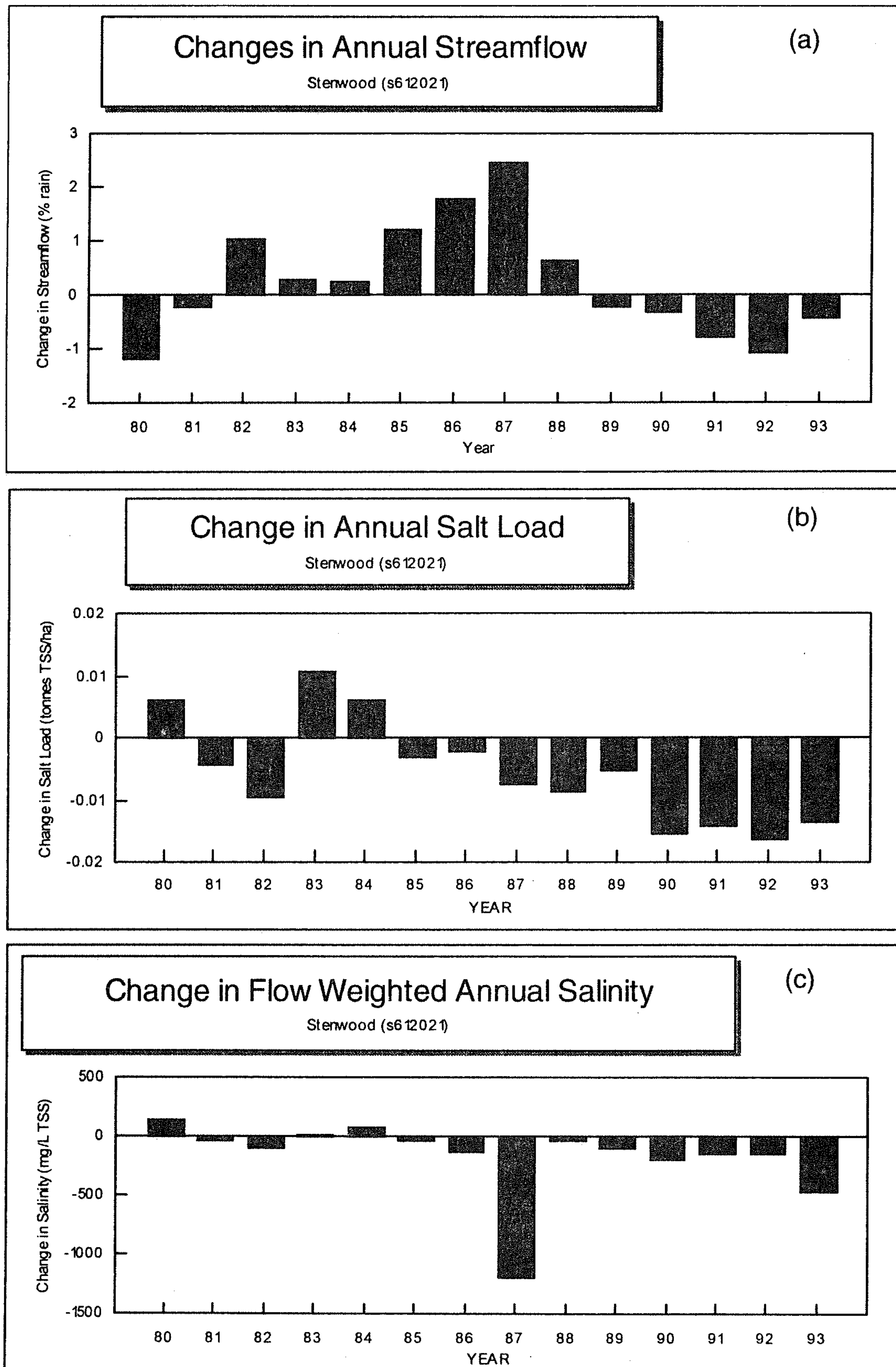


Figure 15 - Stenwood catchment changes in streamflow, salinity and salt load

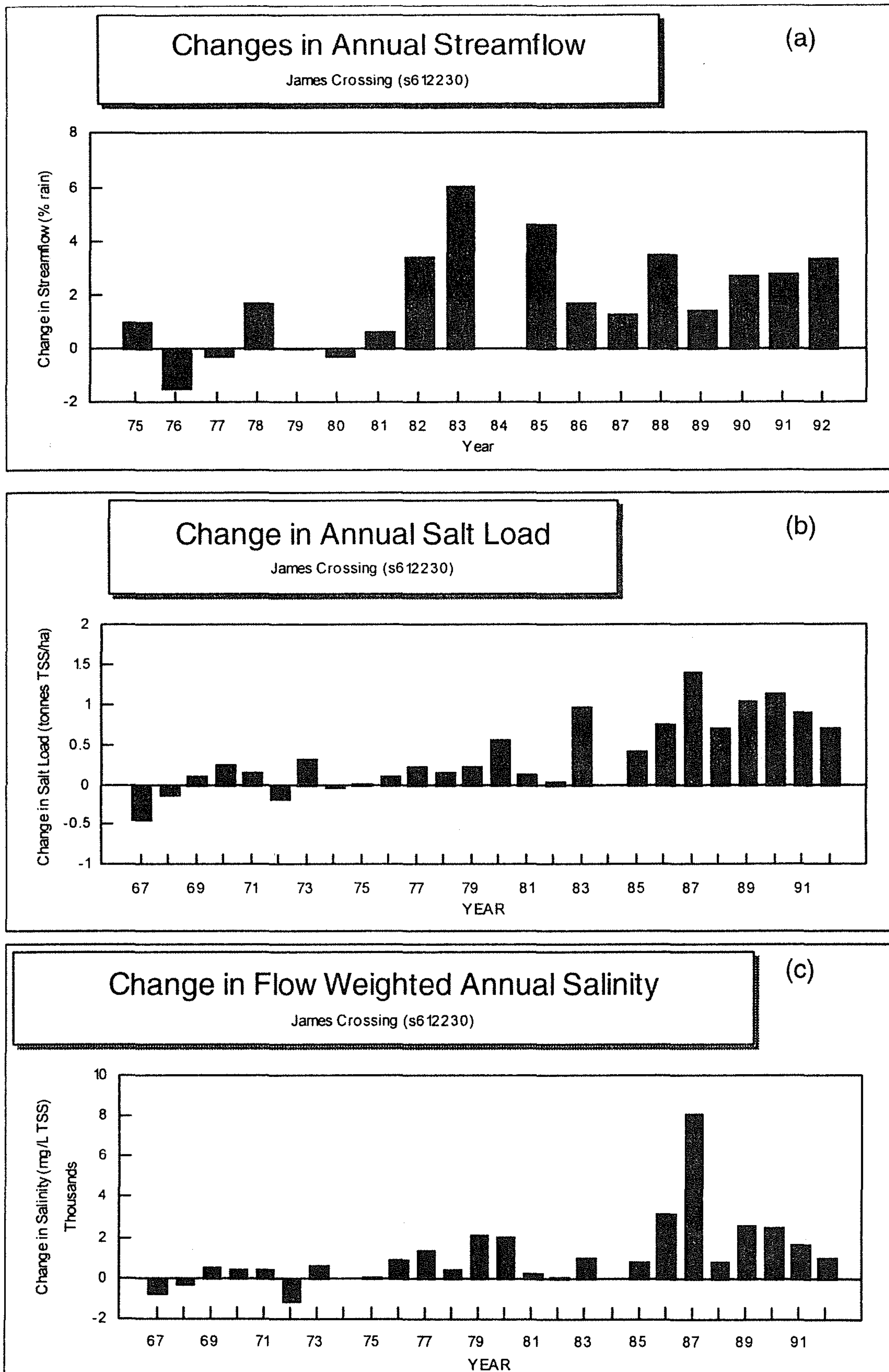


Figure 16 - James Crossing catchment changes in streamflow, salinity and salt load

consistently been above the level of the regression period maximum absolute value. Estimates of stream salinity gave an average increase (1975-92) of 1800 mgL^{-1} TSS (Fig. 16c). The trend over 1967-92 has been for a significant trend (t-test, 95%) of increasing salinity.

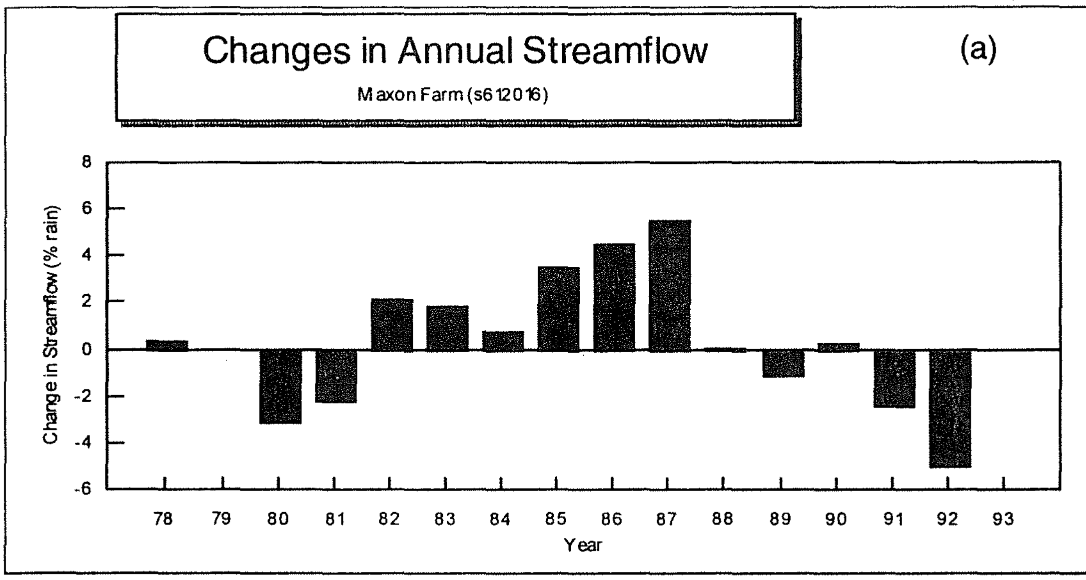
The overall trend for baseflow salinity at James Crossing is to increase with time (Appendix D). As streamflow and salinity in any particular year are inversely related it is possible that increasing baseflow salinity could be associated with a period (of years) of low flow. However, streamflow increased during 1981-92 (Fig. 16a) and therefore the increase to baseflow salinity is not climatic but a real increase. The 5 year back moving average increased from approximately 8200 mgL^{-1} TSS to 15400 mgL^{-1} TSS between 1970 and 1993 which equates to an average rate of increase of 300 mgL^{-1} per year. The trend of increasing baseflow salinity may be levelling out with baseflow salinity declining during 1988-93 though this was associated with relatively higher flow years.

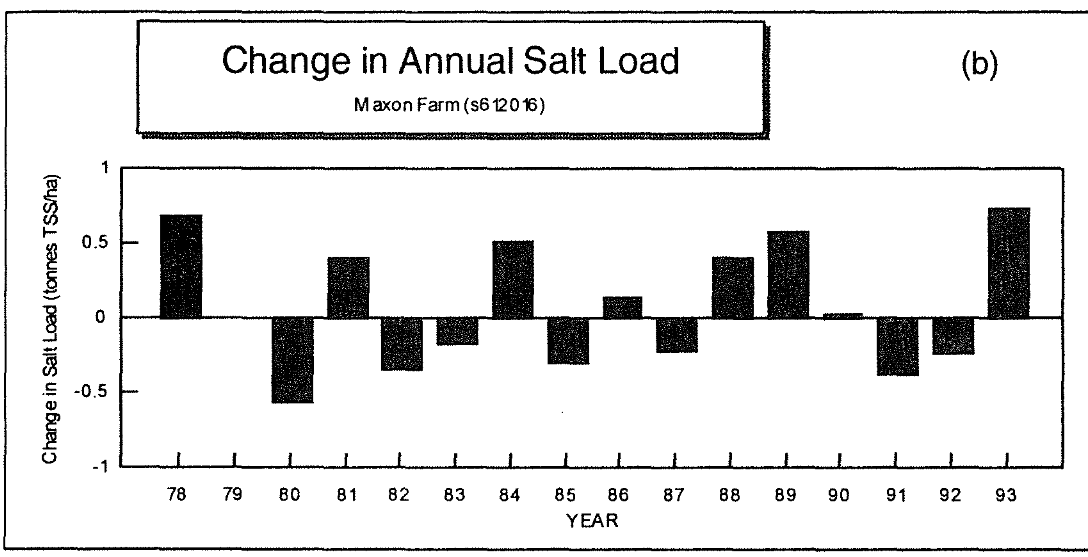
5.4.8 Maxon Farm

Maxon Farm on Batalling Creek is a sub-catchment of the James Crossing catchment and has an area of 16.4 km^2 (Fig. 1,6). Around 1960, the catchment was only about 18% cleared and by 1976/77 clearing amounted to about 53%. Reforestation commenced in 1985 and 25.5% of the area remains as pasture at 1991.

Estimates based on a 1978-84 streamflow-rainfall regression equation (Appendix C) showed an increasing trend with time of streamflow up to 1984 (Fig. 17a) and subsequently a decreasing trend to the end of the study period. The trend in calculated changes to stream yield was for a significant decrease (t-test, 95%) during 1985-93. Thus, it can be concluded that streamflow appears to have stopped increasing in the late 1980s and subsequently began decreasing.

The stream salt load and streamflow data (1978-86) used to develop a regression equation had low correlation (r^2=0.008 for a power fit) (Appendix C). No significant trend (t-test, 95%) with time is evident in the estimated changes to salt load (1987-93) which vary between an increase or decrease (Fig. 17b) in similar fashion to the regression period (1978-86). The stream salinity and flow data have much better correlation (Appendix C) yet the estimated changes in salinity follow the same pattern of trend as salt load (*i.e.* only climatic variation).





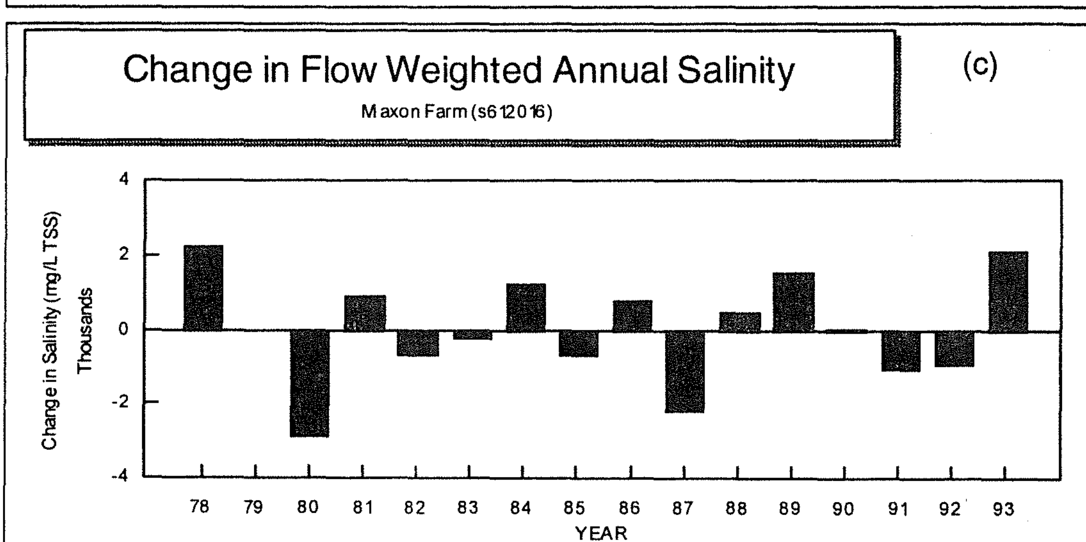


Figure 17 - Maxon Farm catchment changes in streamflow, salinity and salt load

5.5 Relative Contributions of Streamflow and Salt Load

The average streamflow and salt load during 1982-91 from each of the selected catchments was calculated (Table 3). As Mungalup Tower is the last major gauging station on the Collie River before it flows into the reservoir, relative contribution of streamflow and salt load from each catchment to the total recorded at the Mungalup Tower was calculated.

Table 3 - Relative contributions of streamflow and salt load

Gauging Station	Flow (Mm^3)	Load (tonnes TSS)	%Flow	%Load
Coolangatta Farm	48.794	76071	38.1	67.0
Mungalup Tower	127.993	113550	100.0	100.0
Lemon	0.160	93	0.1	0.1
Wights	0.396	200	0.3	0.2
Palmer- Bingham River	6.987	1863	5.5	1.6
Maxon Farm - Batalling Creek	0.718	2863	0.6	2.5
Stenwood - Bingham River	0.564	200	0.4	0.2
James Well	6.678	15528	5.2	13.7
Maringee	0.558	2119	0.4	1.9
South Branch	32.522	26383	25.4	23.2
James Crossing - Collie River (East)	8.209	37502	6.4	33.0

The James Crossing catchment on average contributes 6.4% of the flow but about 33% of the salt load which is a ratio of 5.1. Maxon Farm is a sub-catchment of the James Crossing catchment. Maxon Farm has a ratio of 4.5 contributing only 0.6% of the flow to Mungalup Tower but 2.5% of the stream salt load.

The James Well catchment on average contributes 5.2% of flow but 13.7% of salt load which is a ratio of 2.6. Maringee Farm is a sub-catchment of the James Well catchment. The Maringee catchment has an even higher ratio (4.3) contributing only 0.4% of the flow to Mungalup Tower but 1.9% of the stream salt load.

Coolangatta Farm, to which the eastern catchments drain, contributes 38% of the flow to Mungalup Tower but 67% of the salt load (ratio 1.8). Thus, the eastern catchments produce most of the salt load.

6 DISCUSSION

6.1 Rainfall

Collection of streamflow and groundwater data for many of the sub-catchments in the Wellington Reservoir catchment was initiated in the 1970s or with the establishment of reforestation. Rainfall during this period (1975-90) was about 15% lower than the long term average. Under long term rainfall conditions, the groundwater rise under pasture would have been greater. It is expected that the higher rainfall would effect the magnitude of changes in groundwater levels but not the direction of trends. The average values given for streamflow and stream salt load in Table 3 would also be greater under long term rainfall conditions.

6.2 Vegetation

Collie River salinity at Wellington Reservoir is estimated to have been between 200 and 250 mgL^{-1} TSS before agricultural development (Loh and Anson, 1988). Clearing for agriculture began at the turn of the century and slowly expanded for 30 years then virtually ceased during the depression. Most of this early clearing occurred in the valleys. With the introduction of bulldozers, in the late 1950s and 1960s, land clearing accelerated and extended upslope from the valleys. The expansion of clearing caused salinity deterioration to accelerate in the late 1960s and early 1970s.

Developing concern over the deterioration of Wellington Reservoir inflow salinity led to the government to halt further alienation of crown land for agricultural development in 1960 (Loh, 1988b). Legislation to control large scale clearing on private land was introduced in 1976. Should the level of clearing remain as it was at 1976 it is estimated that salinity will ultimately reach about 1150 mgL^{-1} TSS in a median inflow year (Loh and Anson, 1988). In 1979, a partial reforestation programme was introduced with 6743 hectares being planted by 1994 (G. Kikiros, *pers. comm.*). These plantings are in the eastern (lower rainfall) high salinity hazard areas of the catchment.

Apart from utilising reforestation to mitigate hydrologic forms of land degradation the W. A. Department of Agriculture and the Collie LCDC (Land Conservation District Committee) started a project in 1994 to determine the effect of perennial grasses on water tables in the Pollard Brook catchment (located 15 km downstream of Lemons catchment). Perennial grasses have not been a major part of the agricultural system of south-western Australia. However, recent research has shown that perennial grasses are able to dry out the soil profile as well as providing additional, and out of season feed. A benefit of having out of season feed would be the reduction of grazing pressure on remnants during summer. Improving the water use of pasture areas in the Wellington catchment is expected to lower groundwater tables and ultimately reduce discharge of saline groundwater to streams.

After 5 years of reforestation at Padbury Road catchment (located about 50 km south of Wellington catchment) streamflow and salt load began a systematic reduction with time (Bari, 1992b). The catchment was 63% cleared at 1976 then by 1992, 72% of the cleared area had been reforested. By contrast, Stenwood catchment first showed reductions in stream salt load that were greater than the regression period maximum absolute value after 10 years of reforestation and streamflow had ceased increasing within that period (Fig. 15a,b). Maringee Farm (Fig. 13a,b) and Maxon Farm (Fig. 17a,b) appear to be more like Stenwood than Padbury Road in their response to reforestation as streamflow and salt load had not decreased after 5 years of reforestation.

Loh and Anson (1988) recorded that the inflow salinity for Wellington Reservoir is not expected to reduce till the mid to late 1990s and then stabilise at a new equilibrium level around 2010. While groundwater levels appear to have a new equilibrium 10 years after reforestation (Bari and Boyd, 1994), the experience at Stenwood indicates that streamflow and salt load have not begun to be reduced till 10 years after reforestation (the magnitude of these changes while consistently reductions are not yet significant at the 95% level). Considering that most of the reforestation was planted in the 1980s, streamflow and stream salt load are anticipated to begin reducing about 10 years after the time of planting. On the basis of this time interval, the reduction in streamflow and salt load from these catchments is expected to first be apparent by the mid to late 1990s.

6.3 Livestock Grazing on Native Vegetation

In administering the Catchment Clearing Control legislation (1976) it was accepted that there would be limited use of areas of remnant vegetation left on farmland for stock shelter and grazing. These concessions were made in negotiations regarding compensation claims by farmers for not being able to fully develop their land. This was based on the premise that degradation would be minimal. However, Pettit and Froend (1994) record that the majority of native vegetation remaining on farmland (remnants) in the Wellington catchment are in poor condition. Continuous grazing over a number of years eventually results in loss of understorey species, weed invasion and passive clearing as old trees die and are not replaced. If only 20% of the area of remnants were lost then this loss of tree cover would negate the efforts of the reforestation programme (Pettit and Froend, 1994). Therefore, management and protection of remnant vegetation is an important part of controlling the inflow salinity to Wellington Reservoir.

6.4 Groundwater Levels and Salinity

Groundwater levels under pasture increased over the study period. At Dons catchment (near Lemon catchment), the groundwater under native forest declined by 2.3m during 1977-89 (Ruprecht and Schofield, 1991b). The falling levels under native forest is likely a climatic response due to below average rainfall. The effect of reforestation was to reverse the trends seen under pasture resulting in falling groundwater levels.

The most successful of the reforestation strategies was the extensive, dense planting at Stene's arboretum site which substantially lowered the saline groundwater table across the valley floor. This had the effect of eliminating saline groundwater discharge to the stream in a short (~10 years) period of time. However, Bari *et. al* (1991) considered extensive reforestation had limited application in agricultural areas and is more appropriate for land of little agricultural value as a result of salinization.

Of the three reforestation strategies trialed at Stene's Farm the extent of groundwater table lowering appeared in proportion to the percentage of cleared area reforested. The groundwater table at the arboretum (70% of cleared area reforested) declined 8.0m relative to pasture, agroforestry (56%) declined 2.0m and the valley site (35%) declined 1.68m. Though the agroforestry and valley reforestation sites are not directly comparable as the agroforestry has lower average stem density and crown cover. This could explain why the agroforestry site decline in water table was only slightly greater than at the valley site as although a greater fraction of the cleared area at the agroforestry site was planted this is partly offset by the lower percentage crown cover.

Clearing of the Stenwood catchment at 1976 was less than 10% of the area. After reforestation, the remaining pasture area amounted to only 2.0% at 1991. The changes in groundwater level due to greater water use by trees compared to pasture has led to declining groundwater tables under reforestation while bores in pastured locations recorded rising groundwater levels (Fig. 4b). Thus, the decline in groundwater table is attributed to the reforestation. Changes in streamflow, salt load and stream salinity were determined from regression equations developed for the period when the reforestation was first planted. As the reforestation has grown and reduced groundwater levels - streamflow, stream salinity and salt load have begun a decreasing trend. Since 1990, the decrease to stream salt load has been distinguishable from the maximum absolute value in the period used to calculate the regression equations. Thus, 12-14 years after the first plantings stream salt load is consistently reduced but not yet by a statistically significant magnitude (Fig. 15b).

Groundwater salinity reduced at most sites with the greatest reductions recorded at pasture bores. The reduction of groundwater level combined with reduction in groundwater salinity will lead to reduced quantity and salinity of saline groundwater discharge to the streams. In the case of reduced groundwater salinity under pasture it is uncertain whether the net effect will be reduced saline groundwater discharge to the streams as while the concentration (salinity) is reduced the volume has increased due to rising groundwater levels under pasture.

At Maringee Farm, groundwater salinity beneath pasture reduced an average of 15% over eight years. Under reforestation the average decrease was 3% (Bari and Boyd, 1992). Thus, at least on average, evaporative concentration has not increased groundwater salinity. Presumably, the processes of solute leaching from the aquifer and solute deposition in the unsaturated zone has occurred faster than concentration due to evapotranspiration by the reforestation.

6.5 Baseflow Salinity

Baseflow salinity is the salinity of flow at the end of the flow season when the dominant component of streamflow is likely to be saline groundwater discharge. The baseflow salinity was determined at South Branch (1952-93), James Crossing (1966-93) and James Well (1982-92) (Appendix D). At each of these gauging stations the overall trend with time is for baseflow salinity to increase. Generally, stream salinity in a particular year is inversely related to streamflow. While baseflow salinity had an increasing trend, streamflow did not decline (Appendix D). Therefore, the increase to baseflow salinity is considered a real increase rather than a climatic response.

The streamflow record for South Branch starts in the early 1950s and as baseflow salinity was increasing from the beginning of the record (Appendix D) the trend of increasing baseflow salinity precedes the lower than average rainfall of 1975-90. This suggests that the trend of increasing baseflow salinity is not a response to long term climate trends but rather a response to agricultural clearing. Baseflow salinity has not increased since the early 1980s. Stream salinity (1975-93) had increased relative to 1953-74 but did not have an increasing trend with time. The reaching of a plateau in the baseflow salinity, coupled with no apparent increasing trend with time of stream salinity, is evidence indicating stream salinity may be reaching an equilibrium in the south branch of Collie River. While low flow (low rainfall) years are associated with high salinity, a sequence of low flow years can reduce groundwater levels and hence reduce saline groundwater discharge to the stream. Therefore, it is possible that the cessation of increases to baseflow salinity since the early 1980s was a response to the lower than average rainfall of 1975-90.

At Maxon Farm (Batalling Creek), a sub-catchment of James Crossing, the average groundwater salinity was 12000 mgL^{-1} TSS with the maximum being about 25000 mgL^{-1} TSS. The maximum recorded baseflow salinity at James Well is of similar magnitude. As the baseflow is likely to be dominated by groundwater discharge the upper limit that baseflow salinity can increase to is the salinity of the groundwater discharge. By 1987, the baseflow salinity at James Crossing appeared to have reached this level. Stream salinity (1975-92) while increased relative to 1967-74 has an insignificant trend (t-test, 95%) with time of increase. The absence of increasing trend in stream salinity together with baseflow salinity tending to plateau suggests stream salinity may be reaching equilibrium at James Crossing. As streamflow in recent years does not have any obvious trend of increase with time (Fig. 16a) it can be inferred that the volume of saline discharge is also not increasing with time.

Reforestation commenced at Maxon Farm in 1985. The greater water use of these trees is expected to reduce groundwater levels and thus reduce saline discharge to the stream. Groundwater levels are expected to approach a new equilibrium after 10 years of reforestation. An additional five years of data may be necessary to distinguish trends with time from climatic variation. Therefore, further years of data will be necessary to determine the effect of the reforestation on stream salinity and baseflow salinity.

6.6 Streamflow and Salinity

Stream salinity in the eastern catchments remains very high. At Maringee Farm the 1982-91 average salinity was 6300 mgL^{-1} TSS and at Maxon Farm 5370 mgL^{-1} TSS. Water of salinity greater than 5000 mgL^{-1} TSS is classified as saline and the upper limit for fresh water is 500 mgL^{-1} TSS (Steering Committee, 1989). Thus, the streamflow for the more eastern catchments is saline according to water resources classifications.

Reforestation at Maxon Farm commenced in 1985. It is apparent that streamflow has stopped increasing and a significant decreasing trend (t-test, 95%) has now started. The cessation of the increase to streamflow coincides with the halt in the expansion of the saline seep area due to reforestation. Previously this seep areas expansion would have resulted in greater surface runoff and the rising groundwater levels would have given increasing throughflow. The effect of the reforestation in halting the seep area expansion and reducing groundwater levels is to lessen surface runoff and throughflow thereby ending the trend of increasing streamflow. Some delay is expected before the reduction in groundwater levels results in lower stream salt loads as accumulated salts in the valley bottom must first be flushed out.

In the Stenwood catchment, reforestation has reduced groundwater levels with the corresponding result of an end to the trend of increasing streamflow. This trend is now reversed such that streamflow is reducing and stream salinity and salt load have a significant (t-test, 95%) decreasing trend.

Stenwood catchment is so far the only catchment on the eastern boundary of the Wellington catchment to show a trend of reducing salinity and salt load over time. This is probably due to the extent of the reforestation and also the early date (1978/79) of the reforestation. At 1976, Stenwood was less than 10% pasture then subsequent to reforestation only 2.0% of the catchment remained as pasture at 1991. Thus, reforestation covers a significant proportion of the cleared area. By comparison, Maringee Farm was 55% cleared at 1976 and 29.1% pasture at 1991 also Maxon Farm was 53% cleared at 1976 and 25.5% pasture at 1991. Reforestation at Maringee Farm and Maxon Farm had the effect of reducing groundwater levels. Maringee Farm has decreased streamflow and increased stream salt load relative to the regression equations although these changes are not of significant magnitude. At Maxon Farm streamflow, salinity and salt load appear to no longer be increasing. Thus, reforestation has so far been sufficient to quell further increases to groundwater levels, streamflow, stream salinity and salt load. Eight years after reforestation at Maxon Farm, a trend has not yet emerged whereas at Stenwood a trend was evident within five years and became statistically significant after ten years. The less extensive planting approach at Maringee Farm and Maxon Farm would be producing similar results to Stenwood but at a slower rate.

Stenwood catchment is a tributary of Palmer catchment which was less than 10% cleared at 1976 then by 1991 reforestation had left 3.0% as pasture. Streamflow is increasing at an insignificant rate but stream salinity and salt load have an insignificant trend of decrease. The high proportion of reforestation in this catchment is likely the reason for the absence of any increasing trend in stream salinity and salt load.

The magnitude of the stream salinity response to clearing is affected by the extent and location of agricultural clearing. The trend is for more extensively cleared areas to give greater increases in salinity. The rate of increase in salinity with area cleared is greater the lower the average rainfall (Collins and Fowlie, 1981; Schofield *et al.*, 1988). James Well and James Crossing catchments have low rainfall (<650mmyr^{-1}) and at 1976 were more than 50% cleared for agriculture. Together these two catchments produce only 11.6% of the streamflow to Mungalup Tower but contribute 47% of the salt load. Therefore, these catchments being the main cause of the salinity problem ought also be the focus of efforts to manage and reduce the Collie River salinity. Further, reforestation in these catchments can have large impact on the salt load with minor effect on water yield of Wellington Reservoir.

6.7 Inflow Salinity to Wellington Reservoir

The inflow salinity is the dominant factor affecting the quality of supply from Wellington Reservoir though there is some scope to operate the reservoir to minimise supply salinity. Land use and flow regulation have important effect on the inflow salinity. Historically, agricultural clearing has led to increased stream salinities in the Wellington Reservoir catchment. The current reforestation programme has as its objective to control stream salinity. An important regulation of flow is Harris Dam which was built to reduce the supply salinity to the GSTWS.

The Harris Dam was constructed in 1989. A stream gauging station on Harris River at Tallanalla Road measured flow weighted annual stream salinity as averaging 250 mgL^{-1} TSS (1977-88). Thus, the Harris River yields fresh water. The contribution to streamflow at Mungalup Tower is 17.8% whereas the contribution to salt load is only 4.8%. Therefore, the damming of the Harris River will cause an increase to the stream salinity at Mungalup Tower and to the inflow salinity of Wellington Reservoir. Based on average figures for 1982-91 the increase to Wellington inflow salinity attributable to Harris Dam is less than 70 mgL^{-1} TSS.

Inflow salinities to Wellington Reservoir are not expected to reduce until the mid to late 1990s (Loh and Anson, 1988). The analysis of this report may therefore detect reducing groundwater levels and the beginnings of changes or slowing of streamflow and salinity increases. However, as five to ten years data are a minimum to distinguish minor trends from climatic variation it is too early to notice any reduction in inflow salinity. Based on the trends in salinity at different gauging stations an understanding of the future trend in inflow salinity can be developed. Mungalup Tower has a trend of increasing stream salinity and salt load. In fact all the gauging stations that serve a large area are calculated as having increasing salinity and salt load although the magnitude of increase is in some cases not big enough to be significant. The smaller catchments on the eastern boundary of the Wellington catchment are just beginning to display the effect of reforestation.

Stenwood catchment, reforested by 1979, has a trend of reducing stream salinity and salt load. Maxon Farm, reforested more recently in 1985, has a trend of decreasing groundwater level and appears to have ceased increasing in streamflow, salinity and salt load. As these eastern catchments, which contribute much salt load but relatively little streamflow, further decrease in their salt load output the reduction will soon be sufficient to counteract the increasing salinity from the other, but lower salinity hazard, catchments. The effect will be for the inflow salinity to stop increasing and decline.

6.8 Management of the Inflow Salinity

The catchment of the Wellington Reservoir can be considered as 5 main sub-catchment areas. These are the Harris Reservoir catchment area, Bingham River, Collie River - East branch, Collie River - South branch and Collie River West. Comparison of these areas and their land uses will be made to determine their relative importance to the management of the inflow salinity to Wellington Reservoir.

The effect of the Harris Dam on the inflow salinity has been considered in Ch. 6.7. The increase to Wellington inflow salinity attributable to Harris Dam is less than 70 mgL^{-1} TSS. This effect can be managed by releasing fresh water from the Harris Reservoir allowing it to contribute to the Wellington Reservoir inflow.

In the western part of the catchment, rainfall is high and thus there is low salinity risk. Streams of this area are generally fresh and there is limited agricultural clearing (Fig. 2). Thus, focussing management efforts in this area would produce little improvement to the inflow salinity.

Streamflow measured at Palmer gauging station on the Bingham River had an average salinity (1982-91) of 370 mgL^{-1} TSS which is fresh according to water resources classifications. The Palmer catchment produces 5.46% of the flow to Mungalup Tower but only 1.64% of the salt load (Table 3). Thus, Bingham River makes a relatively minor contribution to the problem of high inflow salinity to Wellington Reservoir.

Collie River - South branch had an average inflow salinity of 960 mgL^{-1} TSS (1982-91). The current trends (1975-93) are for significantly increasing (t-test, 95%) stream yield but for insignificantly decreasing stream salt load and salinity. Much of the agricultural clearing in this sub-catchment is on the lower rainfall, eastern side (Fig. 2). Efforts to reduce the stream salt load from this catchment has potential to impact the inflow salinity but not as markedly as the Collie River - East branch (excluding the Bingham River sub-catchment).

Collie River - East branch (excluding the Bingham River sub-catchment) contributes 32.66% of the streamflow to Mungalup Tower and 65.35% of the salt load. Therefore, this sub-catchment is the main producer of stream salt load to Mungalup Tower. Stream salt load and salinity measured at the Coolangatta Farm gauging station have significant (t-test, 95%) trends of increase. The average (1983-91) annual rate of increase of stream salinity is 47 mgL^{-1} TSS. As this sub-catchment is the primary source of the problem of high inflow salinity it is therefore appropriate to concentrate management efforts in this area.

The stream salinity of the East branch (2040 mgL^{-1} TSS) during 1982-91 was at least twice that of the South branch (960 mgL^{-1} TSS) (Table 2). If salinity of the East branch was reduced to the same level as the South branch then the inflow salinity to Wellington Reservoir would have averaged 565 mgL^{-1} TSS rather than 705 mgL^{-1} TSS. Thus, inflow salinity would be about 140 mgL^{-1} TSS less which represents a reduction of 20%.

7 CONCLUSIONS

7.1 Rainfall

(i) Rainfall in the Wellington Reservoir catchment was about 15% lower than the long term average during 1975-90.

(ii) Moving from west to east (heading inland) across the catchment the long term average rainfall decreases.

7.2 Land Use

(i) The catchment area to Mungalup Tower was 24% cleared in 1976. Catchment The area cleared in 1960 was 12% and in the 1940s was 8%. Clearing Control legislation was introduced in 1976 and since then the demand for clearing has reduced.

(ii) Since 1978, clearing licences have been issued for 89.7 km^2 of the Wellington Reservoir catchment while licences were refused for 139.7 km^2 of the area. The number of refusals of clearing licence applications has declined since 1978. Thus, demand for further clearing of the land has reduced.

(iii) A partial reforestation scheme commenced in 1979/80. Reforestation by the Water Authority amounted to 6743 hectares at 1994. Much of the reforestation is in the 600-700 $mmyr^{-1}$ rainfall zone of the catchment.

7.3 Groundwater

(i) The groundwater transects investigated are in the low rainfall, eastern part of the Wellington Reservoir catchment. Trends in groundwater levels in pastured areas were for increasing groundwater levels and those bores under pasture but just upslope of reforestation showed a small reduction in groundwater level. Groundwater levels in the midst of reforestation had the greatest decline. As groundwater levels under reforestation declined relative to the pasture (control) sites the changes are attributed to the reforestation rather than climatic effects.

(ii) Reforestation at the Stene's arboretum site covered 70% of the cleared area. This extensive high density reforestation resulted in groundwater level reducing by 7.3m (1979-93) and the decline relative to pasture was 8.0m. Compared to the other planting strategies employed at the various groundwater transects investigated, Stene's arboretum had the greatest reduction of groundwater level.

7.4 Streamflow

(i) Stream yield was found to be increasing at all the selected sub-catchments apart from Stenwood, Maxon Farm and Maringee. Maringee and Stenwood have insignificant trends of decreasing stream yield whereas at Maxon Farm the trend of decreasing stream yield was significant (t-test, 95%).

(ii) Coolangatta Farm, to which the eastern catchments drain, contributes 38% of the flow to Mungalup Tower but 67% of the salt load (ratio 1.8). Thus, the eastern catchments produce most of the salt load.

(iii) The James Crossing catchment on average contributes 6.4% of the flow but about 33% of the salt load which is a ratio of 5.1.

(iv) The James Well catchment on average contributes 5.2% of flow but 13.7% of salt load which is a ratio of 2.6. Maringee Farm is a sub-catchment of the James Well catchment. The Maringee catchment has an even higher ratio (4.3) contributing only 0.4% of the flow to Mungalup Tower but 1.9% of the stream salt load.

7.5 Stream Salt Load and Salinity

(i) Most of the gauging stations recorded trends of increasing flow weighted annual stream salinity and salt load. However, some of the sub-catchments with reforestation had no significant trend. Stenwood catchment had a significant decreasing trend in stream salt load and salinity.

(ii) The inflow salinity to Wellington Reservoir for a median flow year has increased from 280 mgL^{-1} TSS in 1945 to approximately 1030 mgL^{-1} TSS in the 1991/92 water year.

7.6 Base Flow Salinity

(i) The baseflow salinity was determined at South Branch (1952-93), James Crossing (1966-93) and James Well (1982-92). At each of these gauging stations the overall trend with time is for baseflow salinity to increase.

8 RECOMMENDATIONS

- The hydrological monitoring programme should be continued at the present level. Continuous stream salinity data should be monitored at all gauging stations.

- James Well and James Crossing are identified as producing 47% of the stream salt load to Mungalup Tower but only 11.6% of the streamflow. These catchments are therefore of significance to managing the inflow salinity of Wellington Reservoir. Maxon Farm is a sub-catchment of James Crossing and Maringee Farm a sub-catchment of James Well. These smaller catchments also have useful data (stream gauge, groundwater network). Monitoring of the groundwater levels and salinity at these sites should be continued to further the understanding of the effect of reforestation on reducing groundwater levels and reducing saline groundwater discharge.

- At Maringee Farm data collection ought be continued and then analysed after a further 5 or more years. The aim of this future review would be to assess any changes or trends occurring in streamflow and stream salinity, groundwater levels and groundwater salinity as a consequence of the reforestation.

- An Integrated Catchment Management plan should be developed including consideration of remnant vegetation, reforestation, forest regeneration and high water use agricultural systems. The focus of this plan should, as a priority, seek to reduce the stream salt load from the Collie River East branch (excluding Bingham River).

- It is suggested that the Wellington Reservoir catchment be computer modelled to determine what level of improvement in stream salinities may be possible from reforestation and other catchment management activities. This would have application in the development of catchment management plans.

- A strategy for the management of remnant vegetation should be implemented. Grazing by livestock has degraded the majority of areas of remnant vegetation in the Wellington Reservoir catchment. The potential loss of these areas would negate the clearing bans and reduce the effectiveness of the reforestation programme. This remnant vegetation strategy would serve to protect existing remnants and allow degraded remnants to regenerate.

9 ACKNOWLEDGMENTS

We are grateful to the regional staff of the Water Authority of WA for all the hydrological data collection.

To the staff in the Water Resources Division of the Water Authority of WA :-

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- We are grateful to John Ruprecht, Ray Froend and Geoff Mauger who reviewed the report and made helpful suggestions.

10 REFERENCES

Bari, M. A. (1992a). Early Streamflow and Salinity response to Partial Reforestation at Batalling Creek Catchment in the south-west of Western Australia. Water Authority of WA. Rep. No. WS 107.

Bari, M. A. (1992b). Early Streamflow and Salinity response to Non-Valley Reforestation at Padbury Road Catchment in the south-west of Western Australia. Water Authority of WA. Rep. No. WS 114.

Bari, M. A., Schofield, N. J. and Boyd, D. W. (1991). Groundwater Level and Salinity response under Agroforestry at Stene's Farm in the Darling Range of Western Australia. Water Authority of WA. Rep. No. WS 77.

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 WA. Rep. No. WS 98.

Bari, M. A. and Boyd, D. W. (1994). A Review of Reforestation Experiments to Control Land and Stream Salinity in Western Australia. Water Authority of WA. Rep. No. WS 141.

Collins, P. D. K. and Fowlie, W. G. (1981). Denmark and Kent River basins water resources survey. Public Works Dept. W. A., Rep. No. WRB 7.

Department of Conservation and the Environment. (1980). Atlas of Natural Resources: Darling System, Western Australia. Map 2: Landforms and Soils.

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

Hookey, G. R. (1985). Groundwater simulation on the effect of catchment clearing and partial reforestation on Maxon Farm, Batalling Creek. Public Works Department, W. A. Rep. No. WRB 123.

Hookey, G. R. and Loh, I. C. (1985). Hydrodynamic Simulation of the Mixing Processes and Supply Salinities of the Harris-Wellington Two Dam System. Water Authority of W.A. Rep. No. WH 1.

Karafilis, D. W. and Ruprecht, J. R. (1993). Harris-Wellington Reservoir System Yield and Salinity Study. Water Authority of W.A. Rep. No. WS 130.

Loh, I. C. (1988a). The History of Catchment and Reservoir Management on Wellington Reservoir Catchment, Western Australia. Water Authority of W. A. Rep. No. WS 35.

Loh, I. C. (1988b). Observed Changes in the Inflow Salinity to Wellington Reservoir, Western Australia. Water Authority of W.A. Rep. No. WS 34.

Loh, I. C. and Anson, B. (1988). Wellington Dam Catchment Regeneration. Water Authority of W. A. Rep. No. WS 16.

Pettit, N. E. and Froend, R. H. (1994). Livestock Grazing on Native Vegetation in the Wellington Reservoir Catchment. Water Authority of W. A. Rep. No. WS 143.

Public Works Department. (1984). Streamflow Records of Western Australia to 1982. Vol. 1. Basins 601-612. Public Works Department, Western Australia.

Ruprecht, J. K. and Schofield, N. J. (1991a). The Effect of Partial Clearing on the Hydrology and Salinity of Lemon Catchment. Water Authority of WA. Rep. No. WS 74.

Ruprecht, J. K. and Schofield, N. J. (1991b). The Effect of Partial Clearing Treatments on the Hydrology and Salinity of Dons Catchment. Water Authority of WA. Rep. No. WS 75.

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. Rep. No. WS 33.

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 W. A. Rep. No. WS 27.

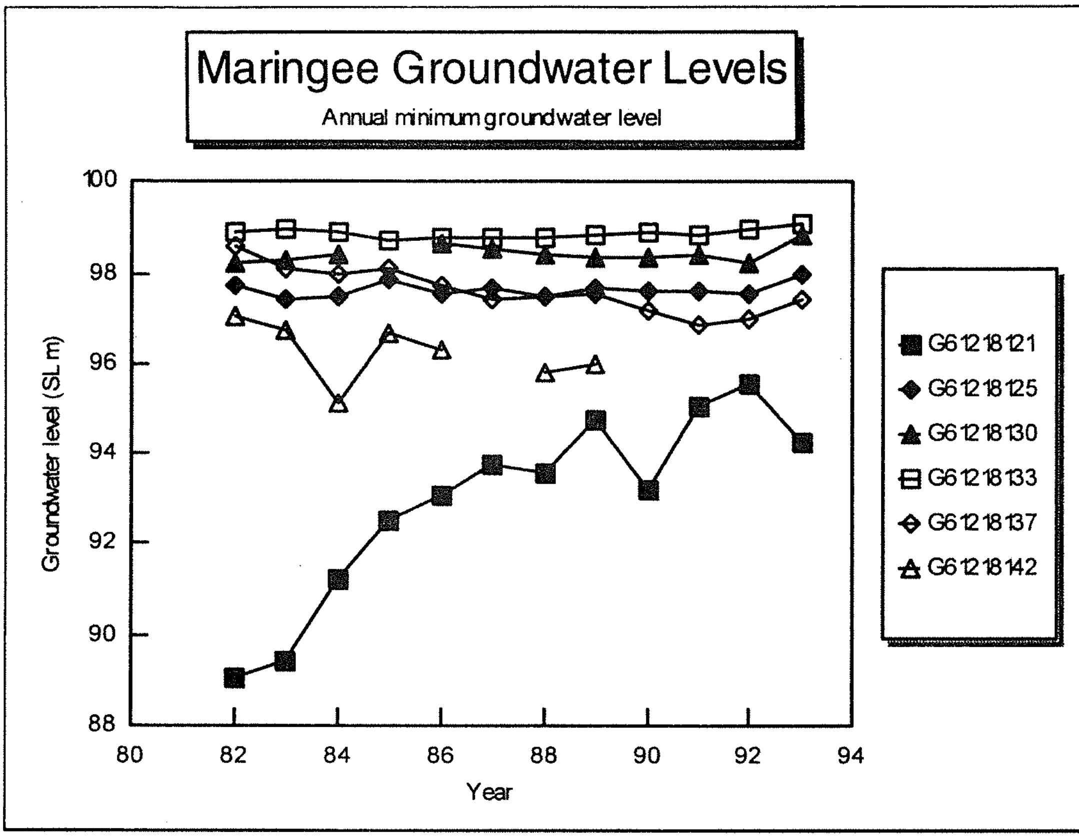
Select Committee on Salinity (Legislative Council of Western Australia). (1988). Stream Salinity Issues in Western Australia and Approaches to their Management. Water Authority of W. A. Rep. No. WS 14.

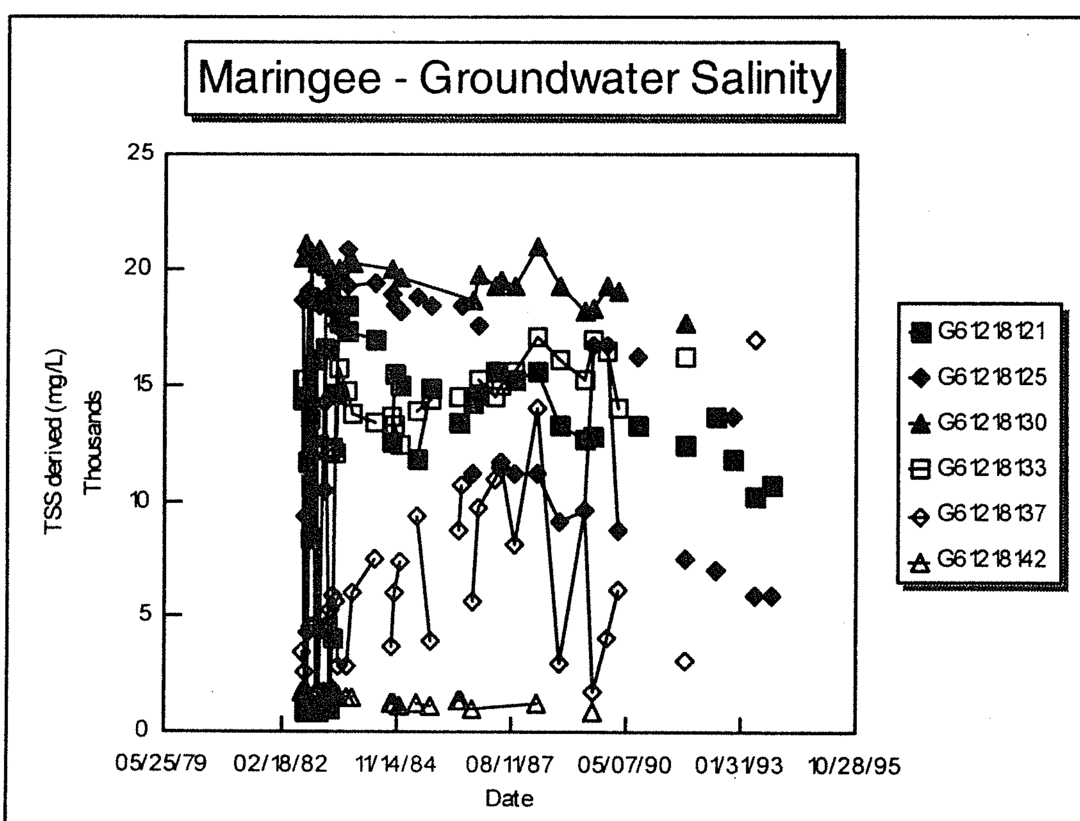
Steering Committee for Research on Land Use and Water Supply (Western Australia). (1989). Stream Salinity and its Reclamation in the south-west of Western Australia. Water Authority of W. A. Rep. No. WS 52. p. 23.

Ventriss, H. B. (1988). *Collie Coal Basin Water Resources Management Strategy*. Water Authority of W. A. Rep. No. WG 60. p. 2.

Waugh, A. S. (1984). Catchment Modelling Collie River. Public Works Department, W. A. Rep. No. WRB 87.

APPENDIX A Groundwater bore data - levels, salinity


Maringee Groundwater Levels
Annual minimum groundwater level
Groundwater level (SL m)
100
98
96
94
92
90
88
80
82
84
86
88
90
92
94
Year
G61218121
G61218125
G61218130
G61218133
G61218137
G61218142


Maringee - Groundwater Salinity
TSS derived (mg/L)
Thousands
25
20
15
10
5
0
05/25/79
02/18/82
11/14/84
08/11/87
05/07/90
01/31/93
10/28/95
Date
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G61218125
G61218130
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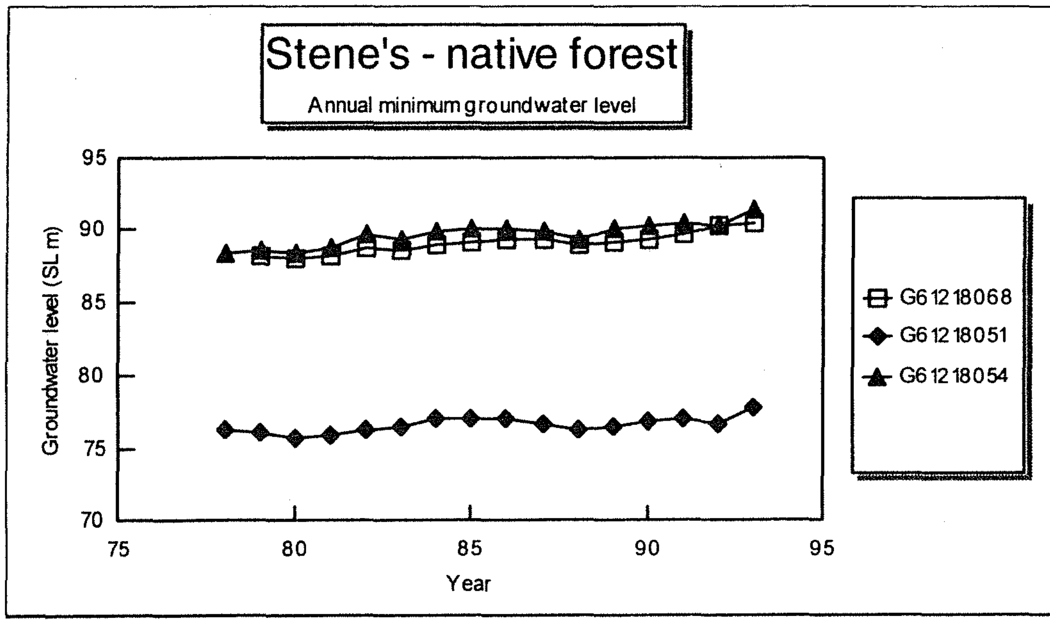
G61218137
G61218142


Stene's - native forest
Annual minimum groundwater level
Groundwater level (SL m)
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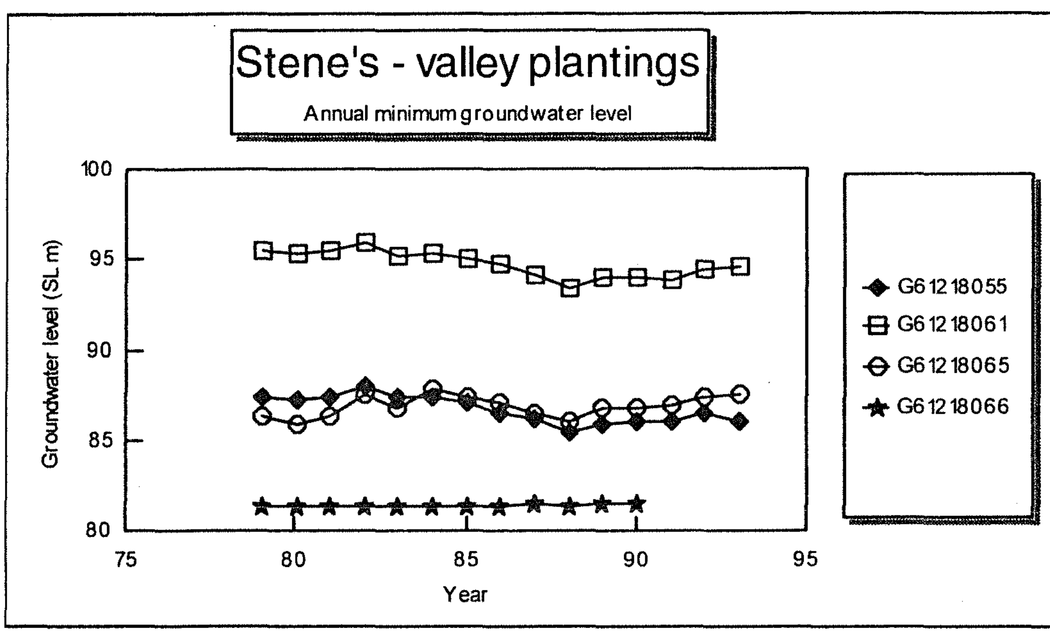
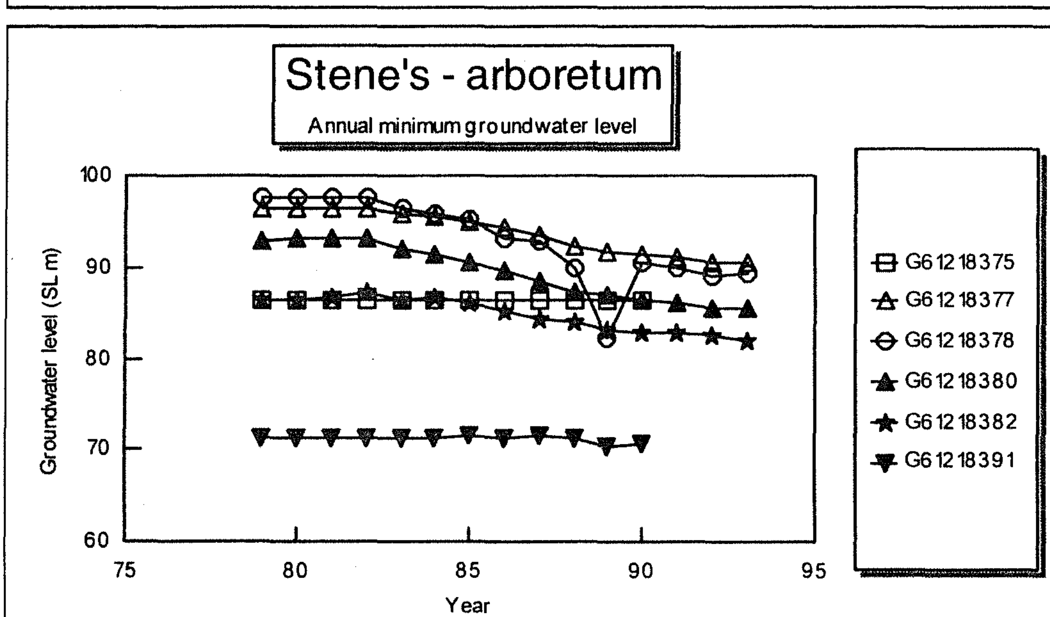
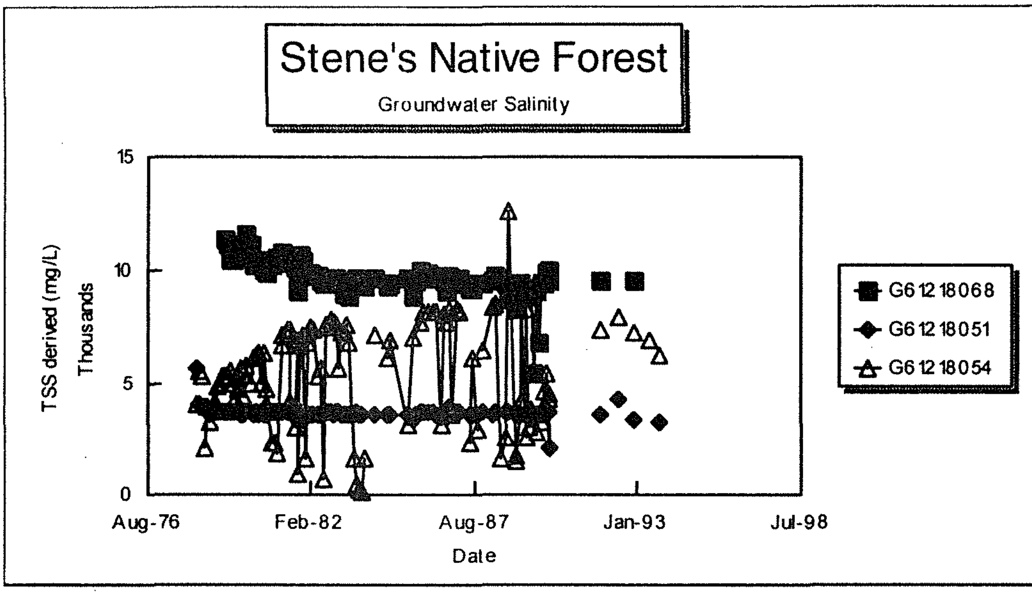
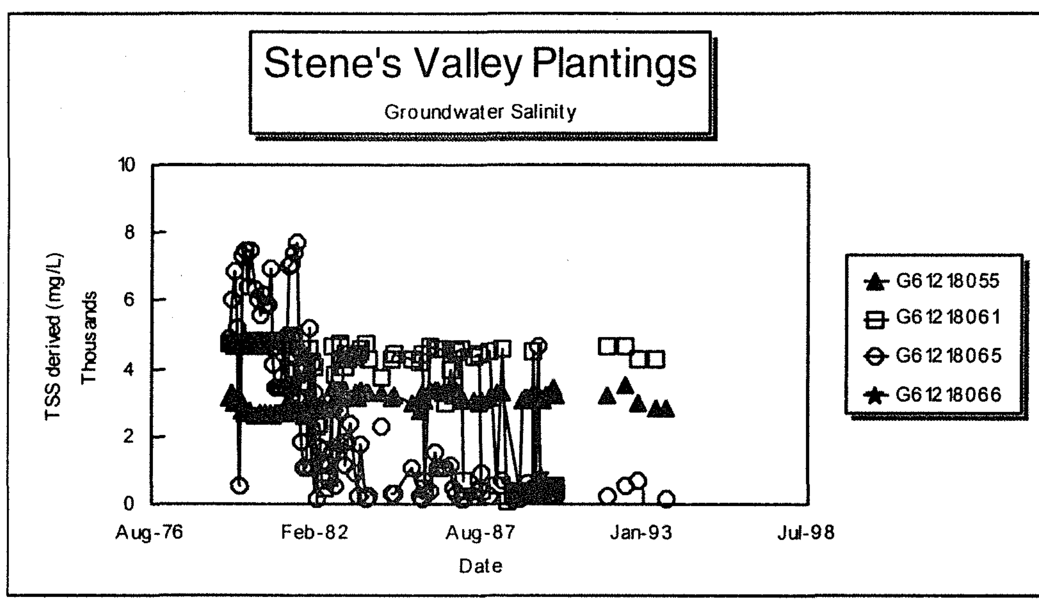
90
85
80
75
70
75
80
85
90
95
Year
G6 12 18068
G6 12 18051
G6 12 18054


Stene's - valley plantings
Annual minimum groundwater level
Groundwater level (SL m)
100
95
90
85
80
75
80
85
90
95
Year
G6 12 18055
G6 12 18061
G6 12 18065
G6 12 18066


Stene's - arboretum
Annual minimum groundwater level
Groundwater level (SL m)
100
90
80
70
60
75
80
85
90
95
Year
G6 12 18375
G6 12 18377
G6 12 18378
G6 12 18380
G6 12 18382
G6 12 18391


Stene's Native Forest
Groundwater Salinity
TSS derived (mg/L)
Thousands
15
10
5
0
Aug-76
Feb-82
Aug-87
Jan-93
Jul-98
Date
G6 12 18068
G6 12 18051
G6 12 18054


Stene's Valley Plantings
Groundwater Salinity
TSS derived (mg/L)
Thousands
10
8
6
4
2
0
Aug-76
Feb-82
Aug-87
Jan-93
Jul-98
Date
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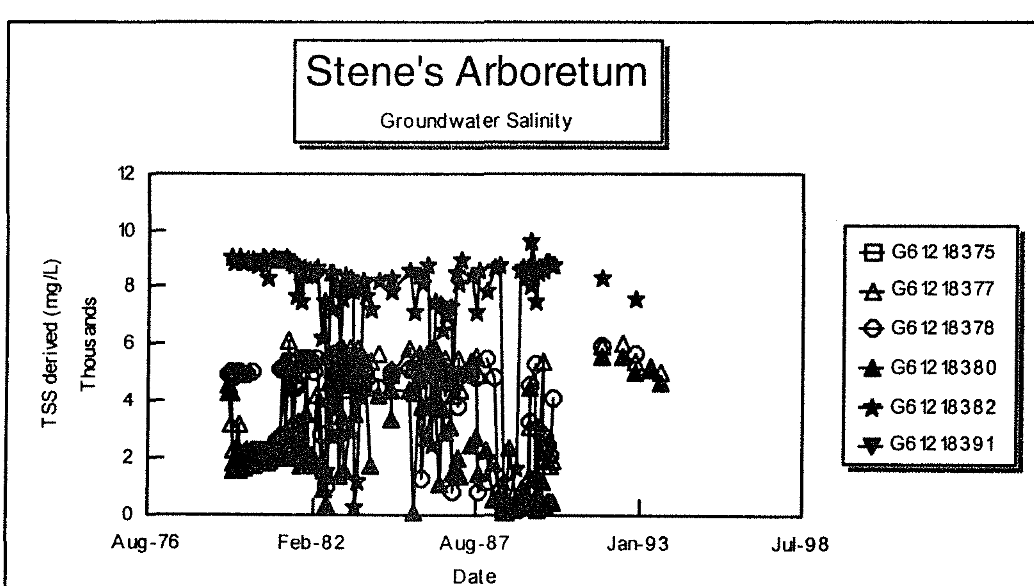
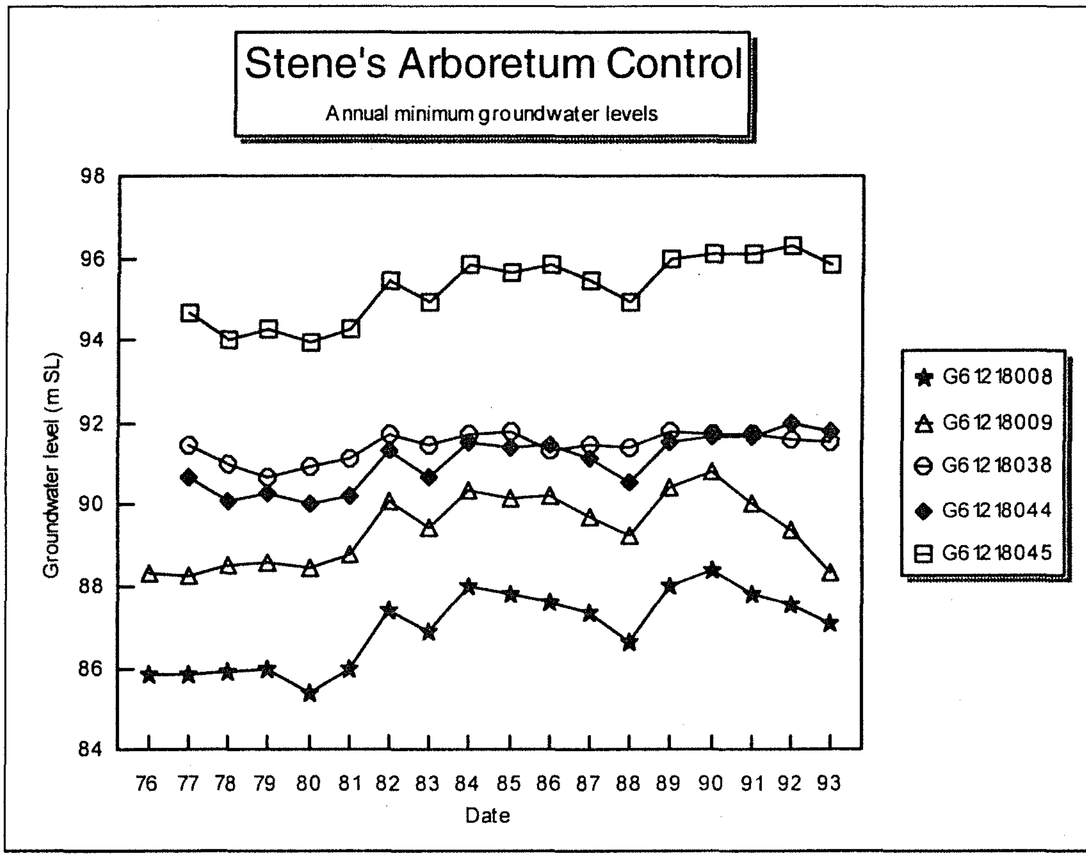
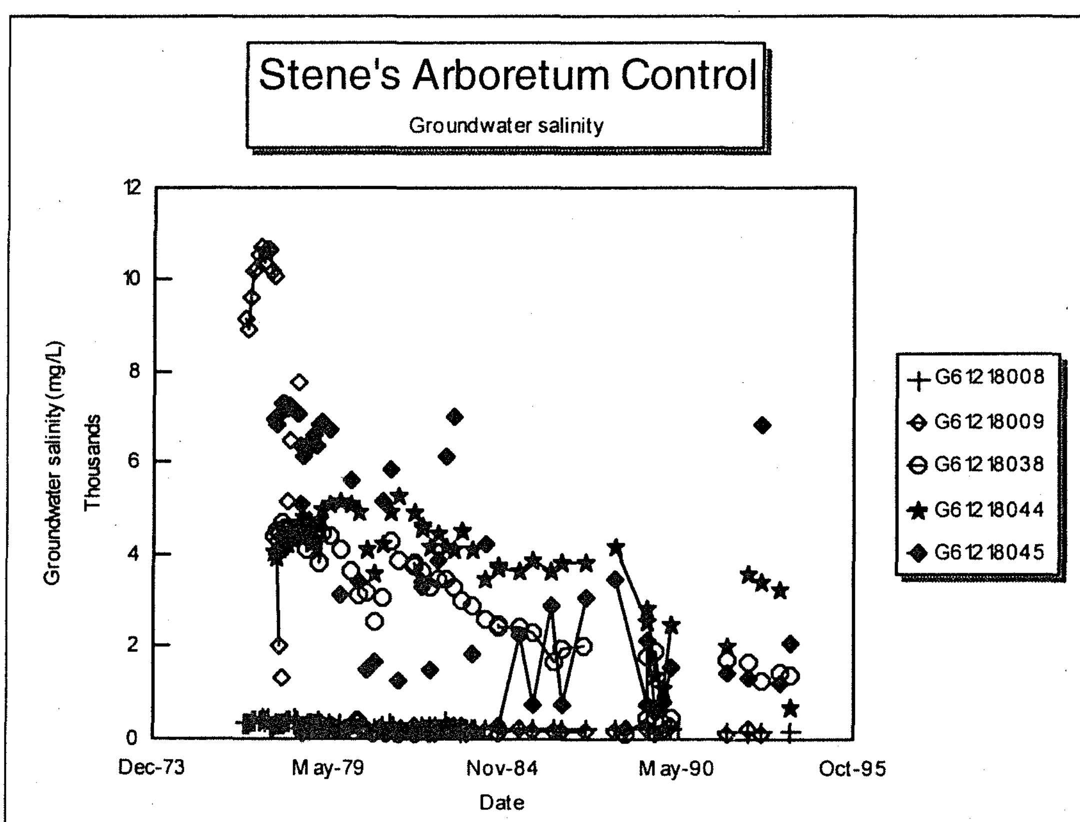
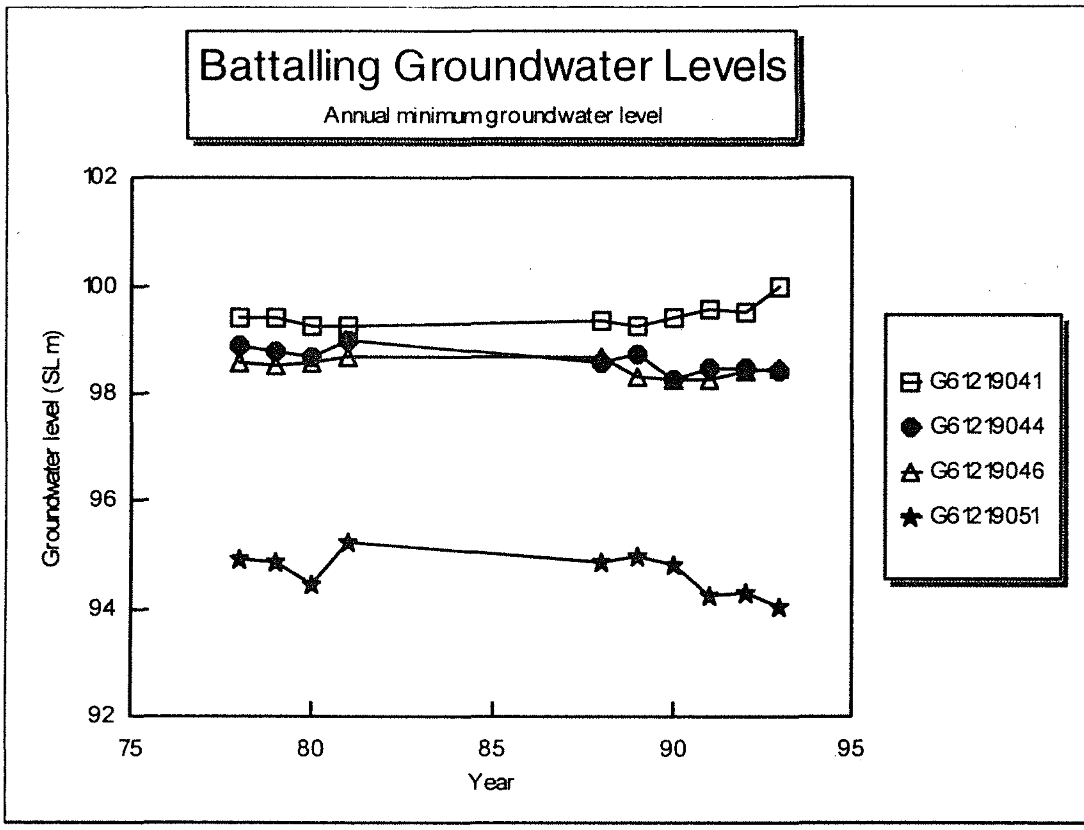
G6 12 18065
G6 12 18066

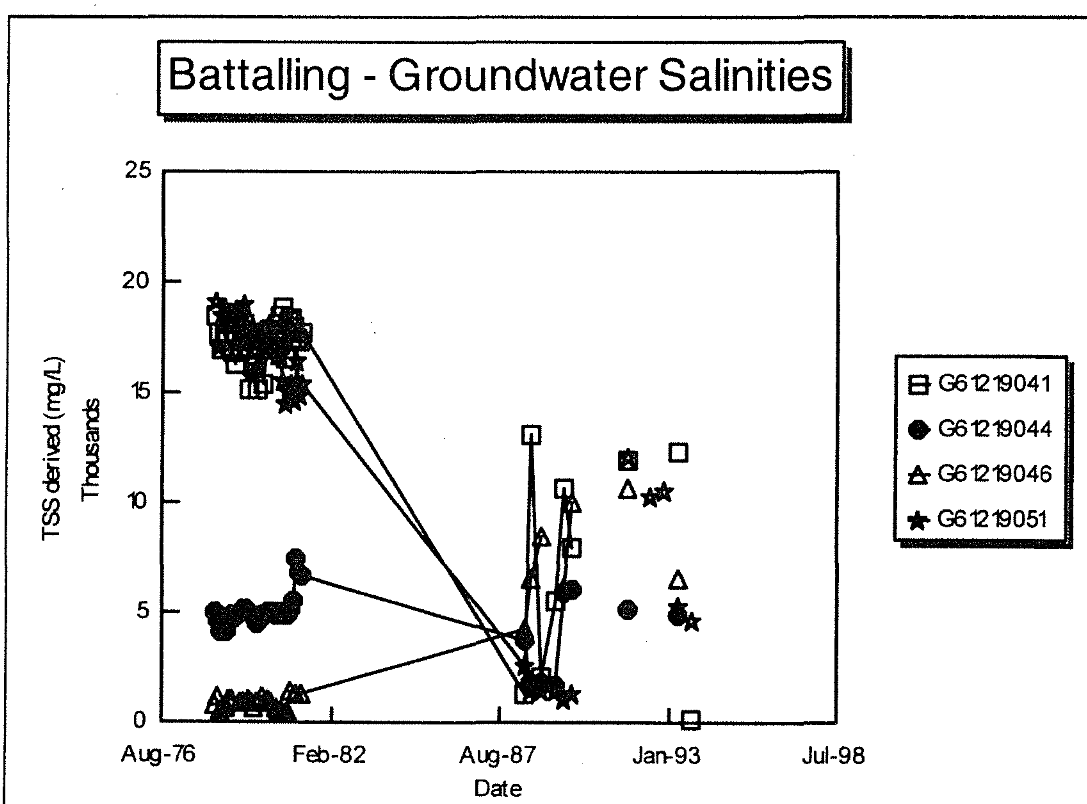

Stene's Arboretum
Groundwater Salinity
TSS derived (mg/L)
Thousands
12
10
8
6
4
2
0
Aug-76
Feb-82
Aug-87
Jan-93
Jul-98
Date
G6 12 18375
G6 12 18377
G6 12 18378
G6 12 18380
G6 12 18382
G6 12 18391


Stene's Arboretum Control
Annual minimum groundwater levels
Groundwater level (m SL)
98
96
94
92
90
88
86
84
76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93
Date
G6 12 18008
G6 12 18009
G6 12 18038
G6 12 18044
G6 12 18045


Stene's Arboretum Control
Groundwater salinity
Groundwater salinity (mg/L)
Thousands
12
10
8
6
4
2
0
Dec-73
May-79
Nov-84
May-90
Oct-95
Date
G6 12 18008
G6 12 18009
G6 12 18038
G6 12 18044
G6 12 18045

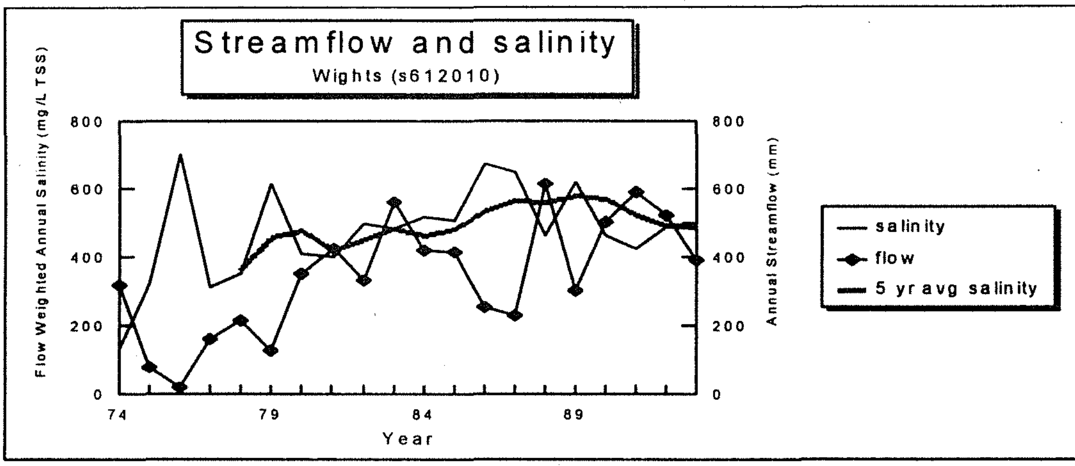


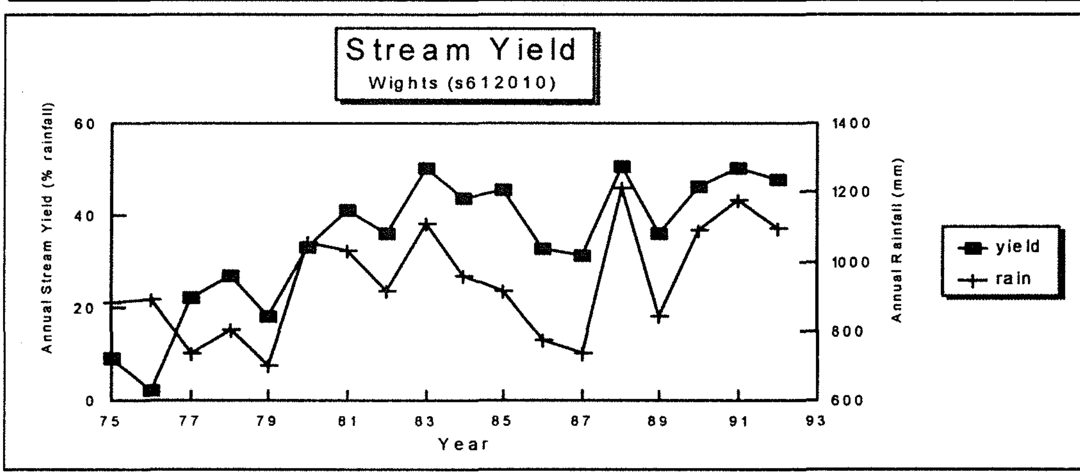
Battalling Groundwater Levels
Annual minimum groundwater level
102
100
98
96
94
92
Groundwater level (SL m)
75
80
85
90
95
Year
G61219041
G61219044
G61219046
G61219051

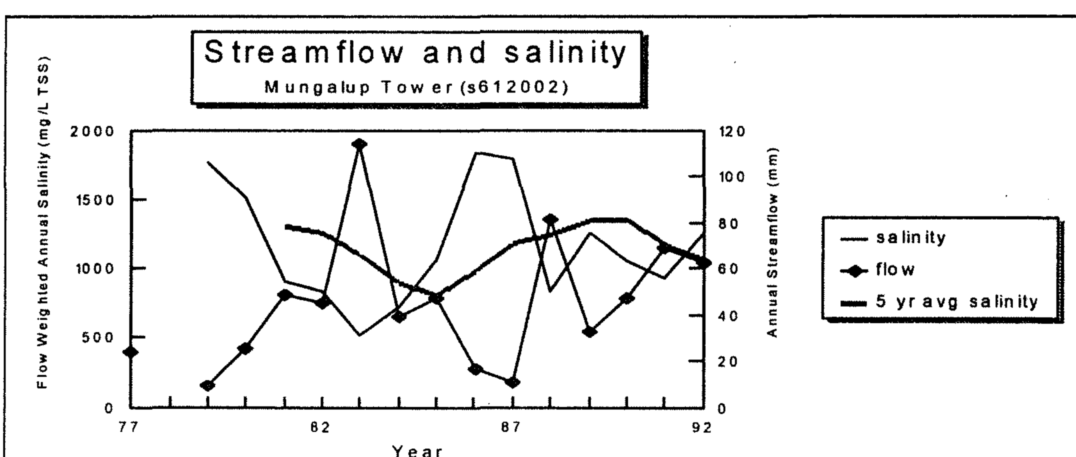


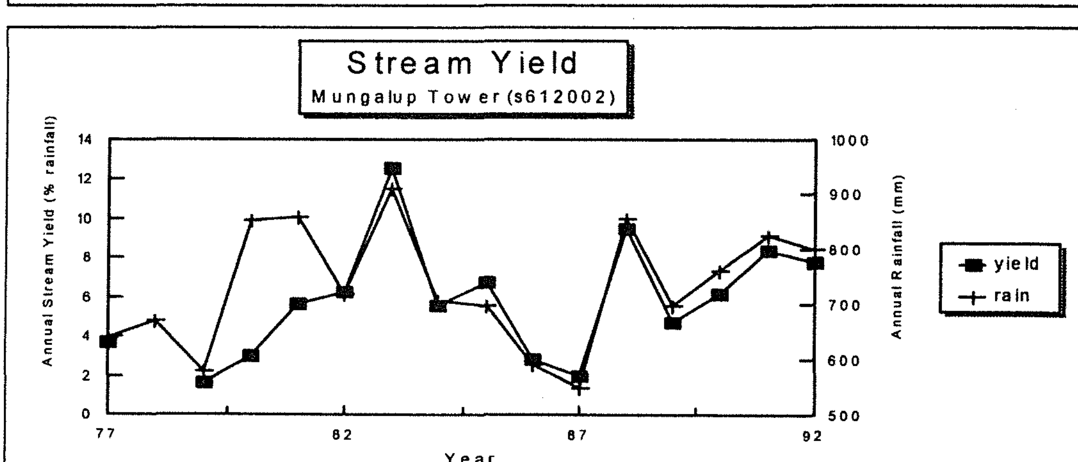
Battalling - Groundwater Salinities
25
20
15
10
5
0
TSS derived (mg/L)
Thousands
Aug-76
Feb-82
Aug-87
Jan-93
Jul-98
Date
G61219041
G61219044
G61219046
G61219051

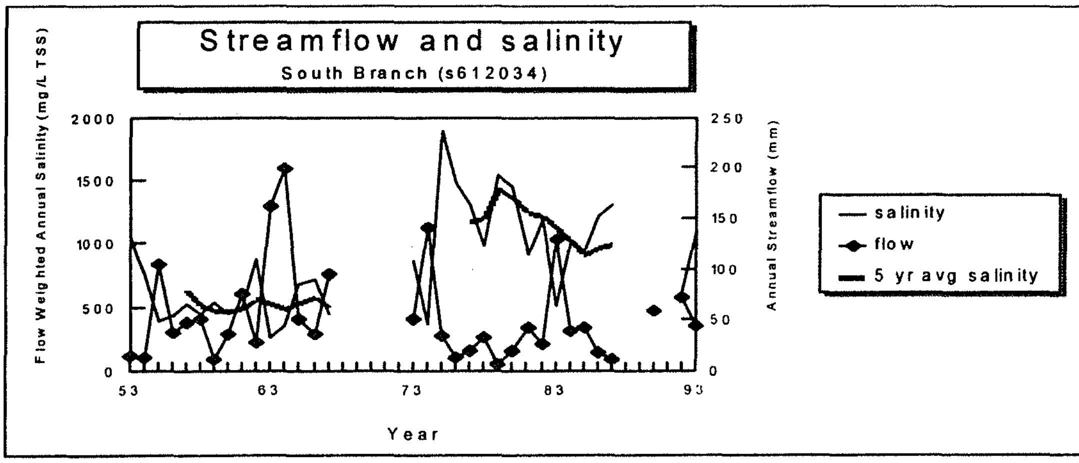
APPENDIX B - Streamflow, salinity and stream yield

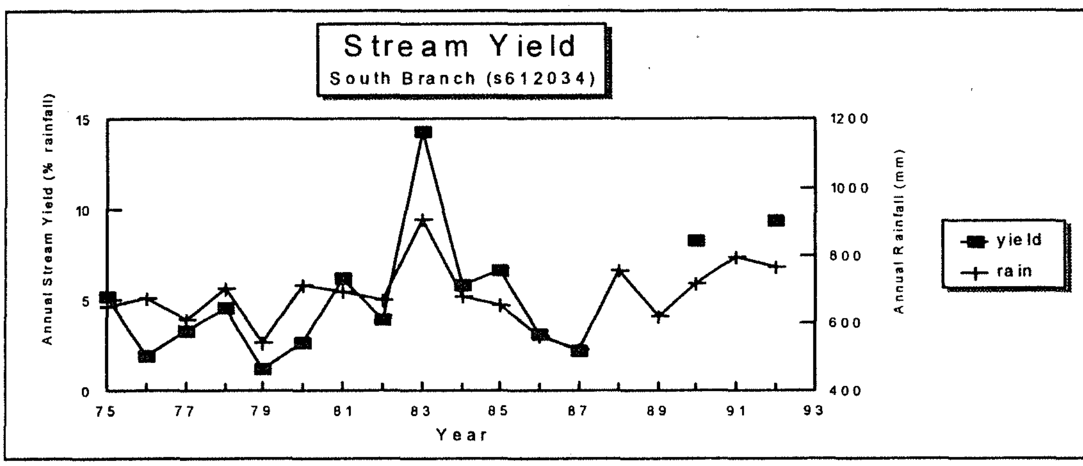

Streamflow and salinity
Wights (s612010)
Flow Weighted Annual Salinity (mg/L TSS)
Annual Streamflow (mm)
Year
salinity
flow
5 yr avg salinity

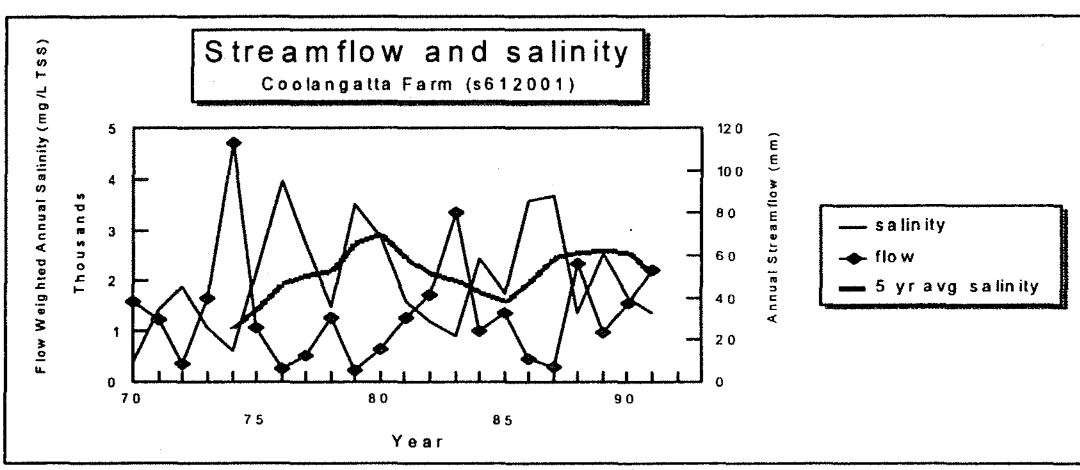

Stream Yield
Wights (s612010)
Annual Stream Yield (% rainfall)
Annual Rainfall (mm)
Year
yield
rain

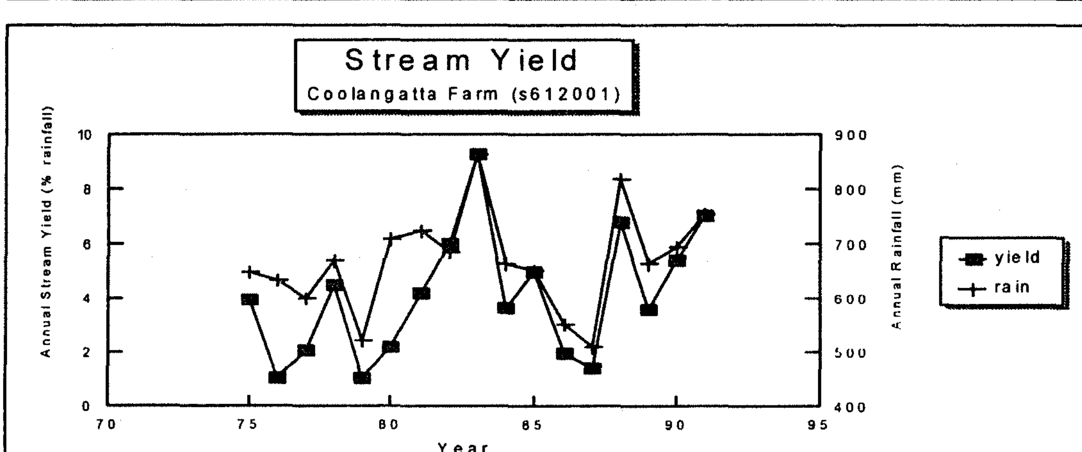

Streamflow and salinity
Mungalup Tower (s612002)
Flow Weighted Annual Salinity (mg/L TSS)
Annual Streamflow (mm)
Year
salinity
flow
5 yr avg salinity

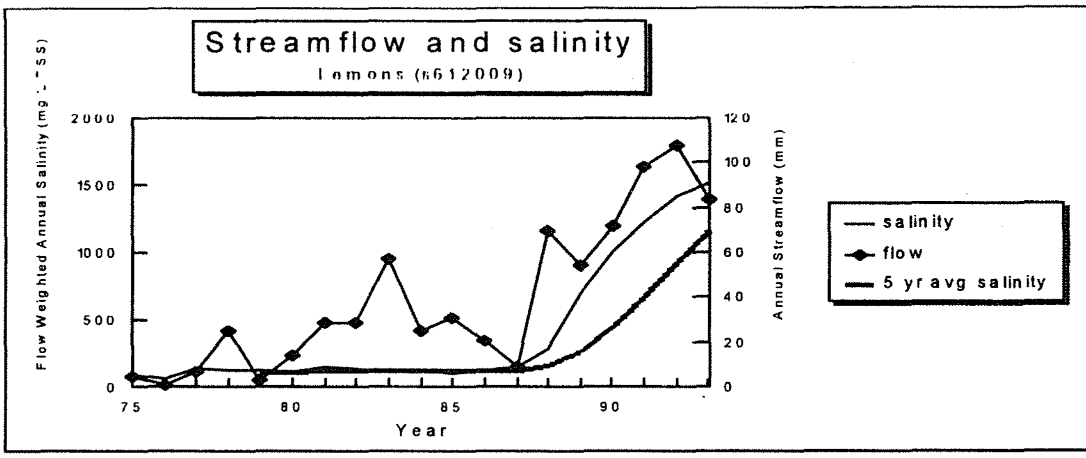

Stream Yield
Mungalup Tower (s612002)
Annual Stream Yield (% rainfall)
Annual Rainfall (mm)
Year
yield
rain

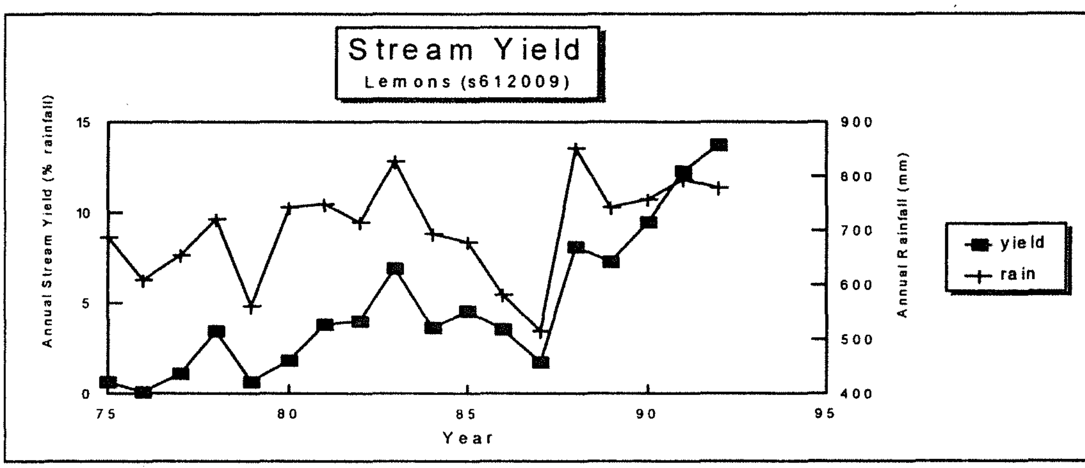

Streamflow and salinity
South Branch (s612034)
Flow Weighted Annual Salinity (mg/L TSS)
Annual Streamflow (mm)
Year
salinity
flow
5 yr avg salinity

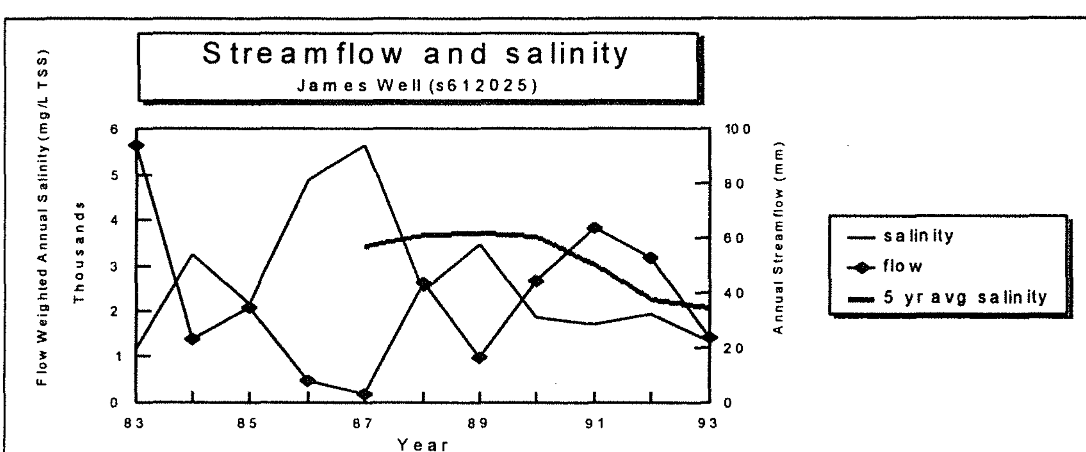

Stream Yield
South Branch (s612034)
Annual Stream Yield (% rainfall)
Annual Rainfall (mm)
Year
yield
rain

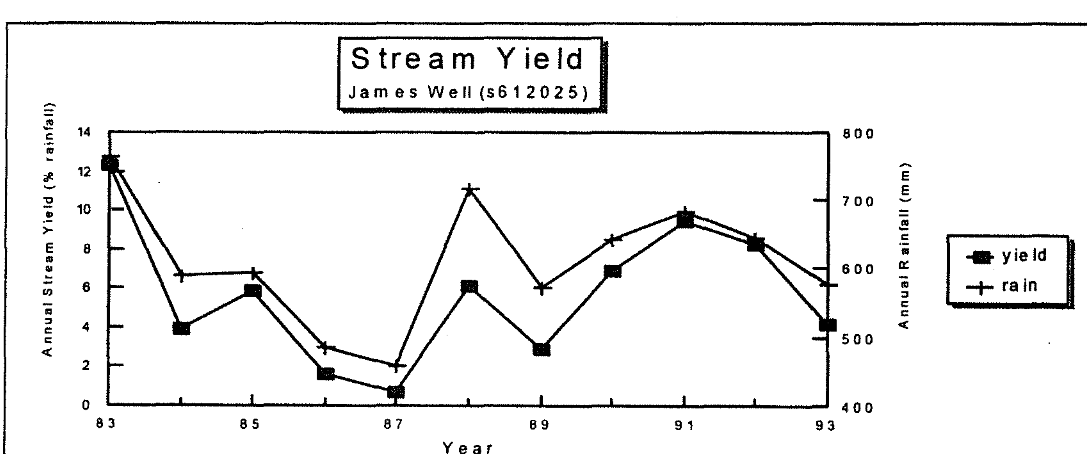

Streamflow and salinity
Coolangatta Farm (s612001)
Flow Weighted Annual Salinity (mg/L TSS)
Thousands
Annual Streamflow (mm)
Year
salinity
flow
5 yr avg salinity

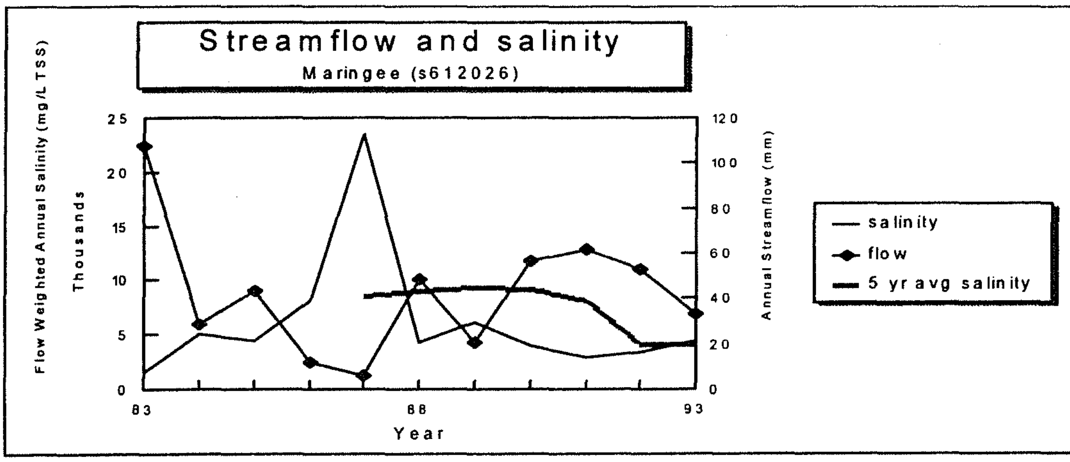

Stream Yield
Coolangatta Farm (s612001)
Annual Stream Yield (% rainfall)
Annual Rainfall (mm)
Year
yield
rain


Streamflow and salinity
Lemons (s612009)
Flow Weighted Annual Salinity (mg/L TSS)
Annual Streamflow (mm)
Year
salinity
flow
5 yr avg salinity

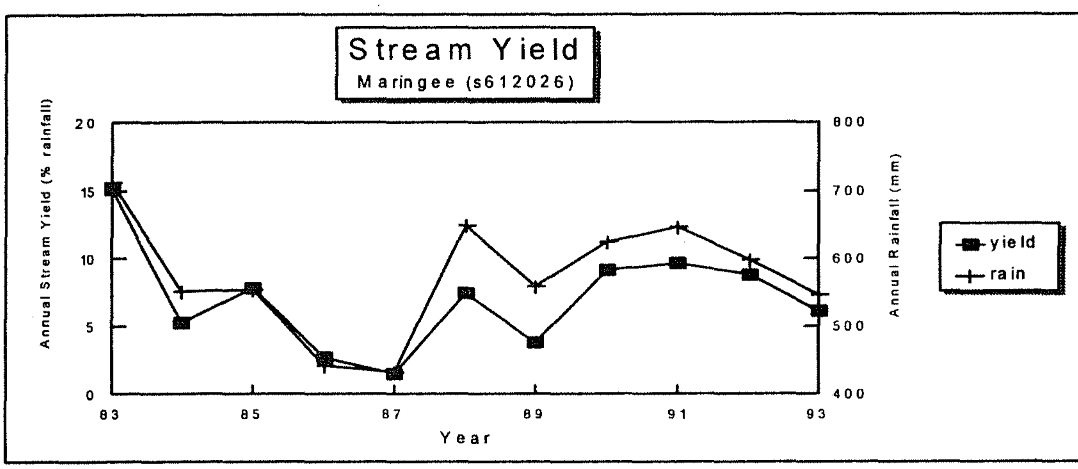

Stream Yield
Lemons (s612009)
Annual Stream Yield (% rainfall)
Annual Rainfall (mm)
Year
yield
rain


Streamflow and salinity
James Well (s612025)
Flow Weighted Annual Salinity (mg/L TSS)
Thousands
Annual Streamflow (mm)
Year
salinity
flow
5 yr avg salinity

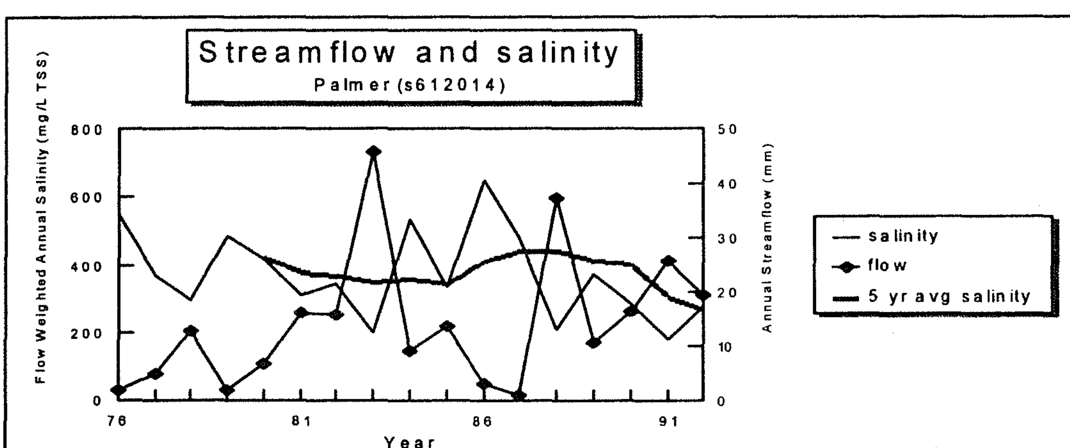

Stream Yield
James Well (s612025)
Annual Stream Yield (% rainfall)
Annual Rainfall (mm)
Year
yield
rain



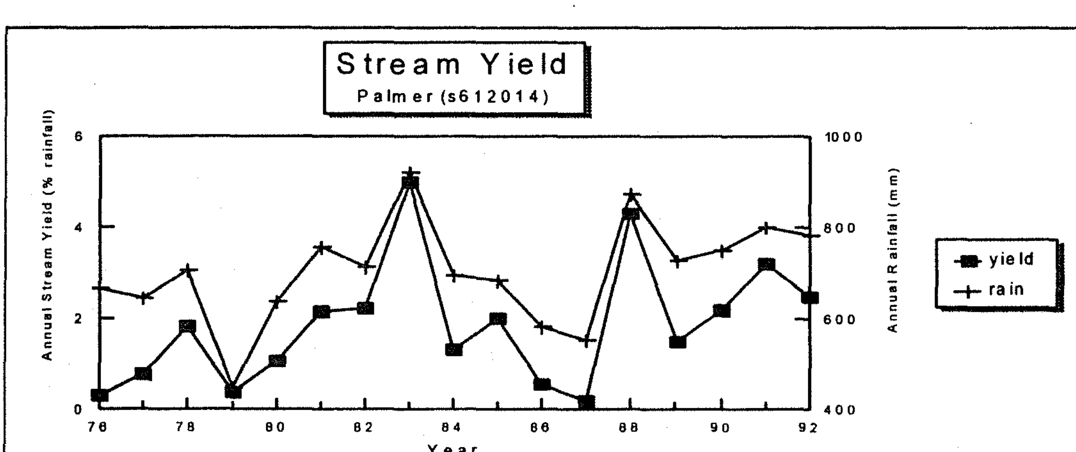
Streamflow and salinity
Maringee (s612026)
Flow Weighted Annual Salinity (mg/L TSS)
Thousands
Annual Streamflow (mm)
Year
salinity
flow
5 yr avg salinity



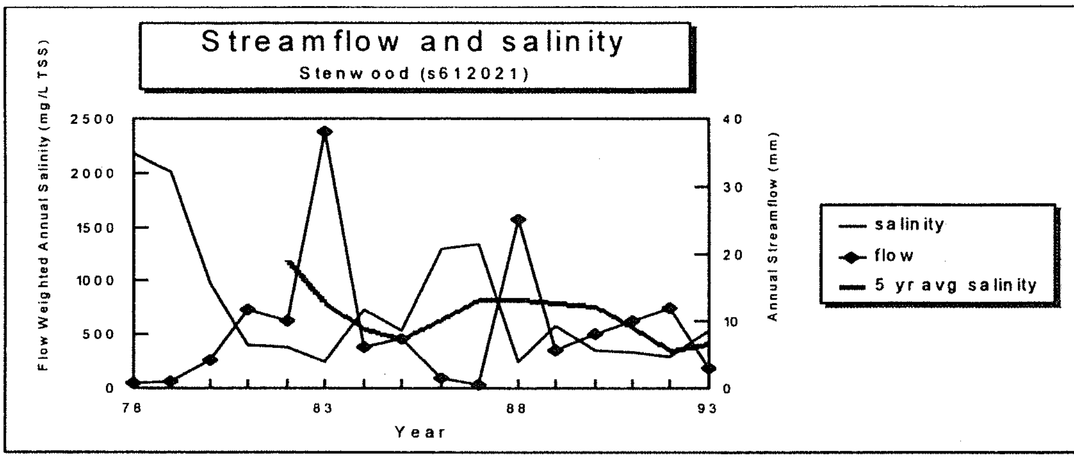
Stream Yield
Maringee (s612026)
Annual Stream Yield (% rainfall)
Annual Rainfall (mm)
Year
yield
rain

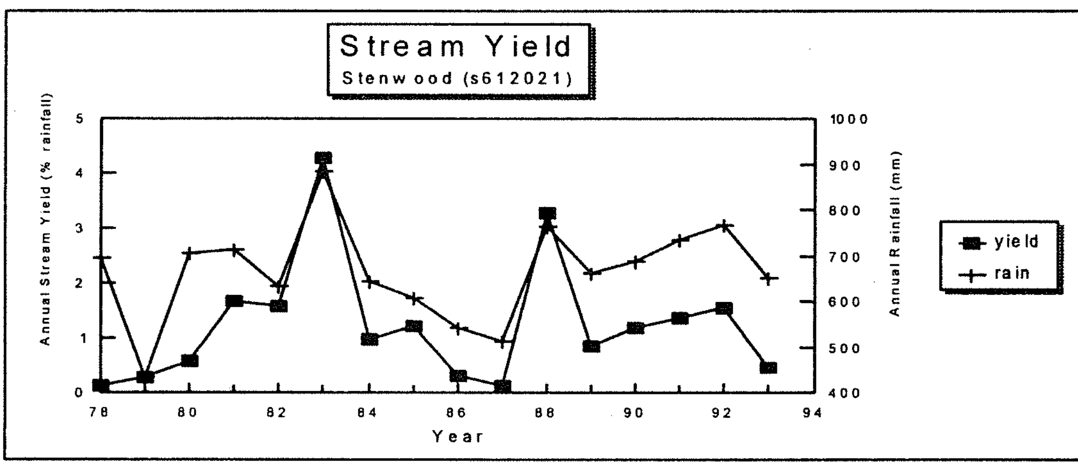


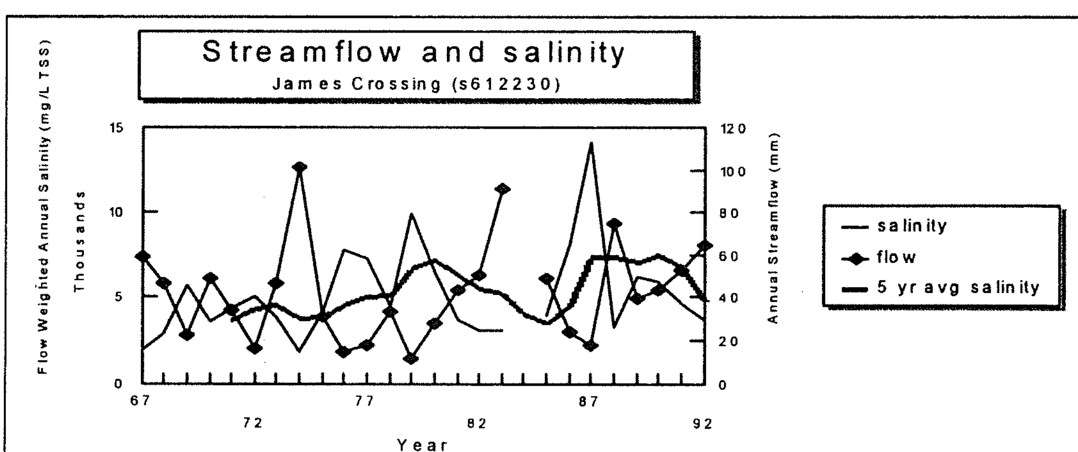
Streamflow and salinity
Palmer (s612014)
Flow Weighted Annual Salinity (mg/L TSS)
Annual Streamflow (mm)
Year
salinity
flow
5 yr avg salinity

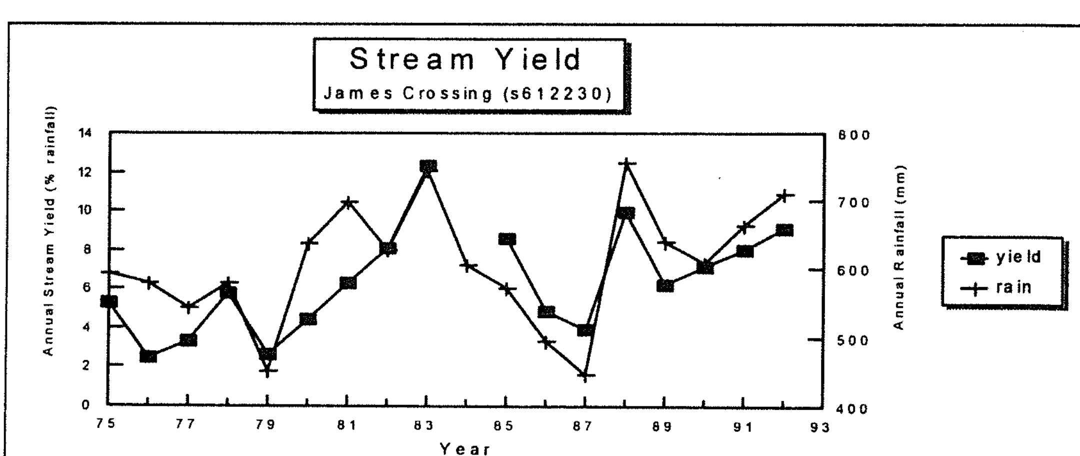


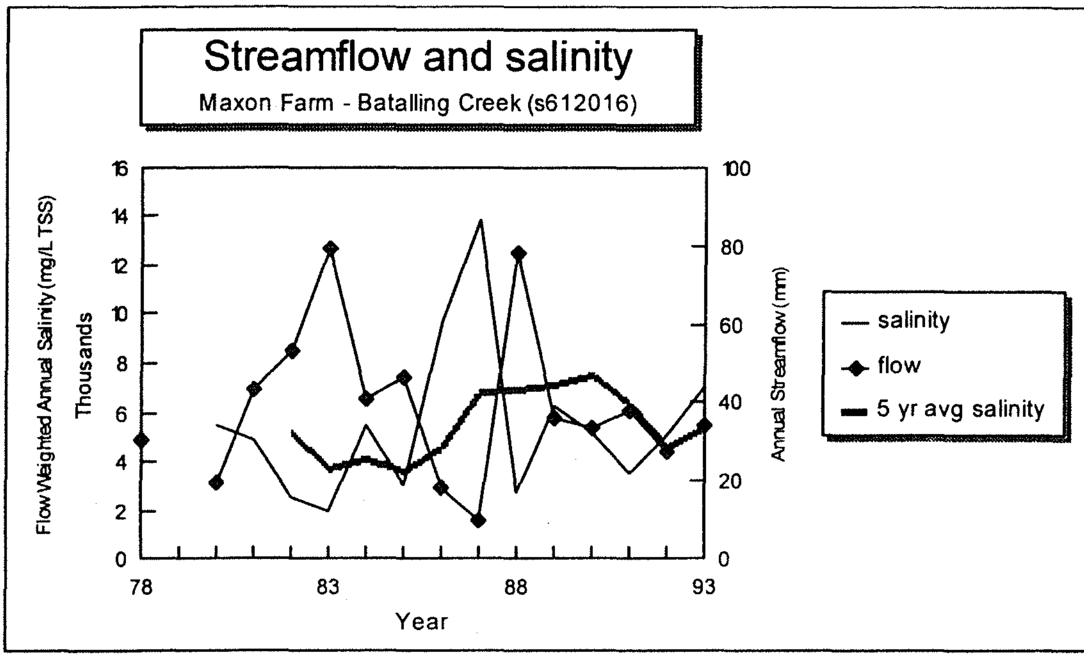
Stream Yield
Palmer (s612014)
Annual Stream Yield (% rainfall)
Annual Rainfall (mm)
Year
yield
rain

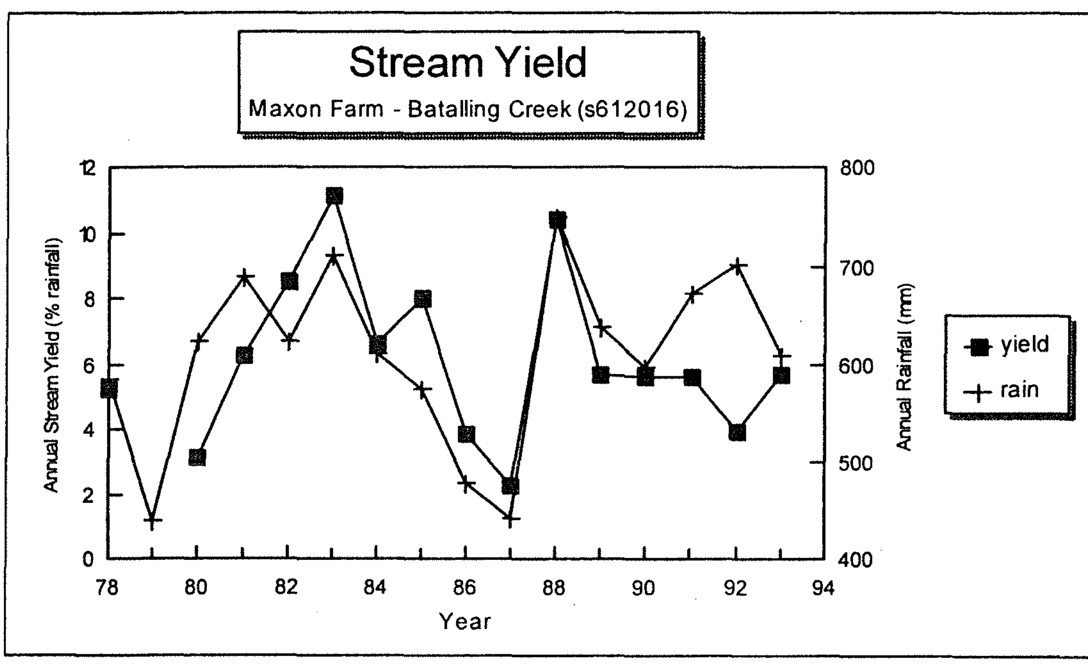

Streamflow and salinity
Stenwood (s612021)
Flow Weighted Annual Salinity (mg/L TSS)
Annual Streamflow (mm)
Year
salinity
flow
5 yr avg salinity


Stream Yield
Stenwood (s612021)
Annual Stream Yield (% rainfall)
Annual Rainfall (mm)
Year
yield
rain

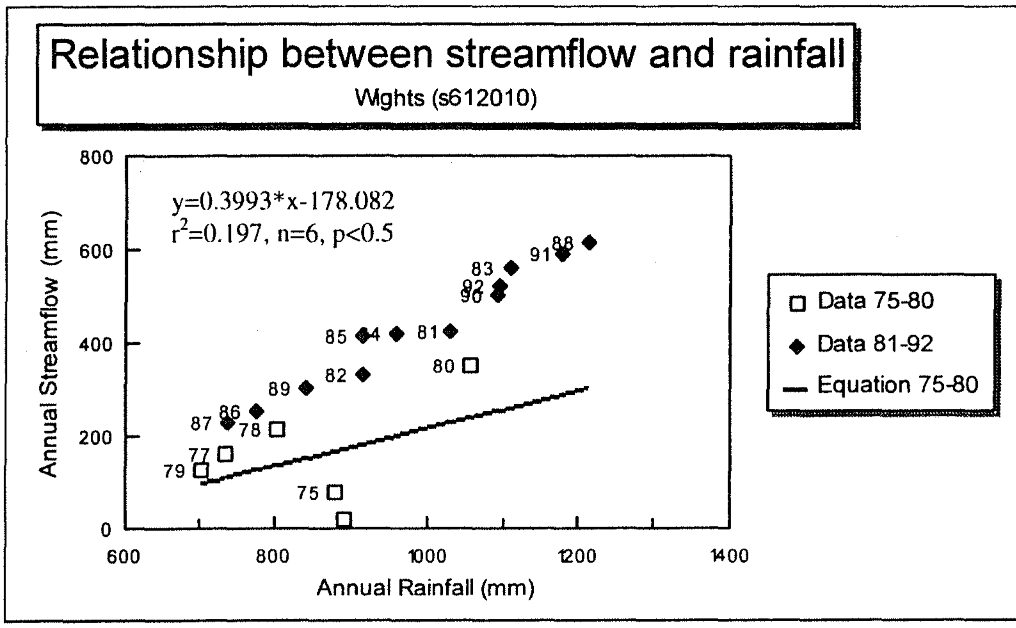

Streamflow and salinity
James Crossing (s612230)
Flow Weighted Annual Salinity (mg/L TSS)
Thousands
Annual Streamflow (mm)
Year
salinity
flow
5 yr avg salinity

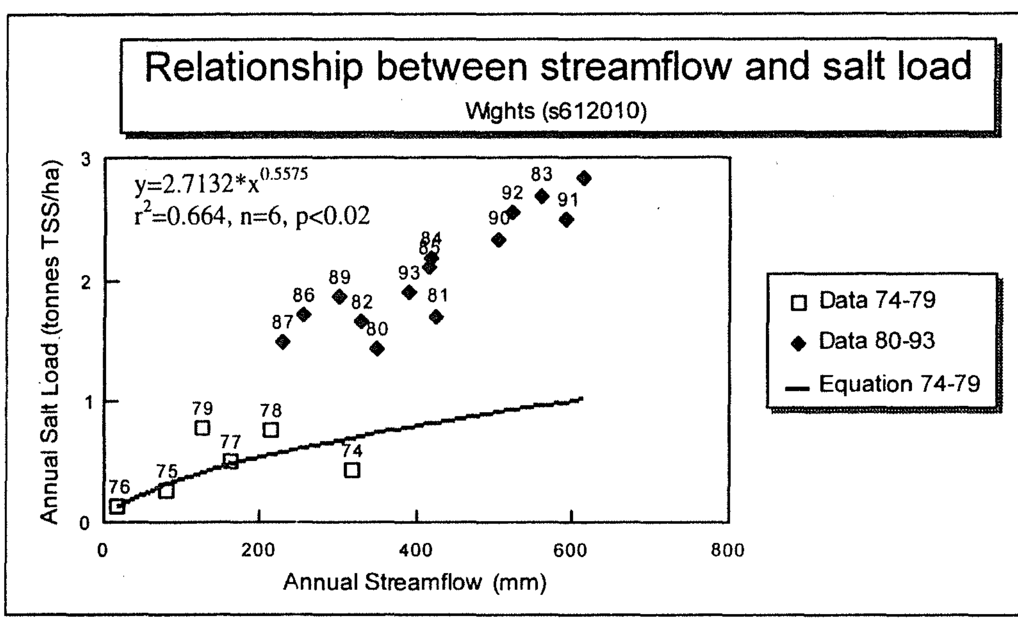

Stream Yield
James Crossing (s612230)
Annual Stream Yield (% rainfall)
Annual Rainfall (mm)
Year
yield
rain

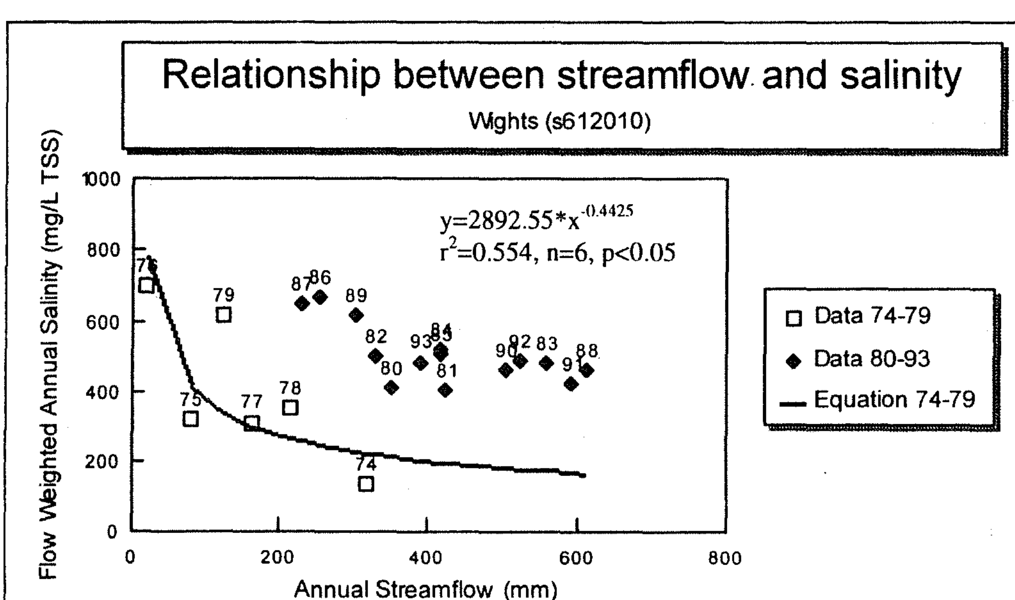

Streamflow and salinity
Maxon Farm - Batalling Creek (s612016)
Flow Weighted Annual Salinity (mg/L TSS)
Thousands
Annual Streamflow (mm)
Year
salinity
flow
5 yr avg salinity

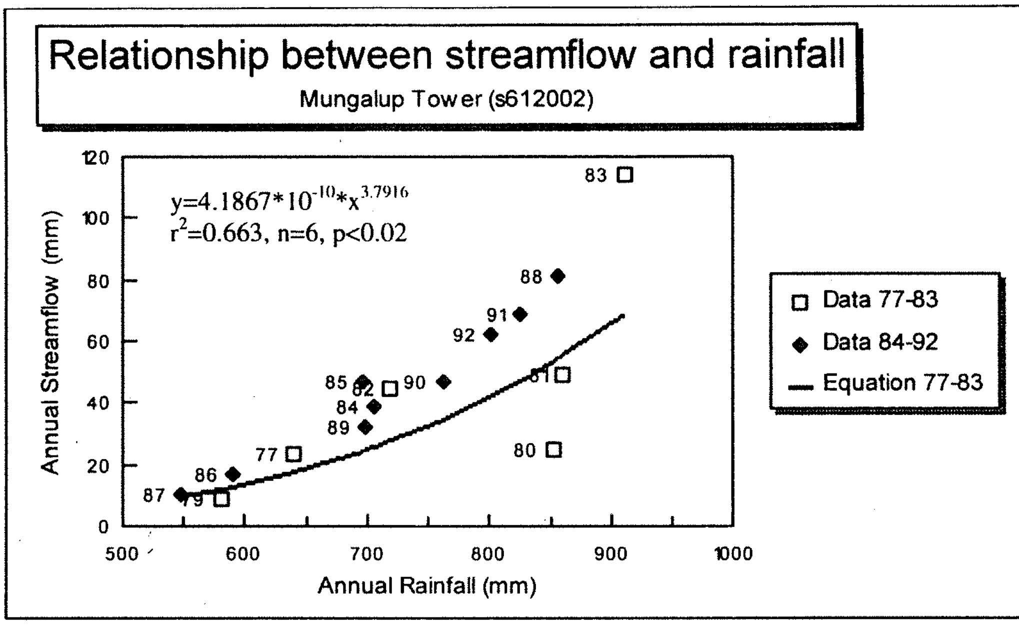

Stream Yield
Maxon Farm - Batalling Creek (s612016)
Annual Stream Yield (% rainfall)
Annual Rainfall (mm)
Year
yield
rain

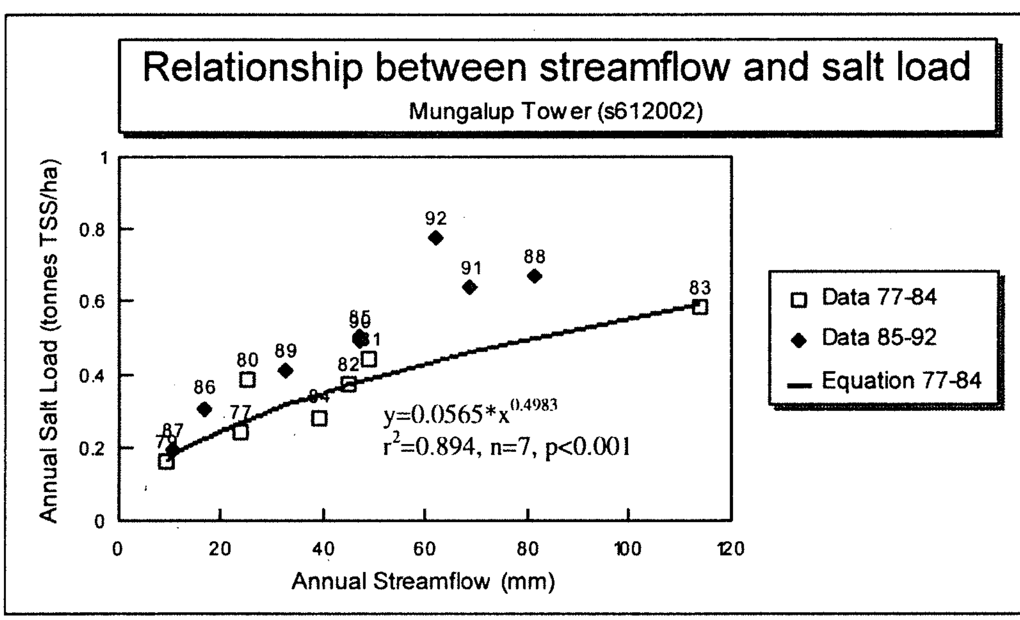
APPENDIX C Streamflow Relationships

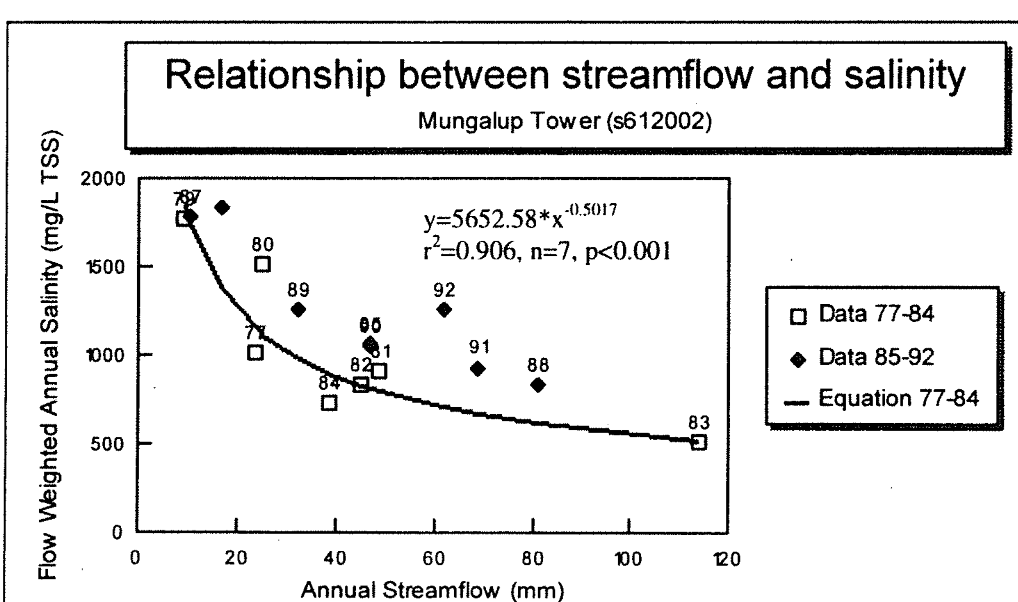

Relationship between streamflow and rainfall
Wghts (s612010)
y=0.3993*x-178.082
r2=0.197, n=6, p<0.5
Annual Streamflow (mm)
Annual Rainfall (mm)
Data 75-80
Data 81-92
Equation 75-80

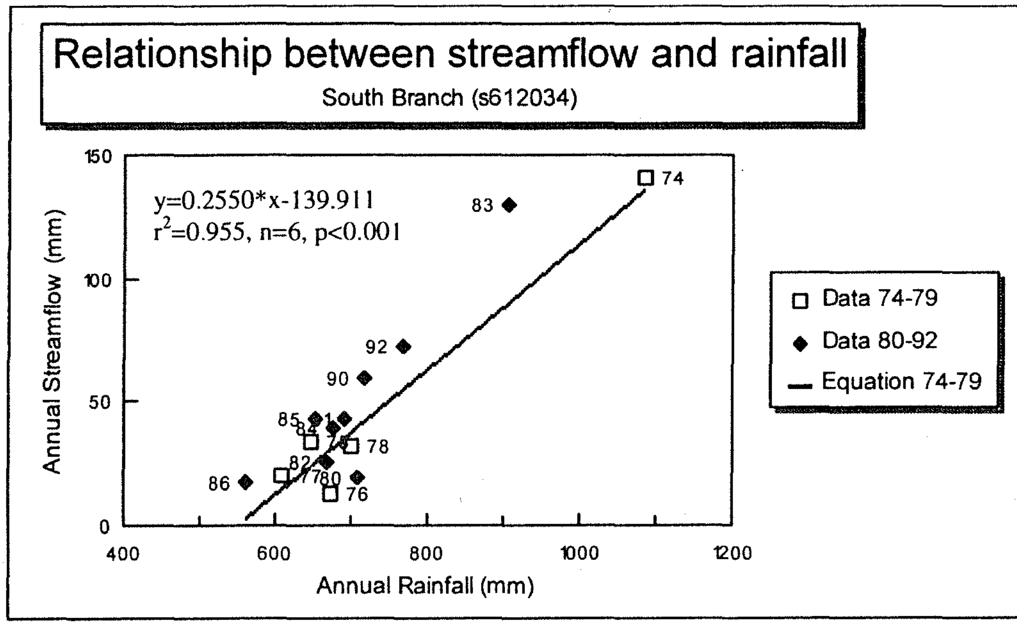

Relationship between streamflow and salt load
Wghts (s612010)
y=2.7132*x0.5575
r2=0.664, n=6, p<0.02
Annual Salt Load (tonnes TSS/ha)
Annual Streamflow (mm)
Data 74-79
Data 80-93
Equation 74-79

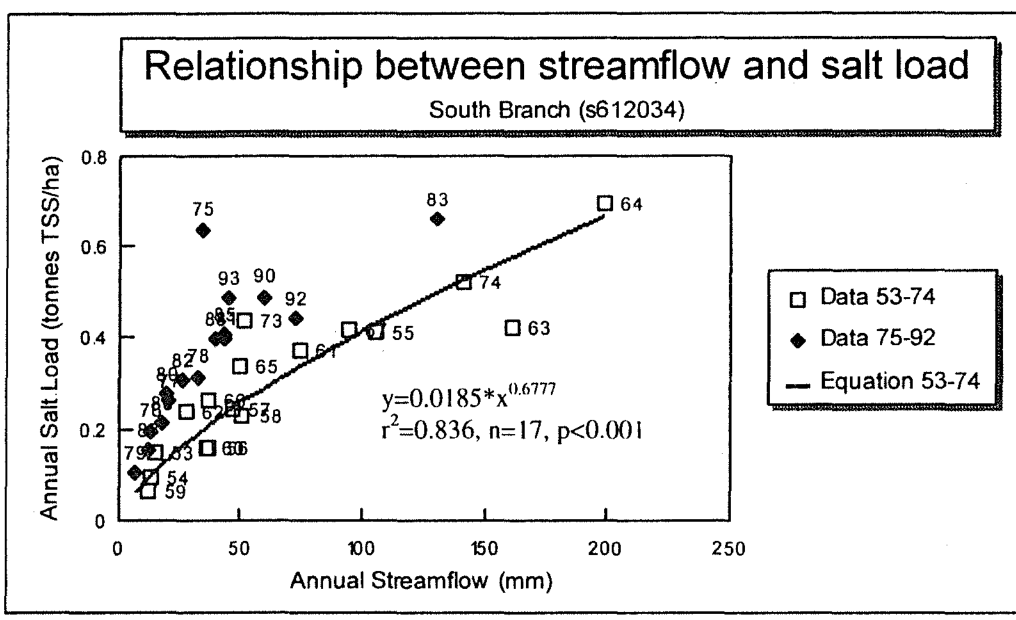

Relationship between streamflow and salinity
Wghts (s612010)
y=2892.55*x-0.4425
r2=0.554, n=6, p<0.05
Flow Weighted Annual Salinity (mg/L TSS)
Annual Streamflow (mm)
Data 74-79
Data 80-93
Equation 74-79

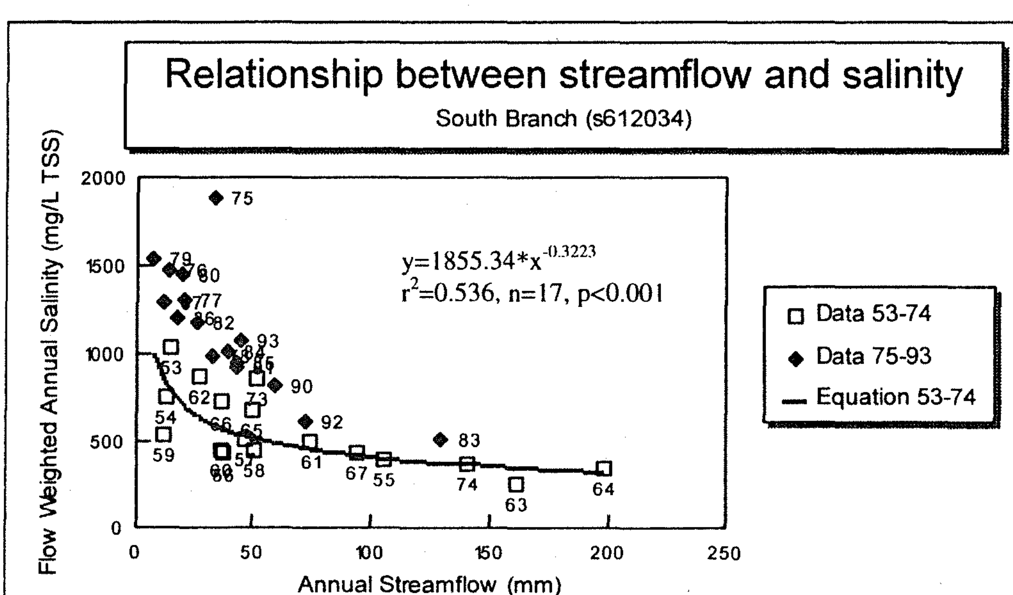

Relationship between streamflow and rainfall
Mungalup Tower (s612002)
y=4.1867*10^-10*x^3.7916
r^2=0.663, n=6, p<0.02
Annual Streamflow (mm)
Annual Rainfall (mm)
Data 77-83
Data 84-92
Equation 77-83

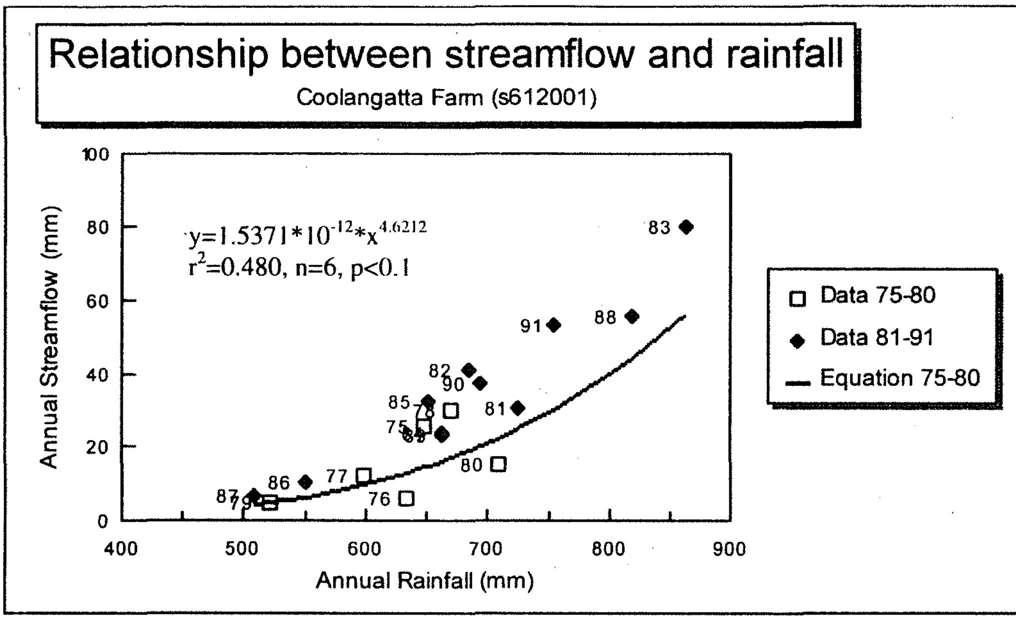

Relationship between streamflow and salt load
Mungalup Tower (s612002)
y=0.0565*x^0.4983
r^2=0.894, n=7, p<0.001
Annual Salt Load (tonnes TSS/ha)
Annual Streamflow (mm)
Data 77-84
Data 85-92
Equation 77-84

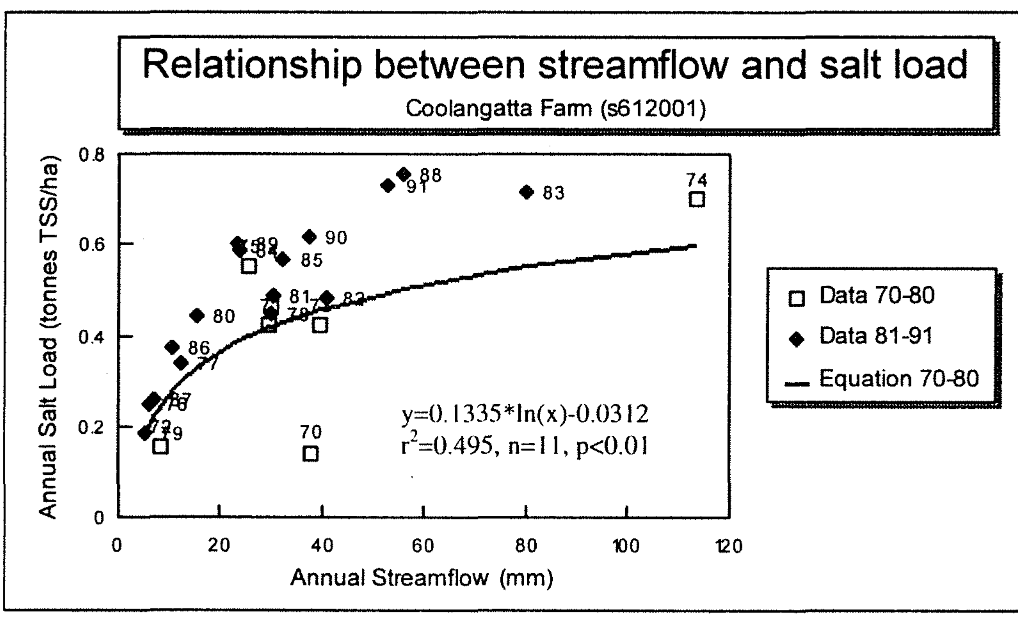

Relationship between streamflow and salinity
Mungalup Tower (s612002)
y=5652.58*x^-0.5017
r^2=0.906, n=7, p<0.001
Flow Weighted Annual Salinity (mg/L TSS)
Annual Streamflow (mm)
Data 77-84
Data 85-92
Equation 77-84

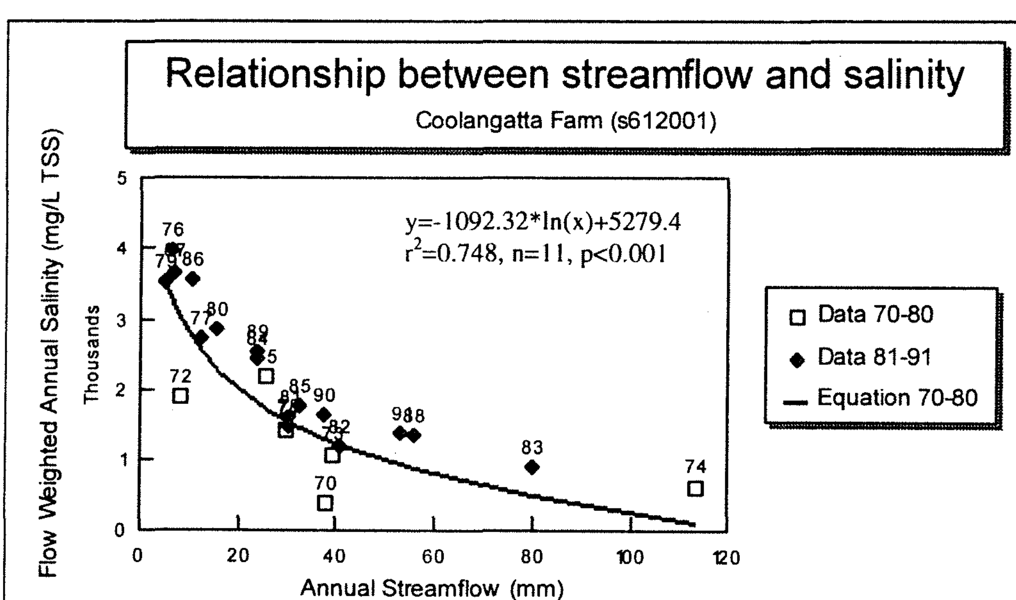

Relationship between streamflow and rainfall
South Branch (s612034)
y=0.2550*x-139.911
r2=0.955, n=6, p<0.001
Annual Streamflow (mm)
Annual Rainfall (mm)
Data 74-79
Data 80-92
Equation 74-79

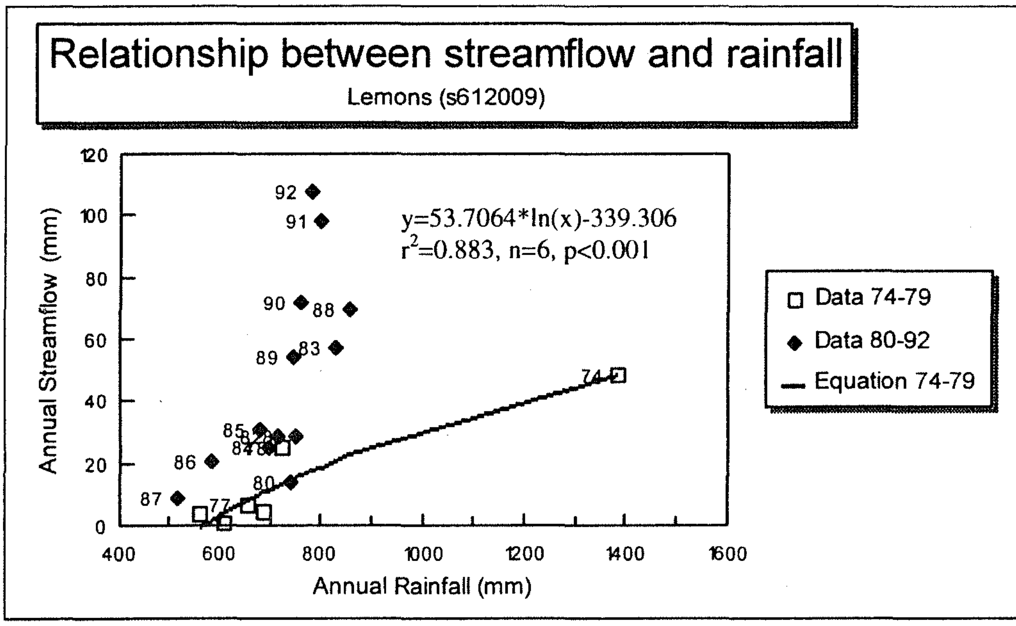

Relationship between streamflow and salt load
South Branch (s612034)
y=0.0185*x0.6777
r2=0.836, n=17, p<0.001
Annual Salt Load (tonnes TSS/ha)
Annual Streamflow (mm)
Data 53-74
Data 75-92
Equation 53-74

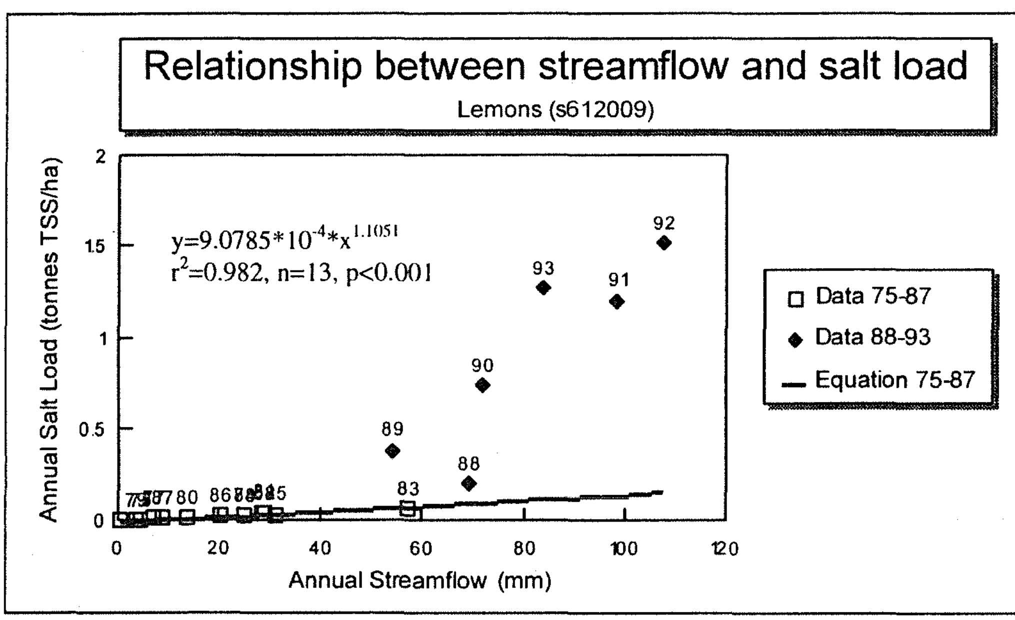

Relationship between streamflow and salinity
South Branch (s612034)
y=1855.34*x-0.3223
r2=0.536, n=17, p<0.001
Flow Weighted Annual Salinity (mg/L TSS)
Annual Streamflow (mm)
Data 53-74
Data 75-93
Equation 53-74

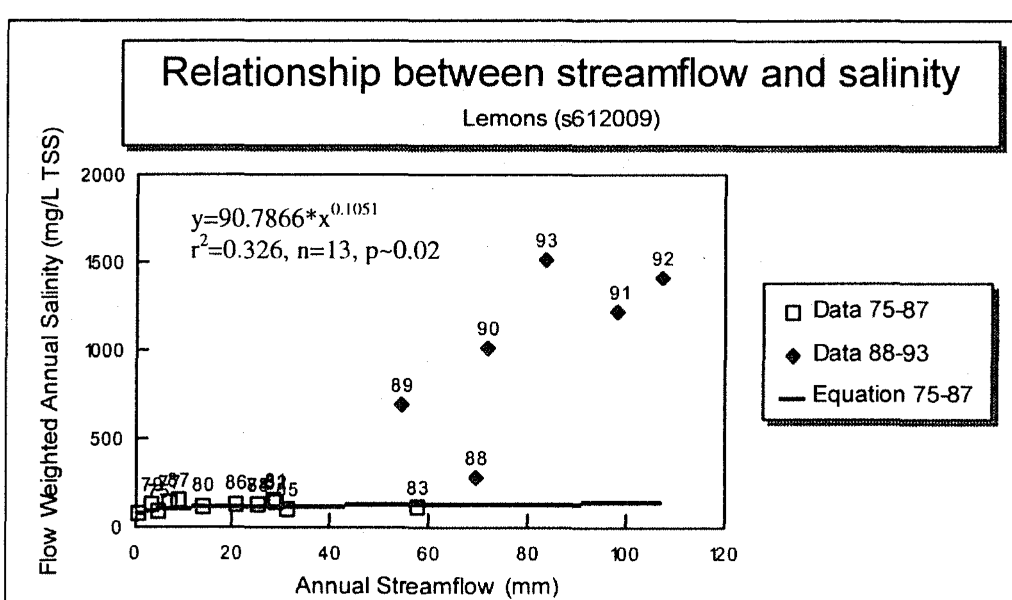

Relationship between streamflow and rainfall
Coolangatta Farm (s612001)
y=1.5371*10^-12*x^4.6212
r²=0.480, n=6, p<0.1
Annual Streamflow (mm)
Annual Rainfall (mm)
Data 75-80
Data 81-91
Equation 75-80

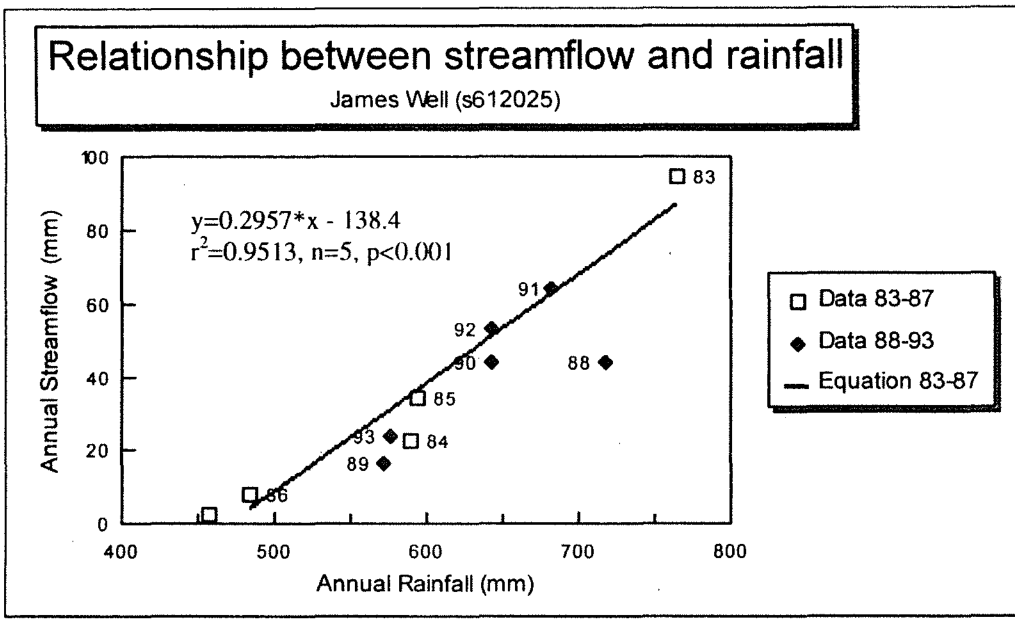

Relationship between streamflow and salt load
Coolangatta Farm (s612001)
y=0.1335*ln(x)-0.0312
r²=0.495, n=11, p<0.01
Annual Salt Load (tonnes TSS/ha)
Annual Streamflow (mm)
Data 70-80
Data 81-91
Equation 70-80

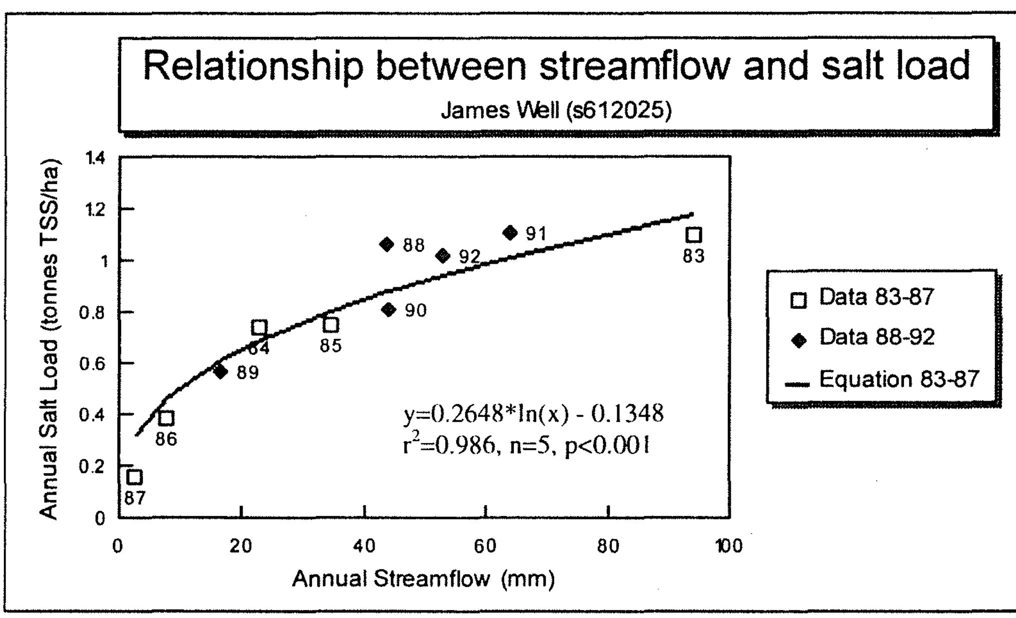

Relationship between streamflow and salinity
Coolangatta Farm (s612001)
y=-1092.32*ln(x)+5279.4
r²=0.748, n=11, p<0.001
Flow Weighted Annual Salinity (mg/L TSS)
Thousands
Annual Streamflow (mm)
Data 70-80
Data 81-91
Equation 70-80

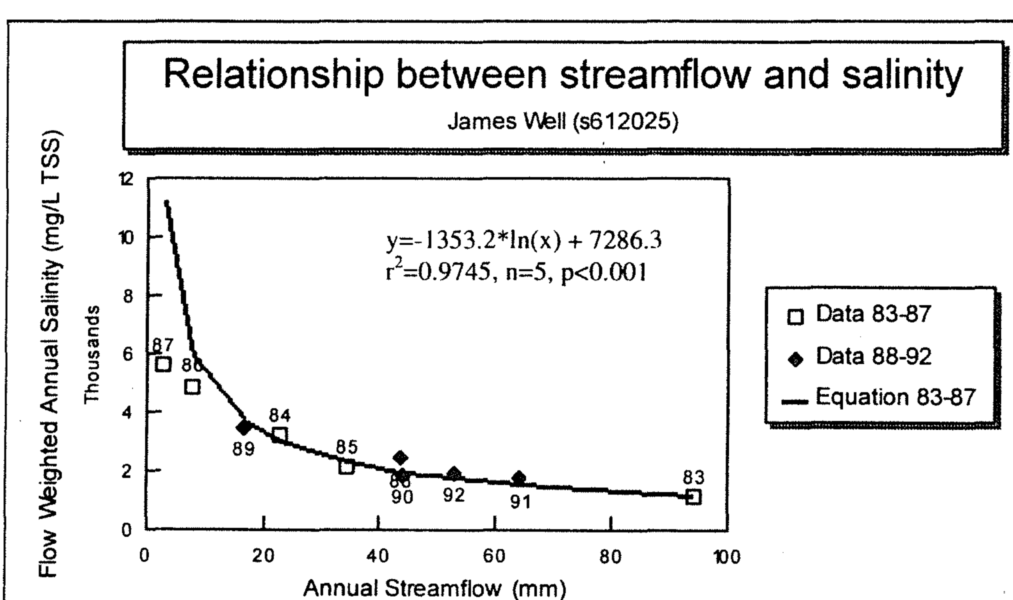

Relationship between streamflow and rainfall
Lemons (s612009)
y=53.7064*ln(x)-339.306
r²=0.883, n=6, p<0.001
Data 74-79
Data 80-92
Equation 74-79
Annual Streamflow (mm)
Annual Rainfall (mm)

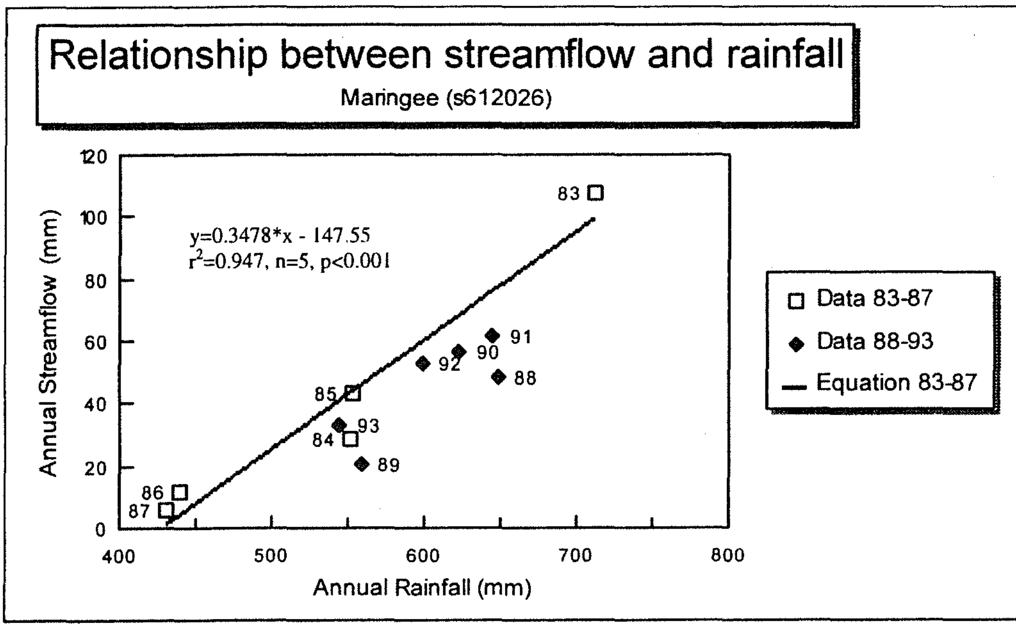

Relationship between streamflow and salt load
Lemons (s612009)
y=9.0785*10⁻⁴*x^1.1051
r²=0.982, n=13, p<0.001
Data 75-87
Data 88-93
Equation 75-87
Annual Salt Load (tonnes TSS/ha)
Annual Streamflow (mm)

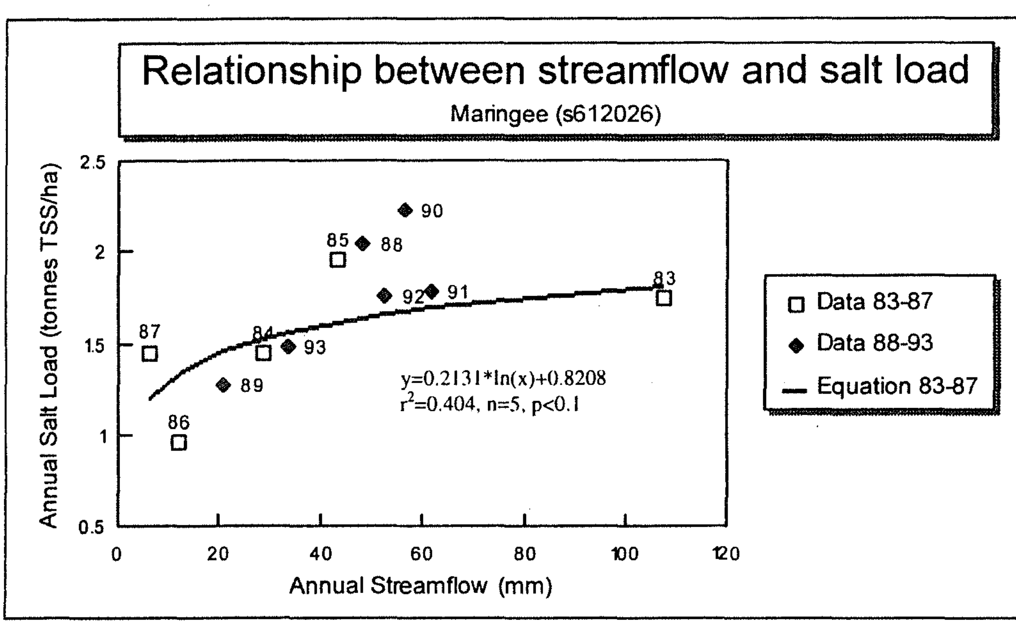

Relationship between streamflow and salinity
Lemons (s612009)
y=90.7866*x^0.1051
r²=0.326, n=13, p~0.02
Data 75-87
Data 88-93
Equation 75-87
Flow Weighted Annual Salinity (mg/L TSS)
Annual Streamflow (mm)

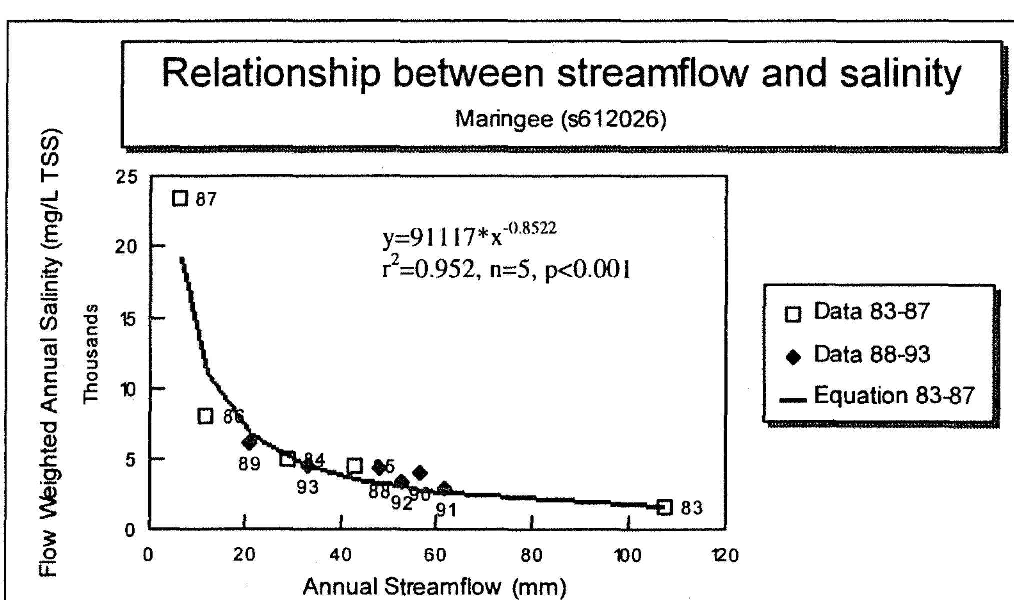

Relationship between streamflow and rainfall
James Well (s612025)
y=0.2957*x - 138.4
r²=0.9513, n=5, p<0.001
Annual Streamflow (mm)
Annual Rainfall (mm)
Data 83-87
Data 88-93
Equation 83-87

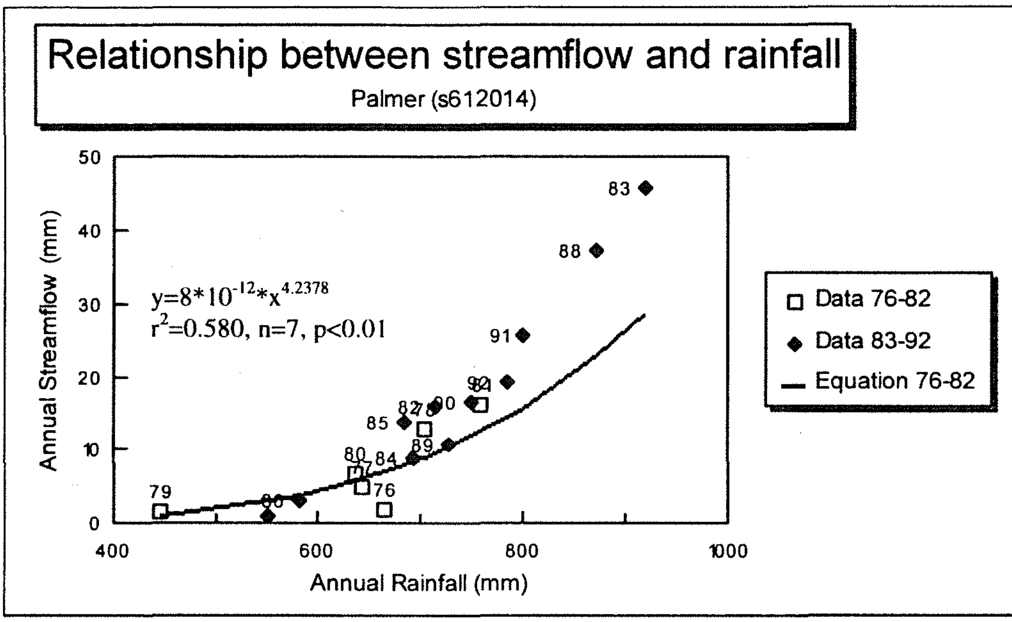

Relationship between streamflow and salt load
James Well (s612025)
y=0.2648*ln(x) - 0.1348
r²=0.986, n=5, p<0.001
Annual Salt Load (tonnes TSS/ha)
Annual Streamflow (mm)
Data 83-87
Data 88-92
Equation 83-87

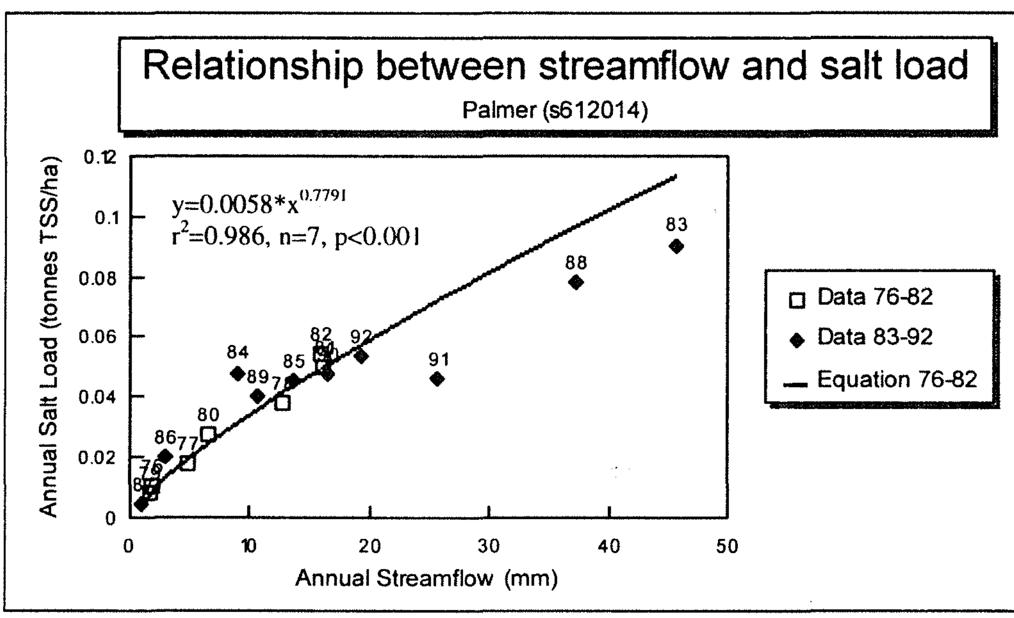

Relationship between streamflow and salinity
James Well (s612025)
y=-1353.2*ln(x) + 7286.3
r²=0.9745, n=5, p<0.001
Flow Weighted Annual Salinity (mg/L TSS)
Thousands
Annual Streamflow (mm)
Data 83-87
Data 88-92
Equation 83-87

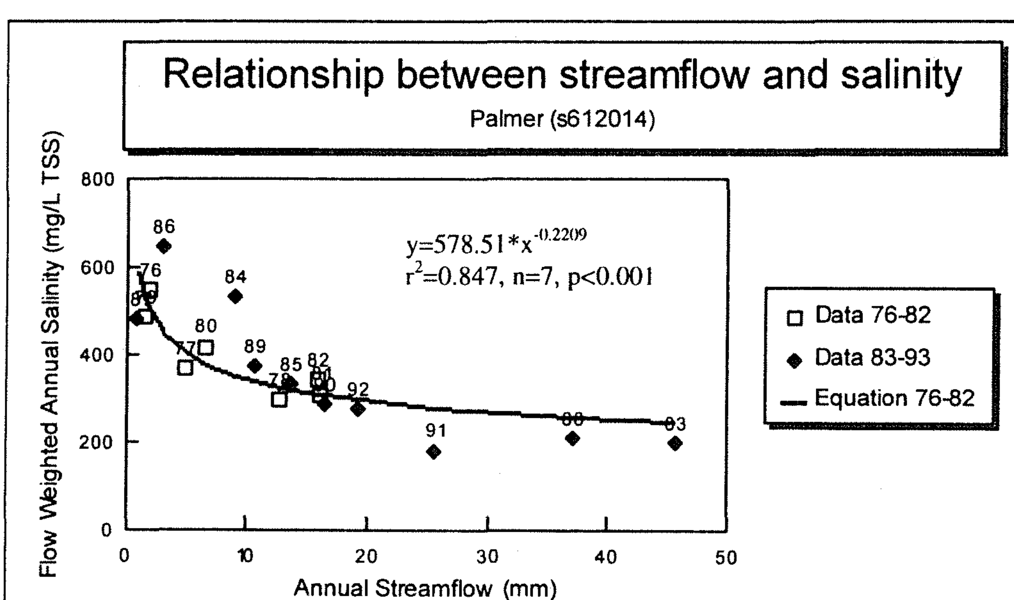

Relationship between streamflow and rainfall
Maringee (s612026)
y=0.3478*x - 147.55
r²=0.947, n=5, p<0.001
Annual Streamflow (mm)
Annual Rainfall (mm)
0
20
40
60
80
100
120
400
500
600
700
800
83
85
84
86
87
91
90
92
88
93
89
Data 83-87
Data 88-93
Equation 83-87

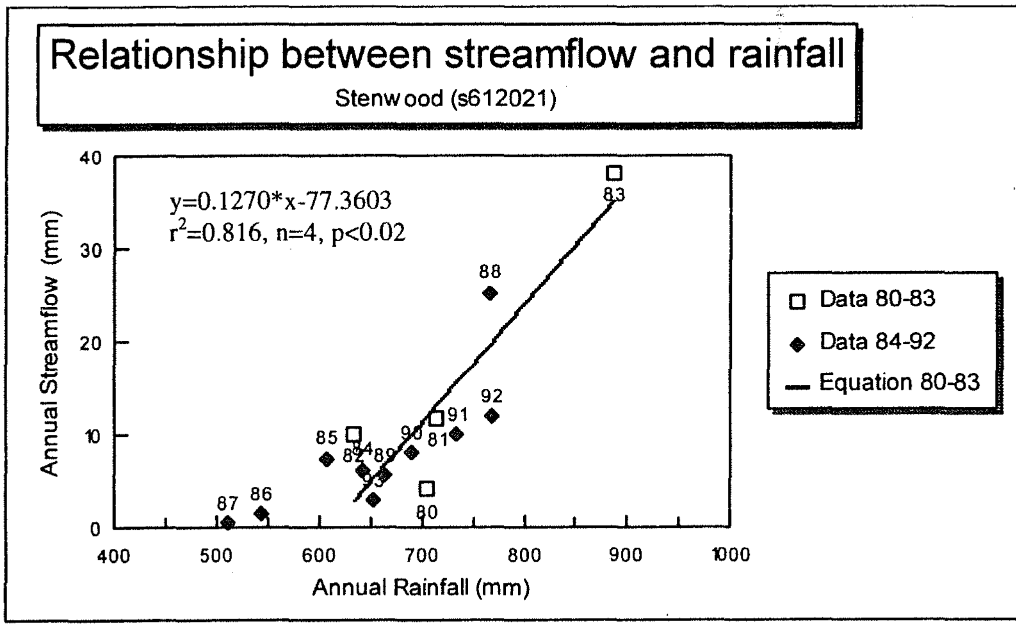

Relationship between streamflow and salt load
Maringee (s612026)
y=0.2131*ln(x)+0.8208
r²=0.404, n=5, p<0.1
Annual Salt Load (tonnes TSS/ha)
Annual Streamflow (mm)
0.5
1
1.5
2
2.5
0
20
40
60
80
100
120
90
85
88
92
91
83
87
84
93
89
86
Data 83-87
Data 88-93
Equation 83-87

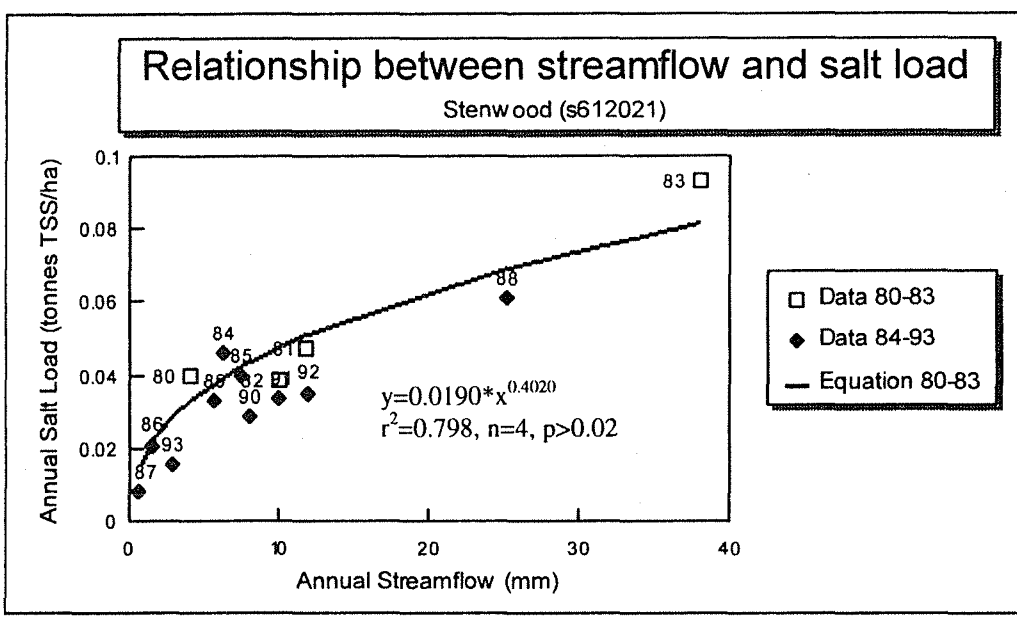

Relationship between streamflow and salinity
Maringee (s612026)
y=91117*x^-0.8522
r²=0.952, n=5, p<0.001
Flow Weighted Annual Salinity (mg/L TSS)
Thousands
Annual Streamflow (mm)
0
5
10
15
20
25
0
20
40
60
80
100
120
87
86
89
84
93
85
88
92
90
91
83
Data 83-87
Data 88-93
Equation 83-87

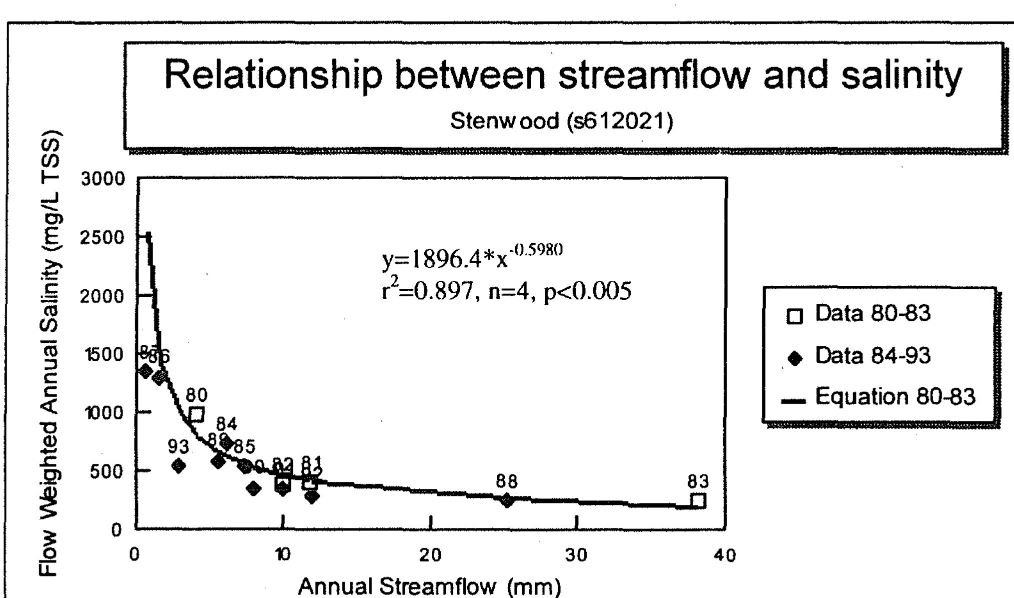

Relationship between streamflow and rainfall
Palmer (s612014)
y=8*10^-12*x^4.2378
r²=0.580, n=7, p<0.01
Annual Streamflow (mm)
Annual Rainfall (mm)
Data 76-82
Data 83-92
Equation 76-82

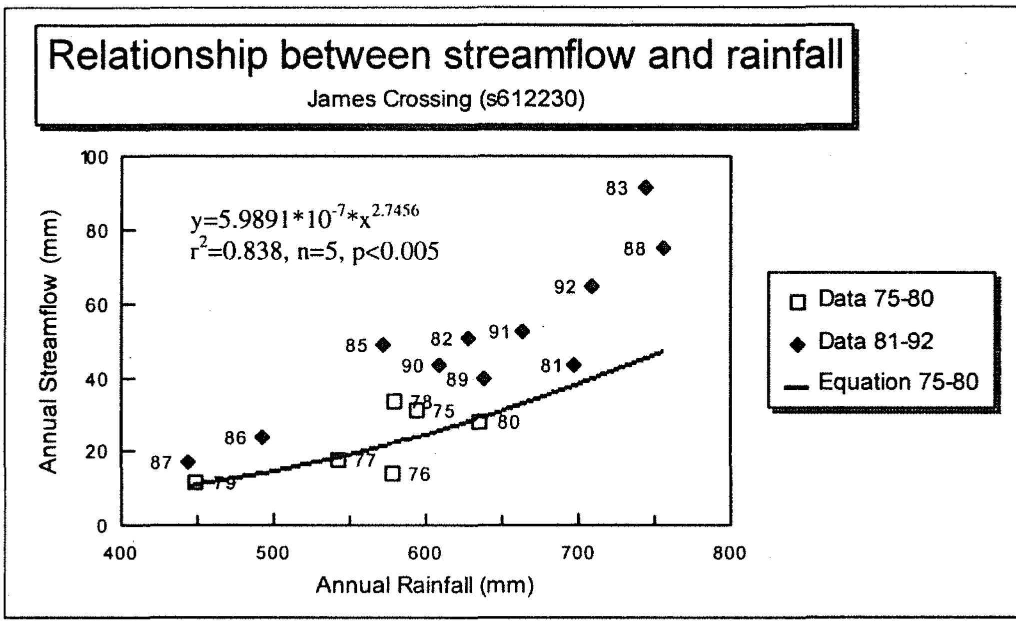

Relationship between streamflow and salt load
Palmer (s612014)
y=0.0058*x^0.7791
r²=0.986, n=7, p<0.001
Annual Salt Load (tonnes TSS/ha)
Annual Streamflow (mm)
Data 76-82
Data 83-92
Equation 76-82

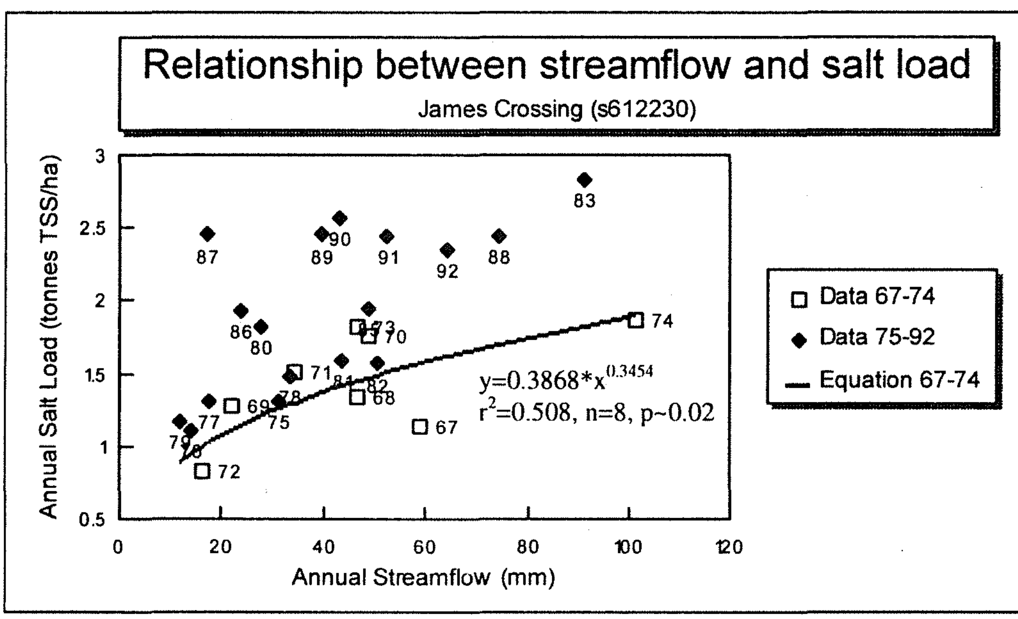

Relationship between streamflow and salinity
Palmer (s612014)
y=578.51*x^-0.2209
r²=0.847, n=7, p<0.001
Flow Weighted Annual Salinity (mg/L TSS)
Annual Streamflow (mm)
Data 76-82
Data 83-93
Equation 76-82

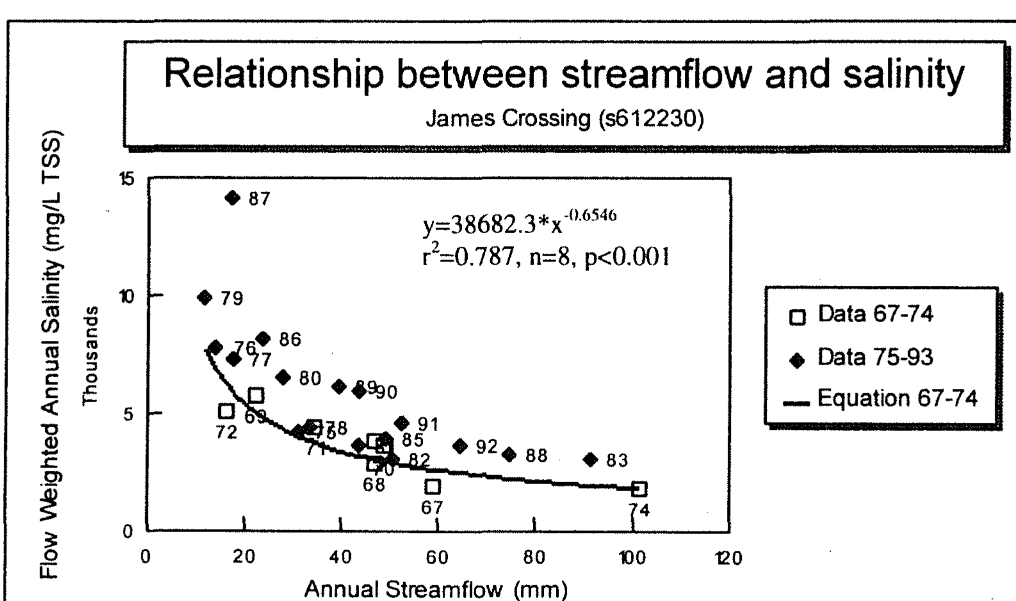

Relationship between streamflow and rainfall
Stenwood (s612021)
y=0.1270*x-77.3603
r²=0.816, n=4, p<0.02
Annual Streamflow (mm)
Annual Rainfall (mm)
Data 80-83
Data 84-92
Equation 80-83

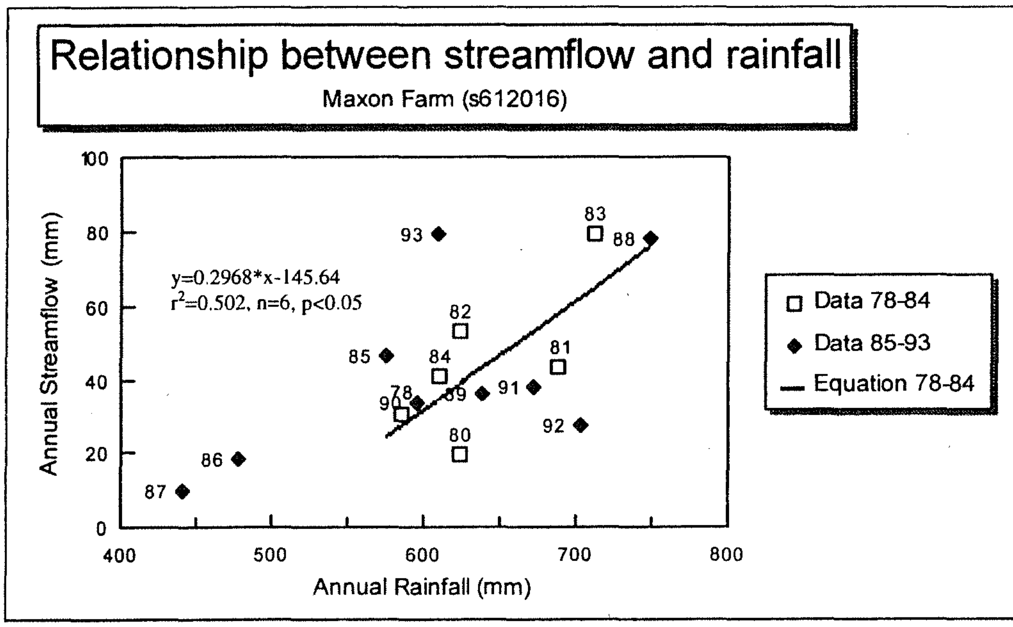

Relationship between streamflow and salt load
Stenwood (s612021)
y=0.0190*x^0.4020
r²=0.798, n=4, p>0.02
Annual Salt Load (tonnes TSS/ha)
Annual Streamflow (mm)
Data 80-83
Data 84-93
Equation 80-83

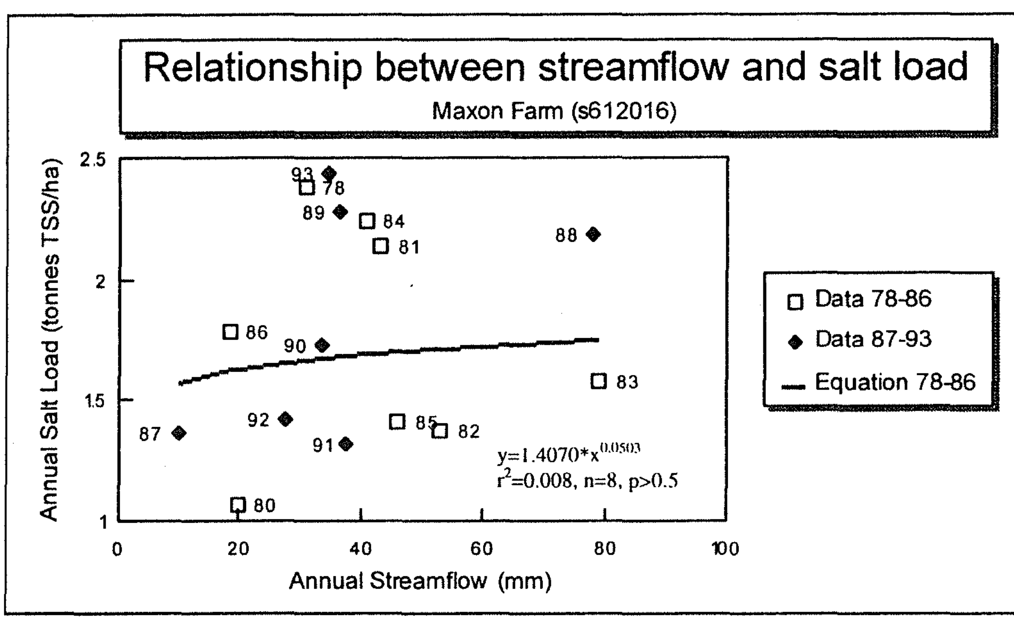

Relationship between streamflow and salinity
Stenwood (s612021)
y=1896.4*x^-0.5980
r²=0.897, n=4, p<0.005
Flow Weighted Annual Salinity (mg/L TSS)
Annual Streamflow (mm)
Data 80-83
Data 84-93
Equation 80-83

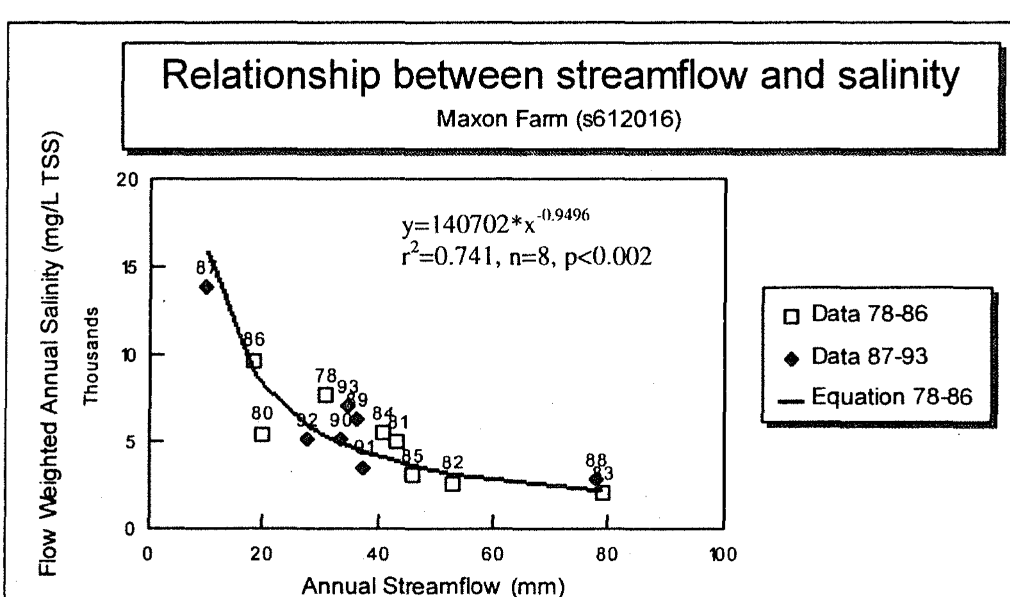

Relationship between streamflow and rainfall
James Crossing (s612230)
y=5.9891*10^-7*x^2.7456
r^2=0.838, n=5, p<0.005
Annual Streamflow (mm)
Annual Rainfall (mm)
Data 75-80
Data 81-92
Equation 75-80


Relationship between streamflow and salt load
James Crossing (s612230)
y=0.3868*x^0.3454
r^2=0.508, n=8, p~0.02
Annual Salt Load (tonnes TSS/ha)
Annual Streamflow (mm)
Data 67-74
Data 75-92
Equation 67-74

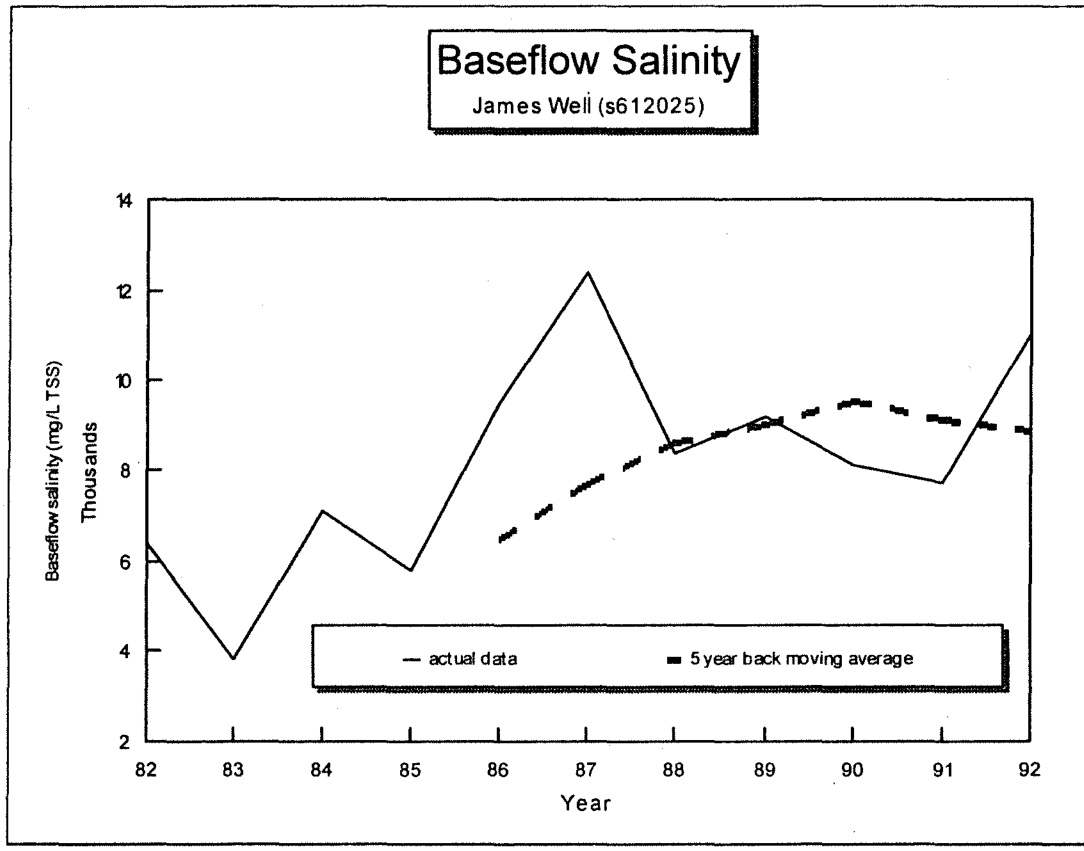

Relationship between streamflow and salinity
James Crossing (s612230)
y=38682.3*x^-0.6546
r^2=0.787, n=8, p<0.001
Flow Weighted Annual Salinity (mg/L TSS)
Thousands
Annual Streamflow (mm)
Data 67-74
Data 75-93
Equation 67-74

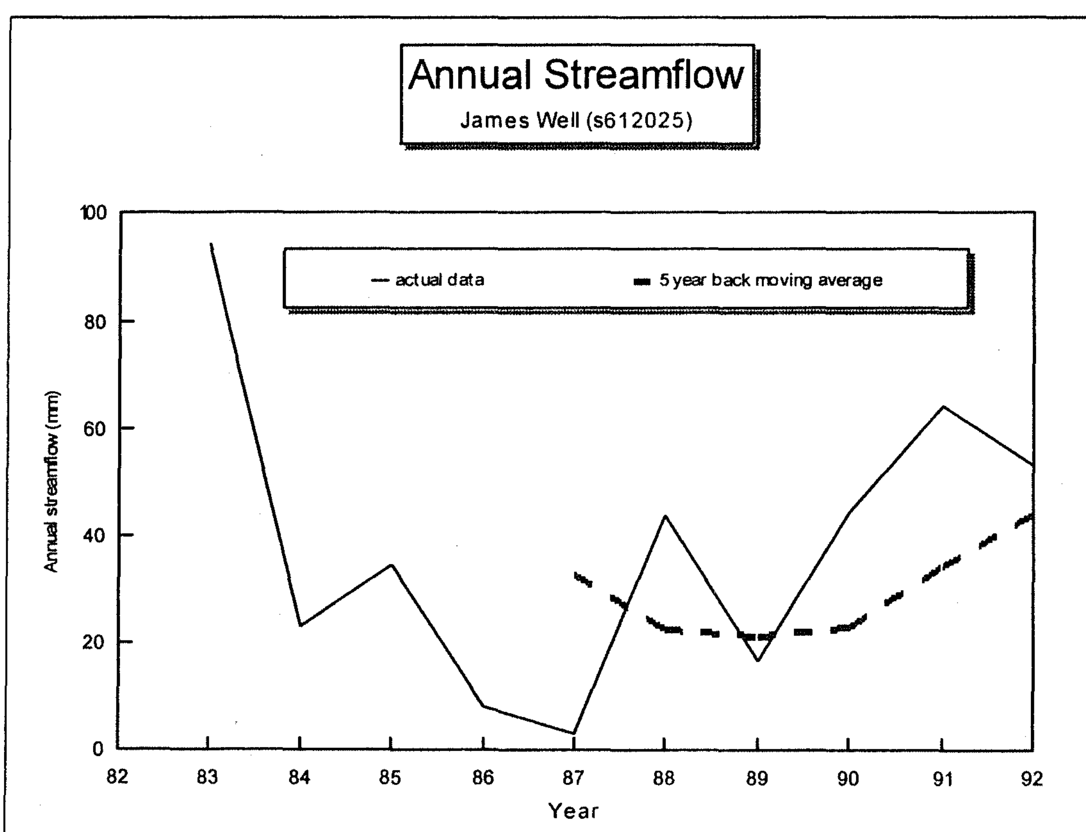

Relationship between streamflow and rainfall
Maxon Farm (s612016)
Annual Streamflow (mm)
Annual Rainfall (mm)
y=0.2968*x-145.64
r²=0.502, n=6, p<0.05
Data 78-84
Data 85-93
Equation 78-84

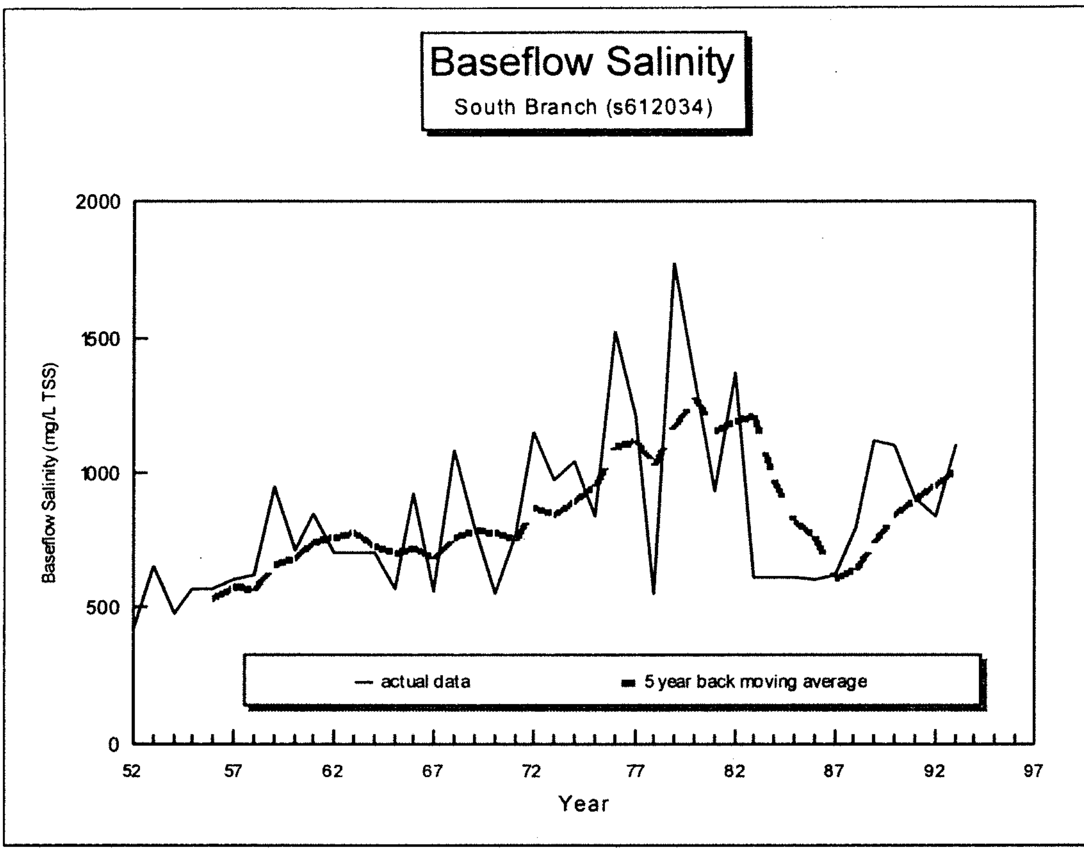

Relationship between streamflow and salt load
Maxon Farm (s612016)
Annual Salt Load (tonnes TSS/ha)
Annual Streamflow (mm)
y=1.4070*x^0.0503
r²=0.008, n=8, p>0.5
Data 78-86
Data 87-93
Equation 78-86

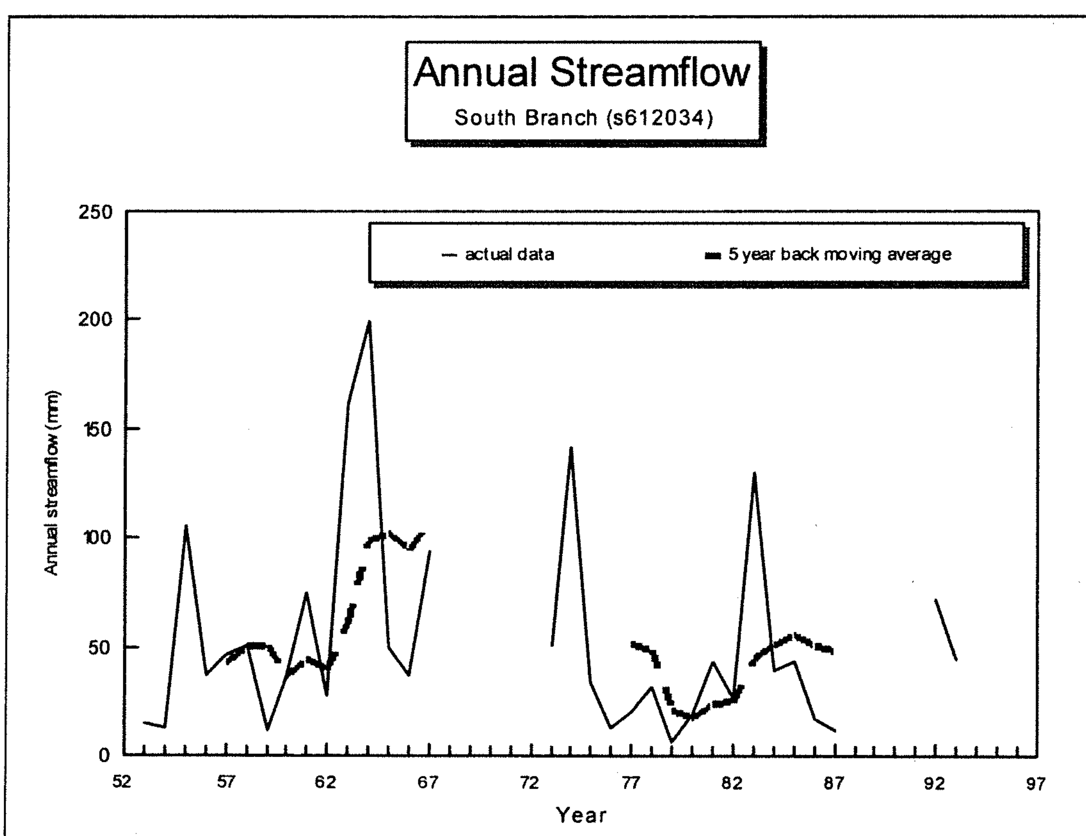

Relationship between streamflow and salinity
Maxon Farm (s612016)
Flow Weighted Annual Salinity (mg/L TSS)
Thousands
Annual Streamflow (mm)
y=140702*x^-0.9496
r²=0.741, n=8, p<0.002
Data 78-86
Data 87-93
Equation 78-86

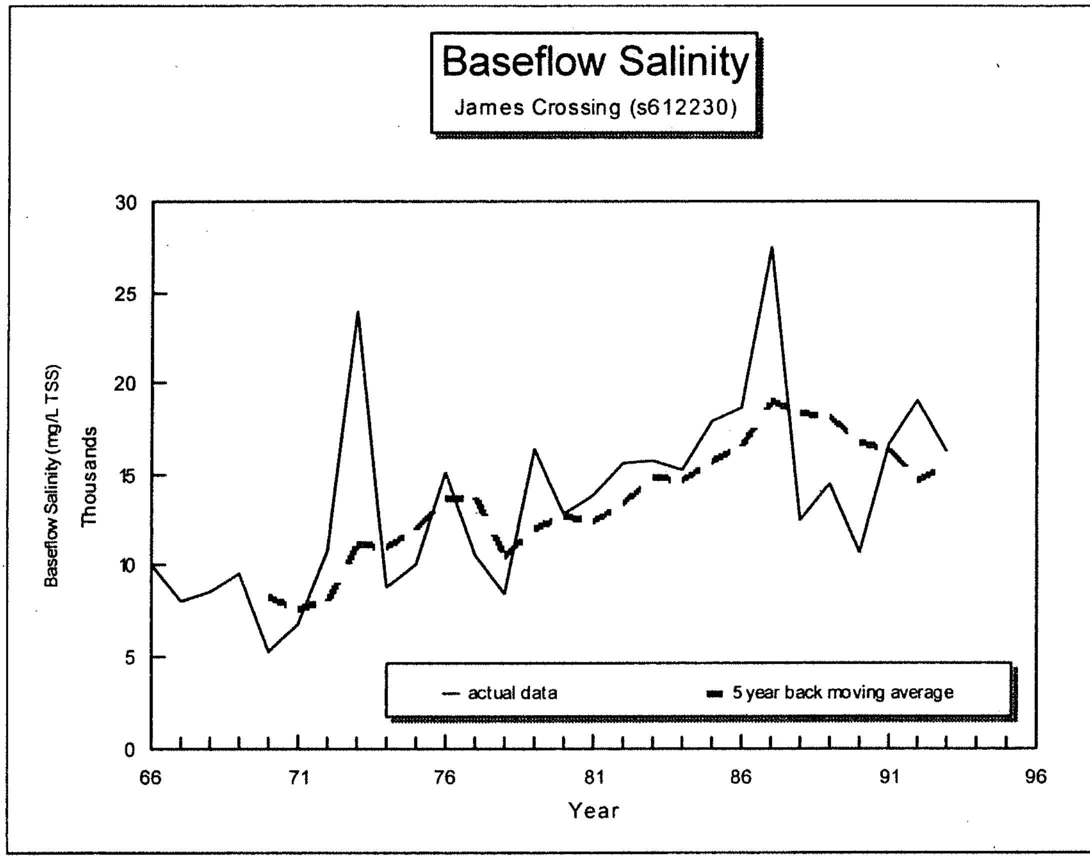
APPENDIX D - Baseflow salinity graphs

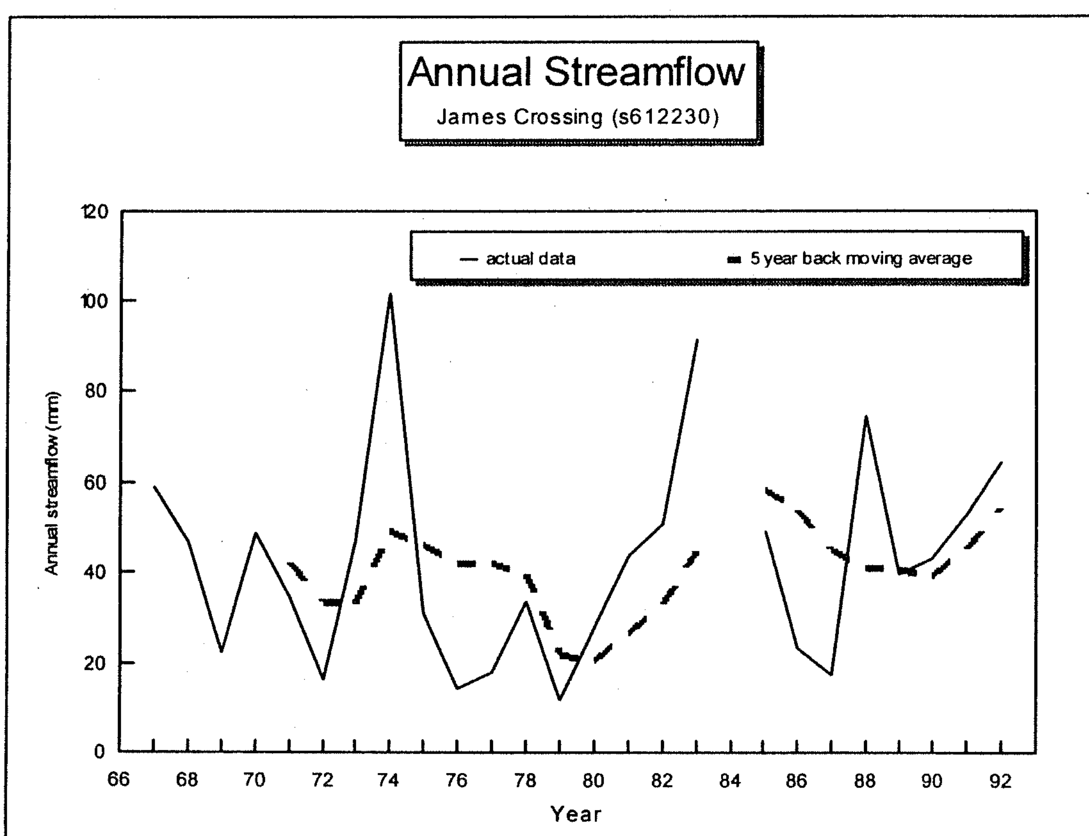

Baseflow Salinity
James Well (s612025)
Baseflow salinity (mg/L TSS)
Thousands
14
12
10
8
6
4
2
82
83
84
85
86
87
88
89
90
91
92
Year
actual data
5 year back moving average


Annual Streamflow
James Well (s612025)
Annual streamflow (mm)
100
80
60
40
20
0
82
83
84
85
86
87
88
89
90
91
92
Year
actual data
5 year back moving average


Baseflow Salinity
South Branch (s612034)
Baseflow Salinity (mg/L TSS)
2000
1500
1000
500
0
— actual data
5 year back moving average
52
57
62
67
72
77
82
87
92
97
Year


Annual Streamflow
South Branch (s612034)
Annual streamflow (mm)
250
200
150
100
50
0
— actual data
5 year back moving average
52
57
62
67
72
77
82
87
92
97
Year


Baseflow Salinity
James Crossing (s612230)
Baseflow Salinity (mg/L TSS)
Thousands
30
25
20
15
10
5
0
66
71
76
81
86
91
96
Year
— actual data
5 year back moving average


Annual Streamflow
James Crossing (s612230)
Annual streamflow (mm)
120
100
80
60
40
20
0
66
68
70
72
74
76
78
80
82
84
86
88
90
92
Year
— actual data
5 year back moving average