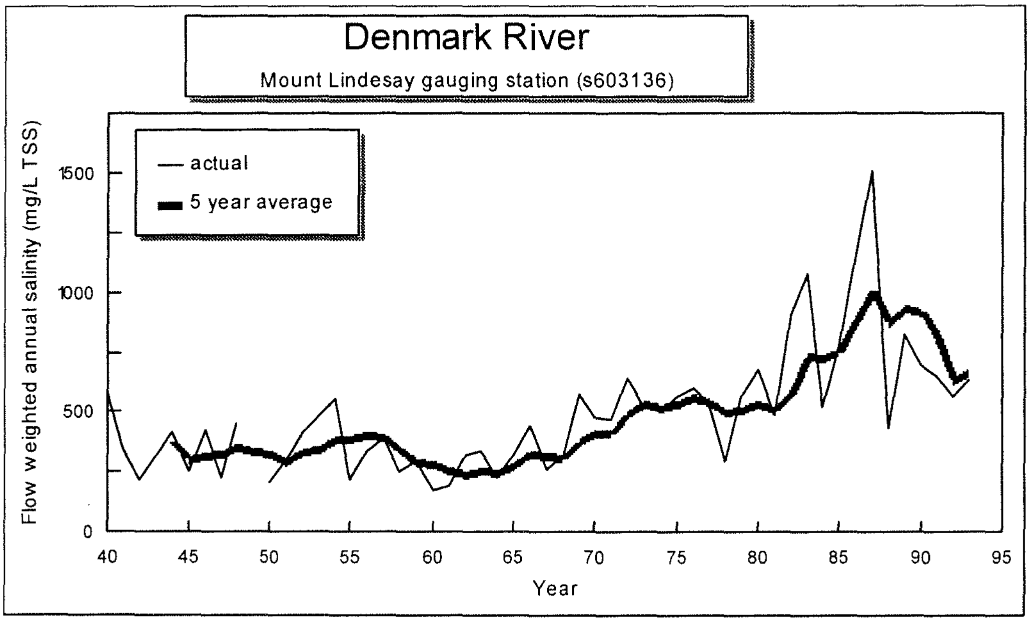
Water Authority
of Western Australia

DENMARK RIVER

STREAMFLOW AND SALINITY

REVIEW



Report WS 152
March, 1995

Water Authority
of Western Australia

Water Resources Directorate
Surface Water Branch

DENMARK RIVER
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REVIEW

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EXECUTIVE SUMMARY

INTRODUCTION

The Denmark River catchment is located in the south-west of Western Australia. A major reservoir could be developed on the Denmark River with a potential yield of approximately 30×10^6 m^3. The area of catchment upstream of the existing pipehead dam is 567 km^2 of which approximately 95 km^2 (17%) was cleared for agriculture by 1984. Stream salinity increased in the 1960s-70s as a result of this clearing. Concern over the increasing salinity led to the extension of Catchment Clearing Control legislation to the Denmark River catchment in 1978 which has resulted in a stabilisation of the area of land cleared.

This report presents the current state of the catchment in terms of its potential use as a water supply and identifies future research and management requirements.

CATCHMENT DESCRIPTION

The Denmark River Basin has a Mediterranean type climate with warm, mostly dry summers and cool, wet winters. **Annual rainfall averages about 1000 mm at the pipehead dam and decreases across the catchment to 700 mm at the northern boundary.** Most of the catchment (55%) consists of laterite plateau uplands with sand and ironstone gravels over mottled clays. Dissected plateau comprises a further 20% of the catchment and incised valleys 15%. The natural vegetation of the catchment is predominantly forest where in most areas the main species are jarrah (*Eucalyptus marginata*) and marri (*E. calophylla*). **The major land uses in the catchment have been the commercial exploitation of timber and agricultural development.** Commercial agricultural development started in the 1860s but the dates of major clearing are between 1946 and 1957 and between 1965 and 1973.

This study has used streamflow data from four gauging stations. The most extensively cleared catchment is Yate Flat Creek which is about 60% cleared followed by Kompup (32% cleared). These catchments are in the low rainfall northern part of the catchment and thus have high salinity risk. Yate Flat Creek is a sub-catchment of Kompup which in turn is upstream of Lindesay Gorge gauging station (now closed) and finally Mt. Lindesay farther downstream.

Table 1: Characteristics of Denmark River Basin

Sub-catchment	Gauging Station	Area	Annual Rainfall (mm)		Area cleared (PWD, 1984)
		(km^2)	Long term	1975-93	(% catchment)
Yate Flat Creek	s603190	56.7	747 (1964-93)	742	60
Kompup	s603003	235	792 (1910-93)	716	32
Mt. Lindesay	s603136	525	872 (1910-93)	781	17

RESULTS AND DISCUSSION

Annual rainfall in the Denmark region had a decreasing trend during the period 1910 to 1983. This may be part of a long term cycle and is not necessarily a permanent decrease. Average rainfall at Kompup during 1984-93 was slightly higher than the preceding ten years (1974-83) but still lower than the long term average. If long term average rainfall conditions had prevailed it is likely that groundwater levels would have risen further beneath pasture. 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.

Groundwater Levels and Salinity

Three sites in and near the upper part of the Denmark River catchment were investigated for changes in groundwater level and salinity. The M Crane site is parkland cleared and has about 20 trees/ha. Groundwater level generally rose over the period 1981-95 but the magnitude of rise was less than at the D Drage and W Crane sites. **The D Drage and W Crane sites had few remaining trees and had gradually rising groundwater levels that were already above the salt bulge. The rising groundwater level is expected to increase the volume of saline groundwater discharge to the stream.** The salinity of the groundwater discharge is not expected to increase much as there is no apparent trend of increasing groundwater salinity. Groundwater salinity has little potential to increase further as the groundwater table is already above the salt bulge in the lower slope areas. Annual stream salinity is expected to increase due to greater volume of saline discharge. The greater volume of saline discharge is expected to increase baseflow but it is not likely to increase the salinity of the baseflow if the saline discharge is near its peak salinity.

Streamflow and Salinity

Table 2 is a summary of the streamflow data recorded during 1975-93. The overall trends observed in this data are indicated.

Table 2: Streamflow and salinity characteristics of Denmark River Basin (1975-93)

Sub-catchment	Gauging Station	Streamflow (mm)	Salinity (mg/L TSS)	TSS Load (kg/ha)	Trend (1975-93)	
					Salinity	TSS Load
Yate Flat Creek	s603190	93	1824	1312	N+I	N+I
Kompup	s603003	58	1617	648	N+I	I
Mt. Lindesay	s603136	57	709	312	N+I	I

Significance level of trends tested by Student's t-test with 95% confidence.

I	Increasing
D	Decreasing
N+I	Increasing trend, but not significant (often due to short period of record)

The short period of streamflow record revealed no obvious increases to stream yield (Table 2). However, **the combined records of Kompup and Clear Hills gauging stations showed increasing stream yield over 1964-93 albeit at an insignificant rate.** Increasing stream yield is expected because of rising groundwater levels in pastured areas of the catchment. Rising groundwater level is likely to increase the quantity of base flow, throughflow and saturation excess runoff which would all result in increased stream yield.

Kompup catchment contributes less than 40% of the streamflow to Mt Lindesay gauging station but 80% of the salt load. Therefore, this catchment should be the focus of efforts to manage stream salinity in the Denmark River. The Yate Flat Creek catchment (a sub-catchment of Kompup) contributes 20% of streamflow and 40% of the salt load yet comprises less than one quarter the area of Kompup. The cause of the high stream yield and salt load is mainly due to the difference in land use with about 60% of the Yate Flat Creek catchment cleared compared to 32% of the Kompup catchment. By comparison, the Lindesay Gorge-Kompup catchment is virtually all forested and contributes about 30% of the flow and about 9% of the salt load.

During 1975-93, Yate Flat Creek had an average flow weighted annual salinity of 1820 mgL^{-1} TSS, Kompup was 1620 mgL^{-1} TSS and Mt. Lindesay was 710 mgL^{-1} TSS. Schofield *et. al* (1988) observed that the magnitude of increase to stream salinity, subsequent to clearing for agriculture, is proportional to location (*i.e.* rainfall of area) and extent of clearing. This observation applies also to the Denmark catchment as stream salinity is greatest in the low rainfall and largely cleared catchments of Kompup and foremostly Yate Flat Creek. An estimate of the rate of salinity increase can be determined from the slope of the 5 year back moving average of flow weighted annual salinity. **At Yate Flat Creek (1975-90) salinity increased by about 75 $mgL^{-1}yr^{-1}$ and at Kompup the rate was also 75 $mgL^{-1}yr^{-1}$ while farther downstream at Mt. Lindesay the rate was less at about 25 $mgL^{-1}yr^{-1}$.** As these rates are calculated from annual salinity data alone they do not take into account climatic variation (*i.e* trends in rainfall).

The limit that determines fresh water according to water resources classification is 500 mgL^{-1} TSS (Steering Committee, 1989). The salinity of the Denmark River at Mt. Lindesay gauging station (1975-93) averaged 709 mgL^{-1} TSS and in 1987 (the second in two successive low rainfall years) was 1510 mgL^{-1} TSS. This salinity level is unacceptable for water supply. The trend during 1978-93 was for an insignificant rate (t-test, 95%) of salinity increase at Mt. Lindesay whereas the rate of salinity increase was significant over 1969-93. Further years of data collection are necessary to determine whether the recent slowing in the rate of salinity increase is indication that the river is nearing its peak salinity or that it is only a climatic effect.

Although clearing controls are expected to limit the potential maximum salinity, this limit is still greater than desirable. While a large storage capacity reservoir may avoid serious problems from high salinity years the salinity of the Denmark River is sufficiently high to warrant remedial catchment management programmes. **Possible measures to reduce salinity in this Low Rainfall Zone include protection of**

remnant vegetation, reforestation, forest regeneration and high water use agricultural systems. A policy on remnant vegetation protection and management needs to be developed and implemented.

Base flow and Base flow Salinity

There were no apparent trends with time in base flow as a fraction of total flow for any of the gauging stations. **Base flow salinity at Kompup gauging station increased from 1250 mgL^{-1} TSS around 1961, peaking at 6500 mgL^{-1} TSS in 1987, and then declined to 4100 mgL^{-1} TSS by 1993.** The peaking of base flow salinity is associated with low annual rainfall and flow and the subsequent decline occurred during high rainfall and flow years. Thus, the overall trend of base flow salinity is for an increase with what appears to be some climatic variation.

CONCLUSIONS

- There was a decreasing trend of rainfall in the Denmark region over the period 1910 to 1993. It is not yet possible to determine if this trend has ceased.

- About 17% of the total catchment was cleared for agriculture by 1984. Most of the clearing (80%) is upstream of the Kompup gauging station. Yate Flat Creek sub-catchment (a sub-catchment of Kompup) is about 60% cleared and Kompup 32% cleared.

- At the M Crane parkland clearing site, potentiometric levels generally rose during 1981-95 by about 0.84 m near the streamline and 2.34 m at an up-slope location. At the fully cleared W Crane site groundwater levels rose by 1.9m (1980-91) while in forest, on the other side of the valley, there was no change.

- Yate Flat Creek contributes less than 20% of streamflow but about 40% of salt load to Mt. Lindesay. The catchment area between Kompup and Yate Flat Creek contributes about 20% of the flow and 40% of the salt load. Lindesay Gorge-Kompup contributes about 30% of streamflow and about 9% of stream salt load. Mt. Lindesay-Lindesay Gorge catchment produces about 30% of flow and 14% of salt load.

- A long period of data was generated by combining the record of Kompup and Clear Hills gauging station. This extended record revealed a trend of increasing stream yield (despite decreasing rainfall) most of which had occurred by the early 1980s.

- The flow weighted annual stream salinity and stream salt load at each gauging station had an increasing trend with time over the study period. These trends were significant (t-test, 95%) at each gauging station except Kompup whose trend of increasing salinity was not significant over the period 1975-93 but was significant during 1975-83. The trends at Yate Flat Creek (stream salinity and salt load) and Mt. Lindesay gauging station (stream salinity) were also insignificant over the shorter period 1975-93.

- Base flow salinity at Kompup gauging station increased from about 1250 mgL^{-1} TSS in the 1960s and peaked in 1987 at 6500 mgL^{-1} TSS but declined to 4100 mgL^{-1} TSS by 1993.

RECOMMENDATIONS

- Continuous recording of stage, conductivity and temperature should be maintained at Mt. Lindesay (s603136), Kompup (s603003) and Yate Flat Creek (s603190) gauging stations. Stream yield calculations also require rainfall data so monitoring of rainfall should continue.

- To develop catchment management strategies for the Denmark River catchment it is necessary to monitor the catchment hydrology which requires data on groundwater level and salinity. Assessing trends in groundwater level and salinity gives an indication of the saline groundwater discharge to the stream which affects the stream salinity. Therefore, monitoring of the M Crane, W Crane and D Drage sites ought be continued/resumed.

- Continue monitoring those groundwater bores (WAWA or other agency) that are situated in the midst of reforestation (current or future). Alternatively, drill new bores to monitor the effectiveness of the reforestation in reducing groundwater levels. The groundwater monitoring results would indicate the level of success the reforestation had in reducing discharge of saline groundwater to the stream.

- Continue with the development and implementation of the Integrated Catchment Management programme begun in 1988. Actions to reduce stream salinity should include remnant vegetation protection, reforestation and high water use agriculture systems. The management strategy should focus mainly on the Intermediate and Low Rainfall Zones.

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1 INTRODUCTION

The town of Denmark was formerly supplied with water from a pipehead reservoir of about 420 000 m^3 capacity on the Denmark River. The salinity in the pipehead dam has deteriorated in recent years (Ruprecht *et al.*, 1985). Construction of a new dam commenced in 1988 located on the Quickup River which is used in place of the Denmark River pipehead dam.

Rising groundwater levels as a consequence of agricultural clearing have been shown to cause large increases in stream salinity in areas of intermediate to low rainfall (<1100 $mmyr^{-1}$) (Schofield *et al.*, 1988; Loh, 1988). 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).

The area of the catchment upstream of the pipehead dam is 567 km^2 of which approximately 25% is alienated and 95 km^2 (17%) was cleared for agriculture by 1984 (Ruprecht *et al.*, 1985). Much of the cleared land (80%) is in the upper reaches of the catchment which receives 700 to 800 mm of rainfall annually. The significant cleared area in the lower rainfall part of catchment represents the greatest salinity hazard. Catchment Clearing Control legislation for the Denmark River catchment was enacted in 1978 to protect the water resource from further deterioration.

A major reservoir on the Denmark River has a potential yield of approximately $30x10^6$ m^3. The most likely reservoir location is at the Mt. Lindesay gauging station (Ruprecht *et al.*, 1985). A study by Ruprecht *et al.* (1985) indicated that the full hydrological effects of clearing will have developed by early next century. They estimate that the 10%, 50% (median) and 90% probabilities of non-exceedance of annual streamflow will be 12, 32 and $82x10^6$ m^3. The associated salinities are likely to be 1080, 725 and 460 mgL^{-1} TSS. Therefore the water resource would be of marginal quality (500-1000 mgL^{-1} TSS) on average.

This report reviews historical information on water quantity and quality (salinity) in the Denmark River. The effects of different land uses (clearing /clearing control bans/ tree planting *etc.*) on water quantity and quality are considered. The current potability and likely future impacts from trends are determined as well as assessing whether salinity (present and future) is acceptable for flora and fauna.

2 CATCHMENT DESCRIPTION

2.1 Location and Climate

The Denmark River Basin is located in the south of Western Australia and lies mostly in the shires of Denmark and Plantagenet (Fig. 1).

Average annual rainfall decreases from about 1000 mm at the pipehead dam to 700 mm at the northern boundary of the catchment (Hayes and Goh, 1983). Pan evaporation averages 1270 $mmyr^{-1}$ across the catchment and the average annual temperature is approximately 15°C (Ruprecht *et al.*, 1985). This region has a Mediterranean type climate with warm, mostly dry summers and cool, wet winters.

2.2 Landforms and Soils

Most of the catchment (55%) consists of laterite plateau which are uplands with sands and ironstone gravels over mottled clays. Dissected plateau covers 20% of the catchment. This landform is comprised of hilly country with yellow mottled soils and gravels. Incised valleys, having moderate to steep slopes with yellow podsolic soils and red earths, comprise 15% of the catchment. Swampy flats with poor drainage cover 10% of the catchment, primarily in the west and north-west (Public Works Department, 1984). The catchment varies in elevation from 240m in the north to 80m in the south, apart from Mt. Lindesay whose peak has an elevation in excess of 450m.

A study by Ferdowsian and Greenham (1992) reported that the majority of salt seeps in the upper Denmark (Kompup) catchment are associated with the intersection of creeks and geological structures. Ferdowsian and Greenham (1992), in a survey of soil salinity, found that 10.9% of the Kompup catchment was salt affected and that an additional 2.1% of the area (creek lines, valleys and swamps) were partly affected.

2.3 Vegetation and Land Use

The natural vegetation of the catchment is predominantly forest. The dominant species over most of the catchment are jarrah (*Eucalyptus marginata*) and marri (*E. calophylla*). In the lower, wetter reaches of the Denmark River Basin there are isolated stands of karri (*E. diversicolor*) (Ruprecht *et al.*, 1985). In the upper Denmark catchment, the eastern part is dominated by jarrah and marri while the western part is dominated by sheoak (*Allocasuarina fraseriana*), banksia (*Banksia spp.*) and jarrah woodland (Ferdowsian and Greenham, 1992).

The commercial exploitation of timber commenced in the 1870s. The number of timber mills in and around the catchment peaked at seven in the 1950s (Ruprecht *et al.*, 1985).

DENMARK RIVER CATCHMENT

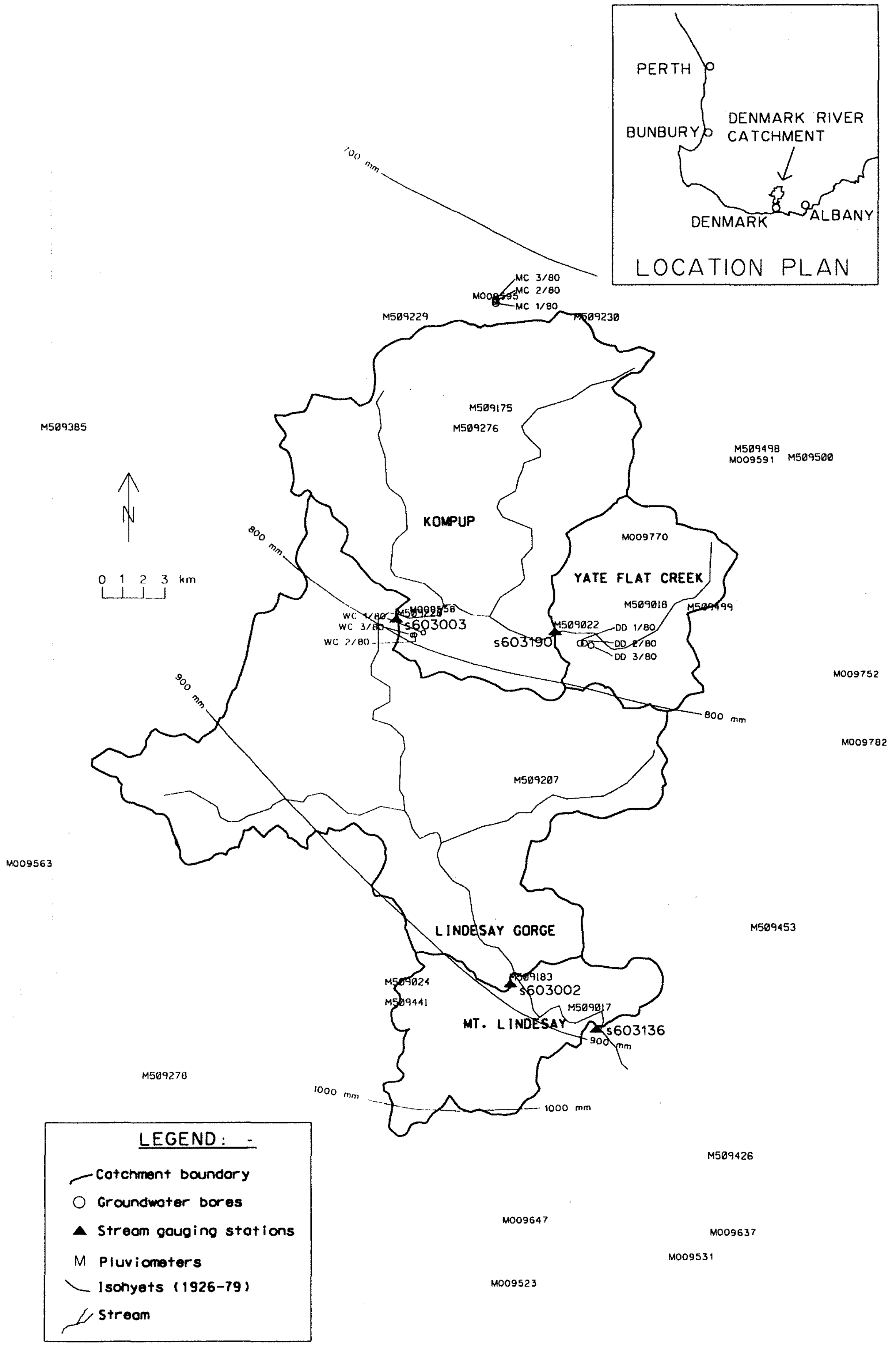


Figure 1 - Instrumentation set-up for Denmark River catchment

Commercial agricultural development started in the 1860s and until the 1890s was confined to extensive pastoralism based on sheep in the Kompup area. At this time small mixed farms were established in the areas that had been clear-felled between Mount Lindesay and Lindesay Gorge (Ruprecht *et al.*, 1985). In the upper Denmark catchment, the current main land use is grazing annual pastures for merino wool and beef production (Ferdowsian and Greenham, 1992). Ruprecht *et al.* (1985) state that the dates of major clearing in the Denmark catchment were between 1946 and 1957 and between 1965 and 1973. The area of land cleared has stabilised since the introduction of Catchment Clearing Control legislation in 1978. The area of the catchment upstream of the pipehead dam is 567 km^2 of which approximately 25% is alienated and 95 km^2 (17%) was cleared for agriculture by 1984. Much of the cleared land (80%) is upstream of the Kompup gauging station (Fig. 2). The most extensively cleared catchment is Yate Flat Creek which is about 60% cleared, followed by the catchments for Kompup (32% cleared) and Mt. Lindesay (17% cleared) gauging stations (Public Works Department, 1984).

Table 1 - Clearing in Denmark River Basin

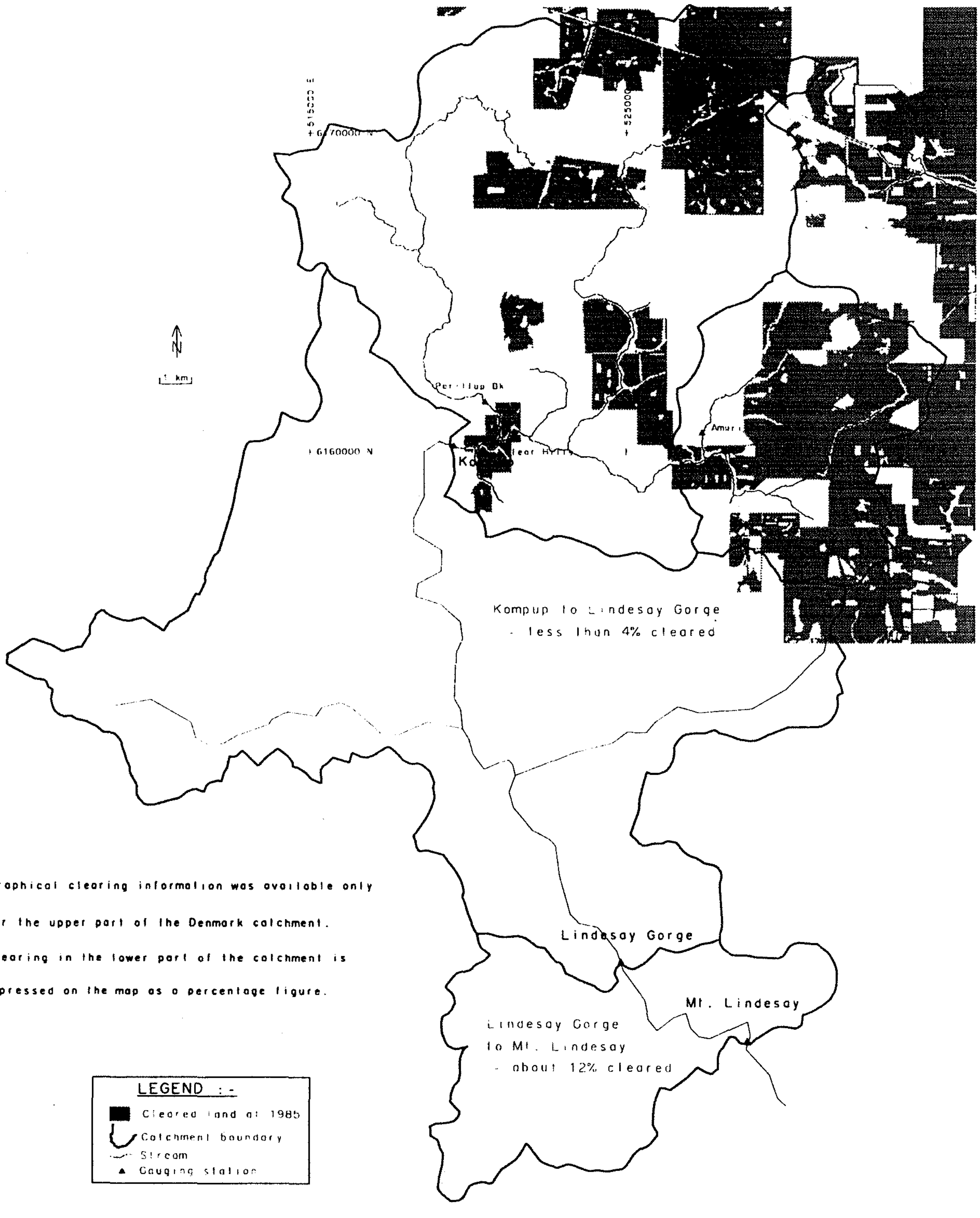
Sub-catchment	Gauging Station	Area (km^2)	Area cleared (PWD, 1984) (% catchment)
Yate Flat Creek	s603190	56.7	60
Kompup	s603003	235	32
Mt. Lindesay	s603136	525	17

Since 1978, clearing licences have been issued for 12.7 km^2 of the Denmark River catchment while licences were refused for 27.5 km^2 of the area. The number of refusals of clearing licence applications has steadily declined since 1978. Thus, demand for further clearing of the land has reduced.

Starting in 1991, some areas were planted with trees for commercial wood production (Table 2).

Table 2 - Kompup catchment tree plantings

YEAR	**AREA PLANTED (ha)**
1991	40
1992	60
1993	65
1994	48



Graphical clearing information was available only for the upper part of the Denmark catchment. Clearing in the lower part of the catchment is expressed on the map as a percentage figure.

Figure 2 - Clearing in the Kompup area at 1984

3 RAINFALL

The Thiessen method was used to calculate mean areal precipitation for each of the sub-catchments.

Ruprecht *et al.* (1985) noted a trend of decreasing annual rainfall in the Denmark region during the period 1910 to 1983 (see also Fig. 3). This may be part of a long term cycle and is not necessarily a permanent decrease. The average rainfall in the Kompup catchment for 1984-93 was 718 mm which is slightly higher than the preceding ten years (1974-83) when the average rainfall was 704 mm (*ie.* a 2% increase over the 1974-83 data). While it is possible that average rainfall may have stopped decreasing it is still the case that average rainfall in the period 1984-93 is below the long term average. The situation is similar for the Lindesay Gorge and Mt. Lindesay sub-catchments whose 5 year back moving averages show systematic increase between 1988 and 1992 (Fig. 4c,d). Despite the recent increase for these sub-catchments the average rainfall for the 1988-92 period remains below the long term average. The yearly variation in rainfall is considerable and therefore at least ten years of data would be necessary to differentiate a change in long term trend from yearly variation. Therefore, it is not yet possible to determine that long term rainfall has ceased its trend of decline from 1910.

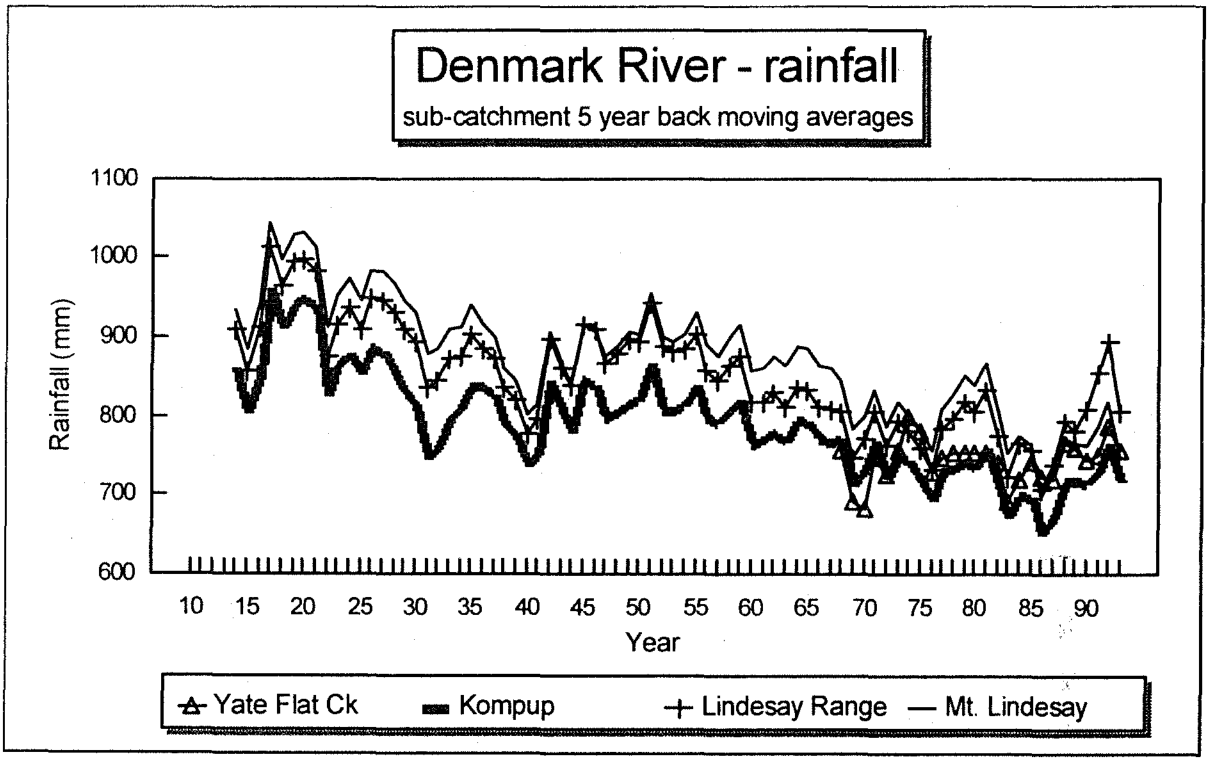


Figure 3 - Rainfall: 5 year back moving averages

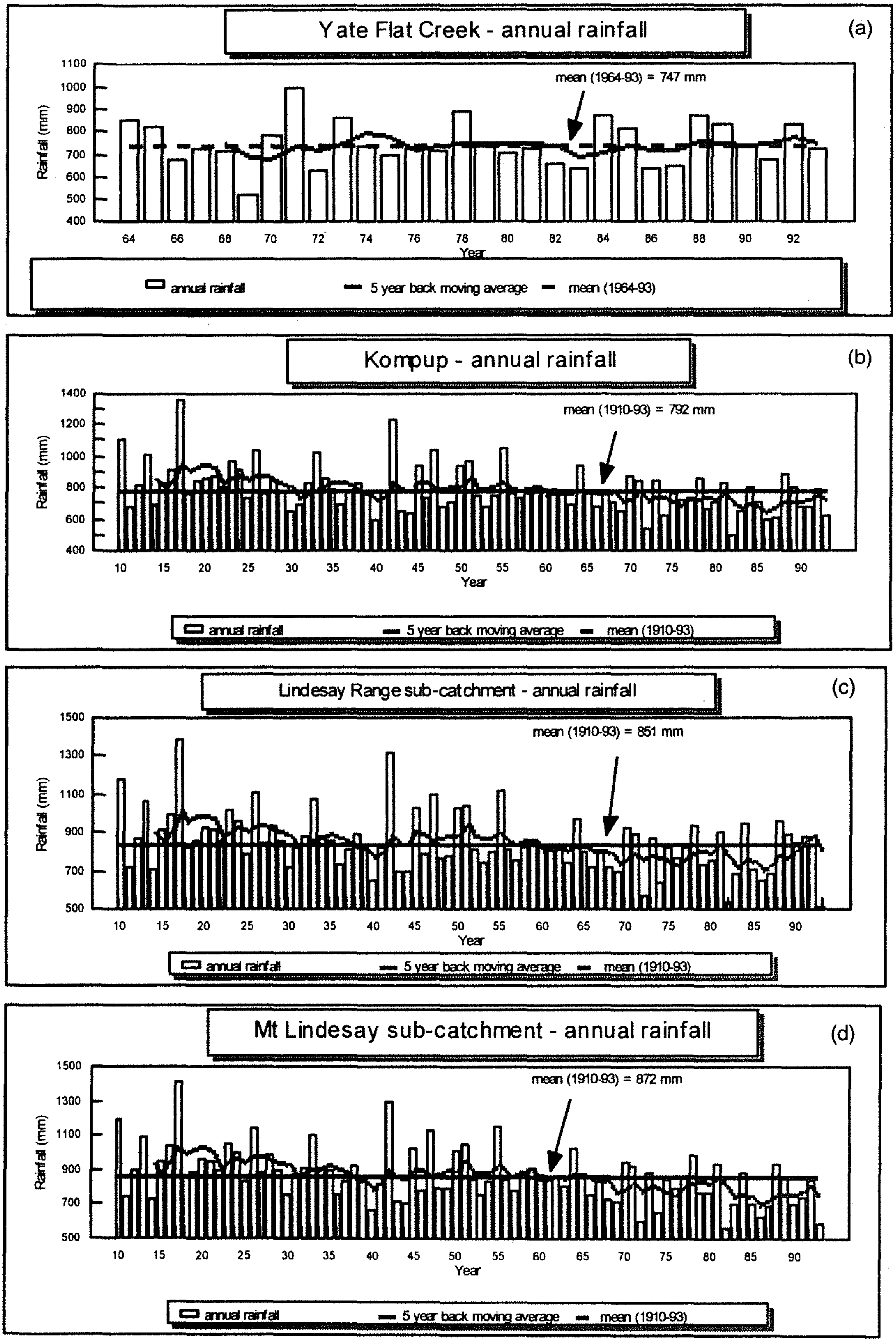


Figure 4 - Long term annual rainfall

4 GROUNDWATER LEVELS AND SALINITY

Three hill-slope bore transects were chosen in and around the Upper Denmark catchment (Fig. 1). The objective was to determine the behaviour of groundwater levels in the area in order to assess the changes to the hydrology of the catchment.

4.1 M Crane bores

The M Crane site is an upland area bore transect (Fig. 5a). It is located in the headwaters of the Kent River catchment and lies just outside the northern boundary of the Denmark River catchment (Fig. 1). Due to its proximity it is a useful indicator of trends in groundwater level and salinity for the Upper Denmark catchment. This site is termed parkland clearing and has about 20 trees/hectare.

Piezometric level in the lower slope area close to the stream rose by 0.84 m between 13-Apr-81 and 15-Mar-95 (Fig. 5a). During this period the potentiometric level in the mid-slope area rose by 1.25 m and further up the slope the rise was 2.34 m. However, the plots of annual minimum potentiometric level together with annual rainfall reveal that this rise in potentiometric levels corresponds to higher rainfall (Appendix A). The years 1988-92 had high rainfall (especially, 1988) and for the duration of this period the groundwater rose considerably.

The piezometric level in the lower slope area intersects the salt bulge and the groundwater salinity appears to have increased from about 8500 mgL^{-1} TSS in 1981 to about 9000 mgL^{-1} TSS by 1995 (Appendix A). This increase to groundwater salinity follows the general trend of the increasing potentiometric level. In the mid-slope area, the potentiometric level remains several metres below the salt bulge (Fig. 5a). The piezometric head in the shallow bore at this location was similar to the deep bore thus there is little depth gradient in piezometric pressure. Therefore, it is inferred that the levels measured at this mid-slope location represent the actual position of the water table. Bari and Boyd (1992a) considered that the apparent reduction in groundwater salinity (Appendix A) is likely due to fresh water leakage from the surface and therefore not a real reduction. Groundwater level in the upslope area remains several metres below the main salt bulge. Few measurements were taken at the upslope area as the bore casing had been knocked over (note: It is still possible to take measurements by holding the casing in place over the bore hole.).

4.2 W Crane bores

The W Crane site is an incised hillslope bore transect (Fig. 5b). One side of the hillslope is pastured whilst the other side is native forest. It is located near to the outlet of the Kompup catchment (Fig. 1).

Data for the annual minimum piezometric level gives misleading results as only four measurements were taken in each of 1988 and 1989 and then only one measurement in each of 1990 and 1991 (Appendix A). The changes in piezometric level have

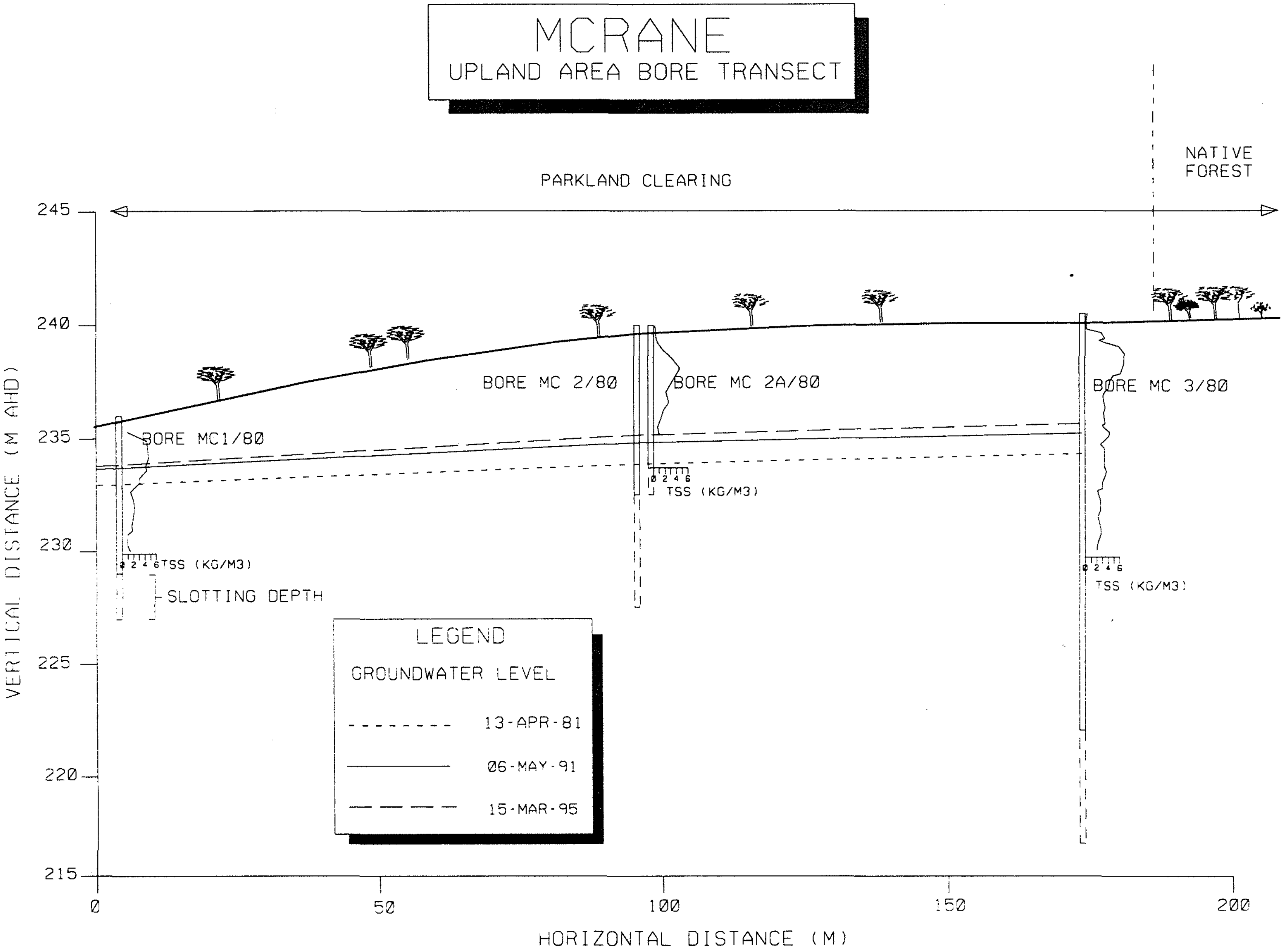


FIGURE 5A - M CRANE GROUNDWATER LEVELS

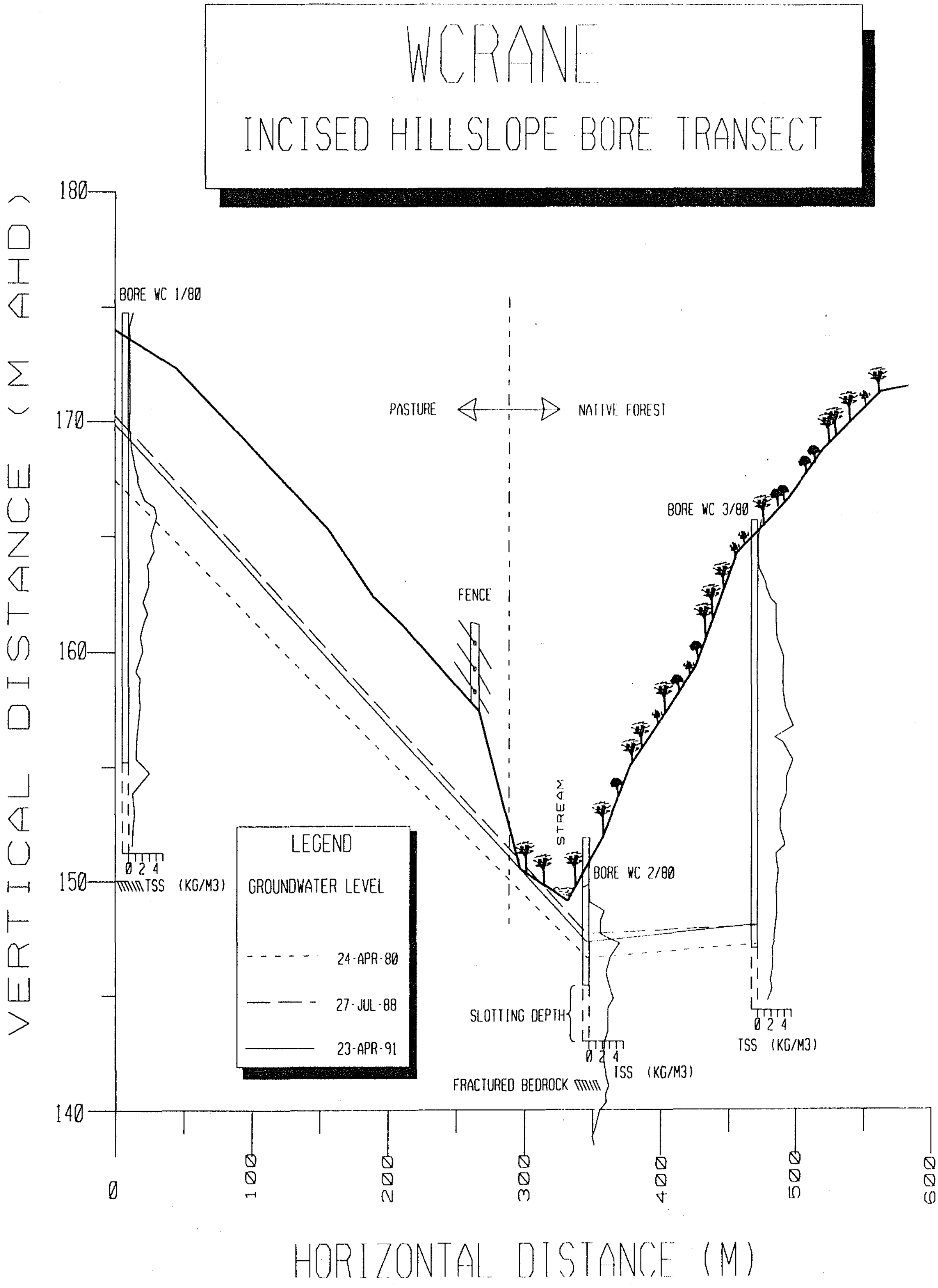


FIGURE 5B - W CRANE GROUNDWATER LEVELS

instead been estimated by comparing measurements taken in the same month of the year.

Groundwater level in the mid-slope pasture area seems to have increased between 19-Aug-88 and 08-Aug-91. The increase was 0.12 m which may not be significant as the seasonal variation in groundwater level was as much as 2.24 m (Appendix A). The uncertainty in this short period (1988-91) is highlighted with the comparison of the levels at 4-Apr-89 with 23-Apr-91 which, instead, imply a 0.32 m decline. Ferdowsian and Greenham (1992) record the deep and shallow groundwater levels in bores WC1/80 and WC1A/80 as having risen 1.89 and 3.22 m between April 1980 and April 1991. Thus, the long term trend appears to be of increasing groundwater level. The groundwater level was above the salt bulge between 1988 and 1991. Groundwater salinity in the deep bore varied between 4000 and 8000 mgL^{-1} TSS over this period (Appendix A). There was no noticeable trend in groundwater salinity.

Bores WC2/80 and WC3/80 are located in native forest on the other side of the valley (Fig 5b). They have use as controls for the WC1/80 bore and other groundwater monitoring sites with similar rainfall. Piezometric level has declined about 0.4 m in the lower slope area of the native forest during the period 1989-91. The piezometric level is about 3 m below the surface and situated just above the peak in the salt bulge. Further up the slope, the groundwater level increased by about 0.05 m (April 1989 - April 1991). Ferdowsian and Greenham (1992) recorded the groundwater level under the forested hill slope as not having risen since 1980. Thus, the long term groundwater level trend in the forest appears to be no change. The piezometric level in the lower slope area is about 3 m below the ground surface and just above the salt bulge peak. The water table in the mid-slope area is about 16.5 m below the ground surface and considerably lower than the salt bulge. Groundwater salinity in both the lower slope and mid-slope areas varied between 400 and 5300 mgL^{-1} TSS during 1988-91 but had no real trend with time (Appendix A).

4.3 D Drage bores

The D Drage site is a less incised mid-slope bore transect (Fig. 5c). The paddocks are totally cleared apart from some clumps of trees remote from the bores. A strip of about 50 m of native vegetation fringes either side of the creek.

Only a limited period of data is available. Between 4-Apr-89 and 23-Apr-91 the groundwater table in the up-slope area rose by 1.25 m. However, the water table is still more than 5 m below the salt bulge. The salinity of the groundwater shows considerable variation but no obvious trend (Appendix A).

In the same period, the groundwater table in the mid-slope area rose by 0.12 m but is already above the peak in the salt bulge. Salt storage at the mid-slope site is less than the upslope and lower slope sites. From the first measurement in August 1988, the lower slope groundwater potentiometric head has been greater than 0.5 m above ground level. The groundwater salinity fluctuates about 4400 mgL^{-1} which is approximately twice the salinity in the upslope area.

DDRAGE

LESS INCISED MID-SLOPE BORE TRANSECT

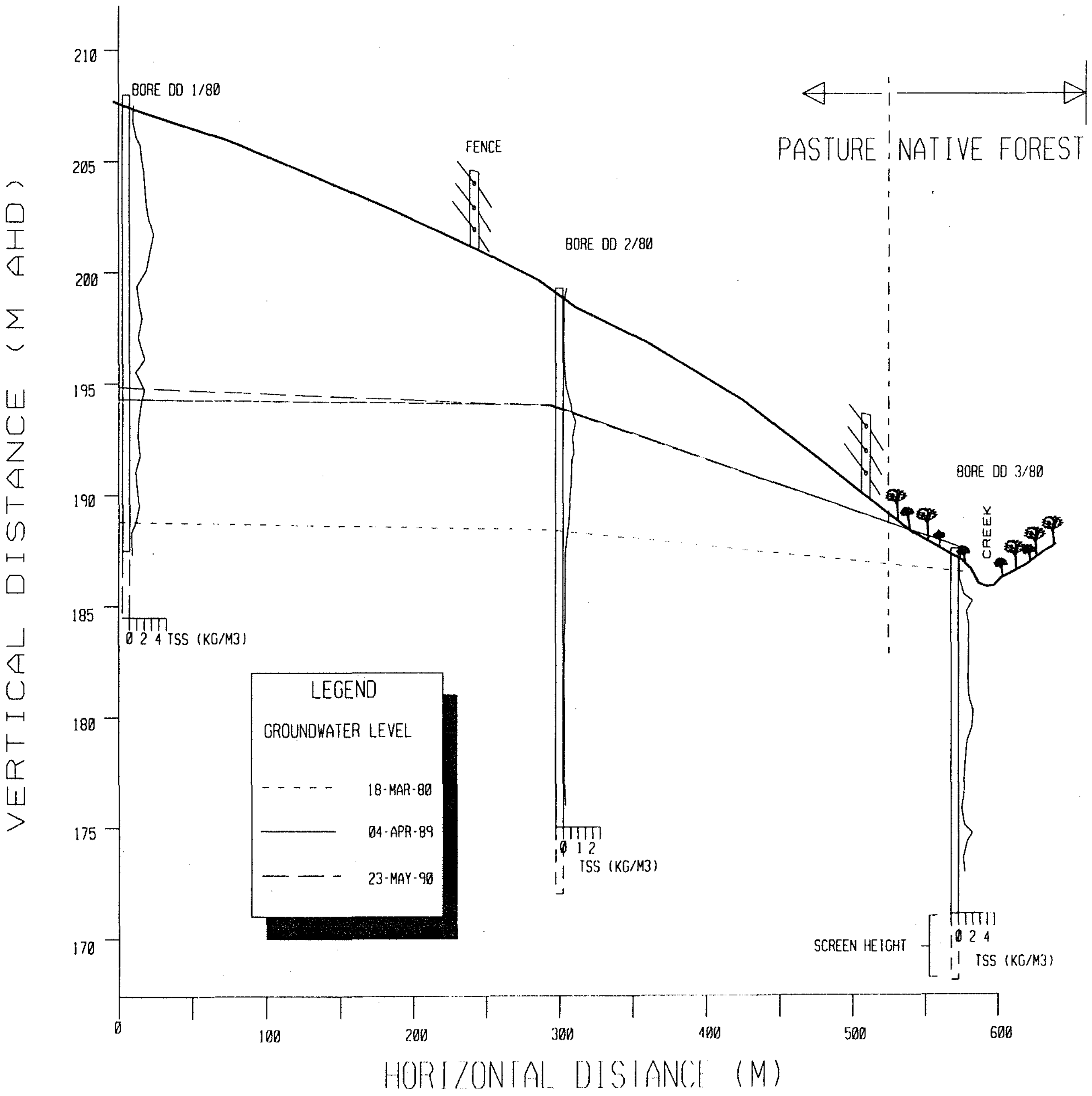


FIGURE 5C - D DRAGE GROUNDWATER LEVELS

5 STREAMFLOW AND SALINITY

Annual streamflow data for each gauging station is given in tabular form at Appendix C.

5.1 Streamflow and Salinity at each Gauging Station

Yate Flat Creek catchment had an average streamflow of 93 mm and a yield of 12.0%. This catchment is about 60% cleared and has greater streamflow and yield than the Kompup (32% cleared) and Mt. Lindesay (17% cleared) gauging stations. The Kompup catchment has less annual rainfall than the Mt. Lindesay catchment but has greater stream yield which is likely due to the greater extent of clearing at the Kompup catchment.

There is a general trend of increase in the flow weighted annual salinity of the Denmark River. For this reason a common period (1975-93) has been used to compare the stream salinity for each gauging station. Yate Flat Creek had an average flow weighted annual salinity of 1823 mgL^{-1} TSS, Kompup was 1617 mgL^{-1} TSS and Mt. Lindesay was 709 mgL^{-1} TSS.

Table 3 - Streamflow and salinity at each gauging station (1975-93)

Gauging Station	Streamflow mm	Salinity mg/L TSS	TSS Load tonnes	Rainfall mm	Stream Yield %
	mean (median, C.V.)	mean (median, C.V.)	mean (median, C.V.)	mean (median, C.V.)	mean (median, C.V.)
Yate Flat s603190	93 (83,0.65)	1823 (1335,0.66)	7440 (6313,0.56)	742 (728,0.11)	12.0 (10.8,0.56)
Kompup s603003	58 (46,0.83)	1617 (1236,0.66)	15229 (15779,0.44)	716 (711,0.13)	7.6 (6.8,0.70)
Mt Lindesay s603136	63 (60,0.62)	709 (633,0.39)	18892 (19591,0.36)	781 (775,0.15)	7.7 (8.2,0.53)

5.2 Streamflow and Salt Load of each Sub-catchment

The relative contribution of each partial sub-catchment of streamflow and salt load to the total recorded at Mount Lindesay varied considerably from year to year.

The Yate Flat Creek catchment on average (1975-86) contributes less than 20% of the total streamflow but about 40% of the salt load. Similarly the Kompup-Yate Flat catchment (*i.e.* Kompup catchment excluding the Yate Flat catchment area) contributes about 20% of streamflow and 40% of salt load. Thus, the agricultural area served by the Kompup gauging station contributes less than 40% of flow but 80% of salt load.

The Lindesay Gorge-Kompup catchment is virtually all forested. This area contributes about 30% of streamflow and about 9% of stream salt load. The Mt. Lindesay-Lindesay Gorge catchment has some clearing and produces about 30% of streamflow and 14% of salt load.

There are no apparent trends in time of the relative contributions from the various sub-catchments.

5.3 Base flows and base flow salinities

5.3.1 Base flow

The algorithm of Lyne and Hollick (1979) to determine base flow did not reveal any trends with time in the percentage of base flow as a fraction of total flow. It did, however, give some indication of the average base flow (as a fraction of total flow) at each stream gauging station. The more downstream stations had a higher percentage base flow as expected if much of their flow comes from upstream rather than from their exclusive catchment (Table 4).

Table 4 - Baseflow as a fraction of total flow

gauging station	data period	average % base flow (*i.e.* base flow/total flow)
s603002 - Lindesay Gorge	74-86	57%
s603003 - Kompup	76-93	43%
s603136 - Mt. Lindesay	61-93	57%
s603190 - Yate Flat Creek	64-93	35%

Figure 6 illustrates that annual base flow and total streamflow, at Kompup, follow the same trend which also mirrors the trend in annual rainfall. Apart from the climatic variation in base flow due to rainfall there is no apparent trend with time.

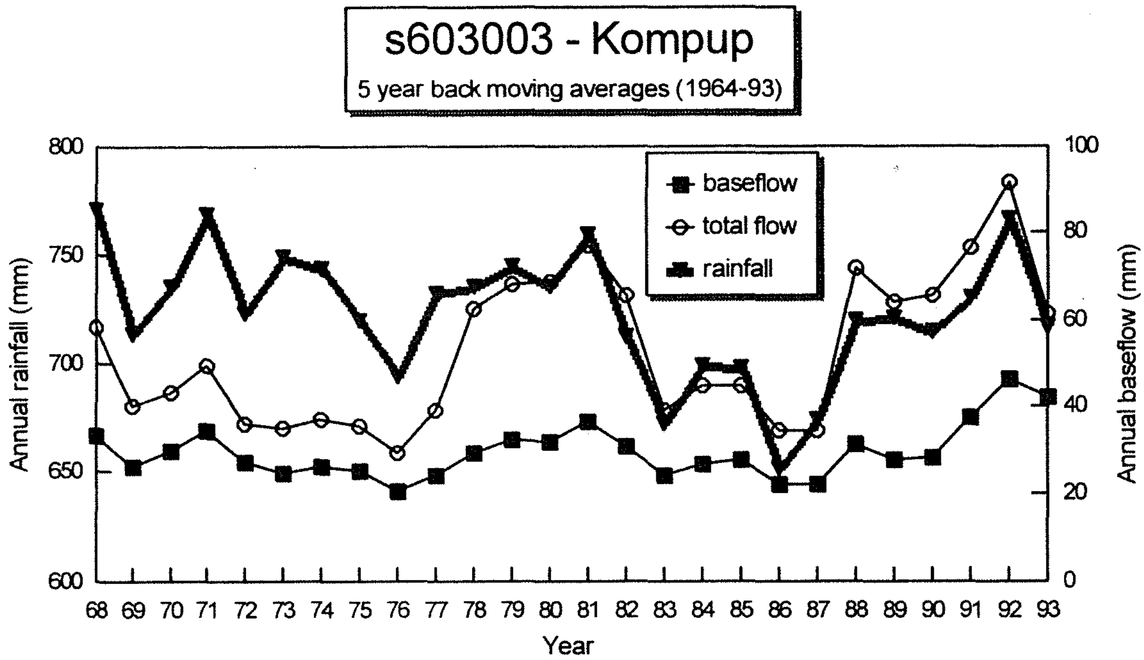


Figure 6 - Kompup baseflow, total flow and rainfall

5.3.2 Base flow salinities

In the 1960s the base flow salinity, at Kompup gauging station (s603003), was as low as 1250 mgL^{-1} TSS (Fig. 7). Base flow salinity increased with time until in 1987 it was 6500 mgL^{-1} TSS. The trend since then has been a decline in base flow salinity to 4100 mgL^{-1} TSS by 1993.

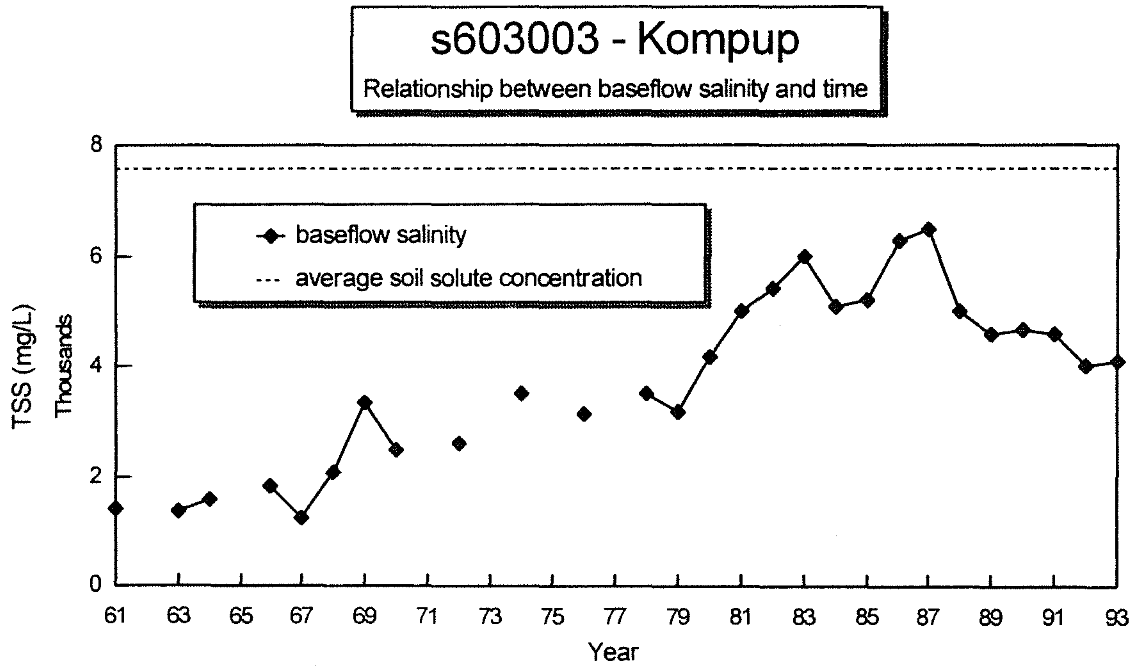


Figure 7 - Relationship between base flow salinity and time at Kompup gauging station

Comparison of figure 6 and 7 reveals that the peak of the base flow salinity curve of 1986-87 is associated with low base flow and total flow. However, the trend of increasing base flow salinity with time is real as apart from climatic variation the volume of base flow appears to be stable with time.

5.4 Changes in Streamflow and Stream Yield

The annual streamflow measured at each gauging station shows considerable yearly variation. The 5-year-back-moving-average reveals no particular trend with time at any of the gauging stations (Fig. 8). Similarly, the annual streamflow calculated for each sub-catchment shows considerable yearly variation but no definite trends with time. Stream yield is the percentage of rainfall that ultimately becomes streamflow. The stream yield at each stream gauging station showed no obvious trends with time although it exhibited considerable yearly variation.

Stream yield calculated for each sub-catchment (*i.e.* the area between sequential gauging stations) also showed considerable yearly variation. This yearly variation coupled with the short period of record results in it not being possible to discern any trends of changing stream yield with time. Combining the records for the Clear Hills and Kompup gauging stations, to give an effectively longer record for Kompup, revealed a slight increase in stream yield over the period 1964-93. This trend in stream yield was for an insignificant annual rate of increase (t-test, 95%). The yearly variation of stream yield is directly proportional to the annual rainfall. However, the five year back moving average for rainfall shows a general downward trend (1964-93) (Fig. 6) while the five year back moving average of stream yield shows a general increase (Fig. 6). Thus, the long term trend appears to be a slight increase in stream yield (despite decreasing rainfall) while the yearly variation is climatic.

The relationships between annual streamflow and annual rainfall for each sub-catchment exhibit considerable scatter. This is to be expected for catchments of large area. Due to this low correlation, good estimates of streamflow for a particular amount of rainfall can not be made from a simple linear regression equation. Thus, changes in streamflow produced for a given amount of rainfall have not been calculated.

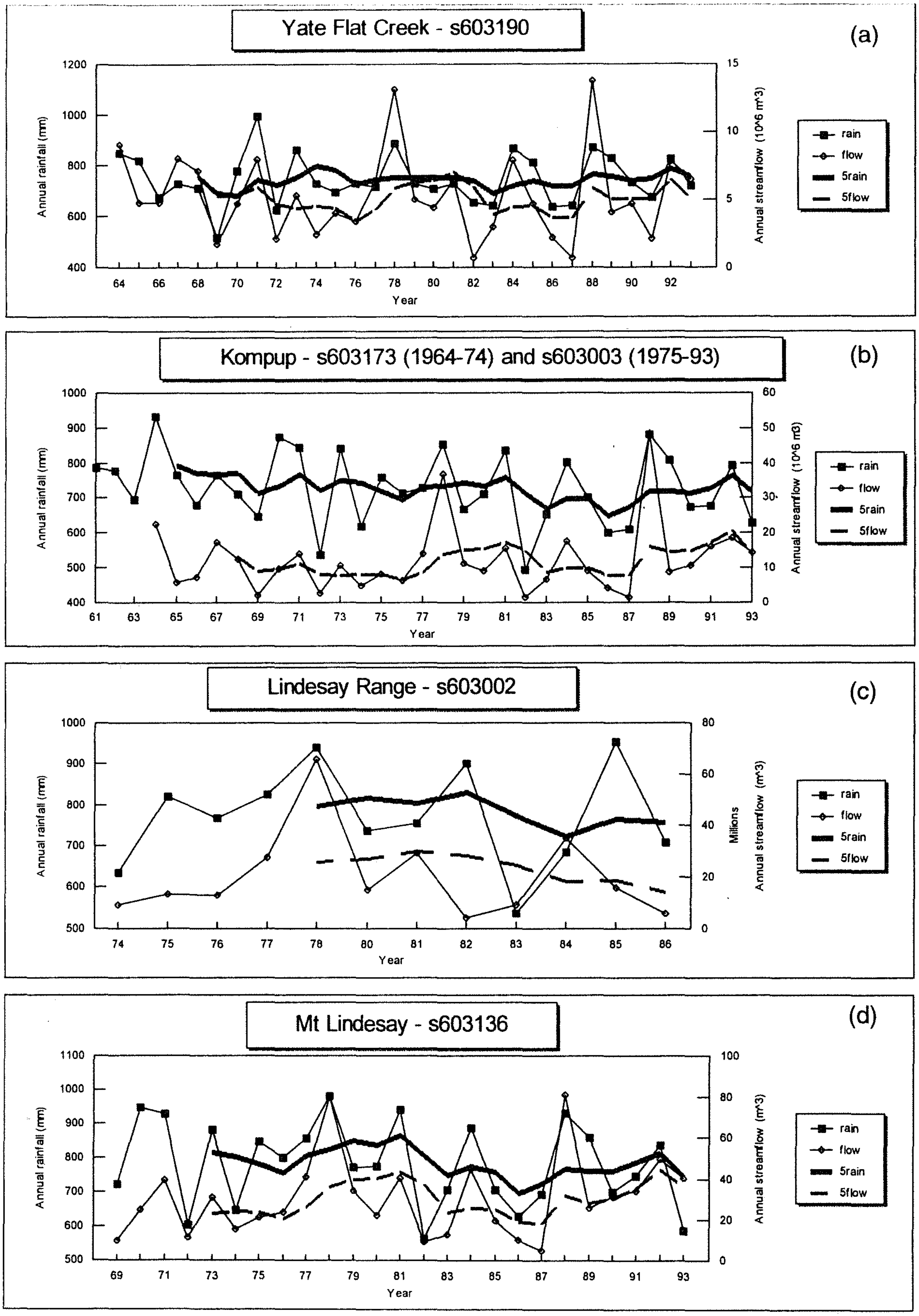


Figure 8 - Annual rainfall and streamflow

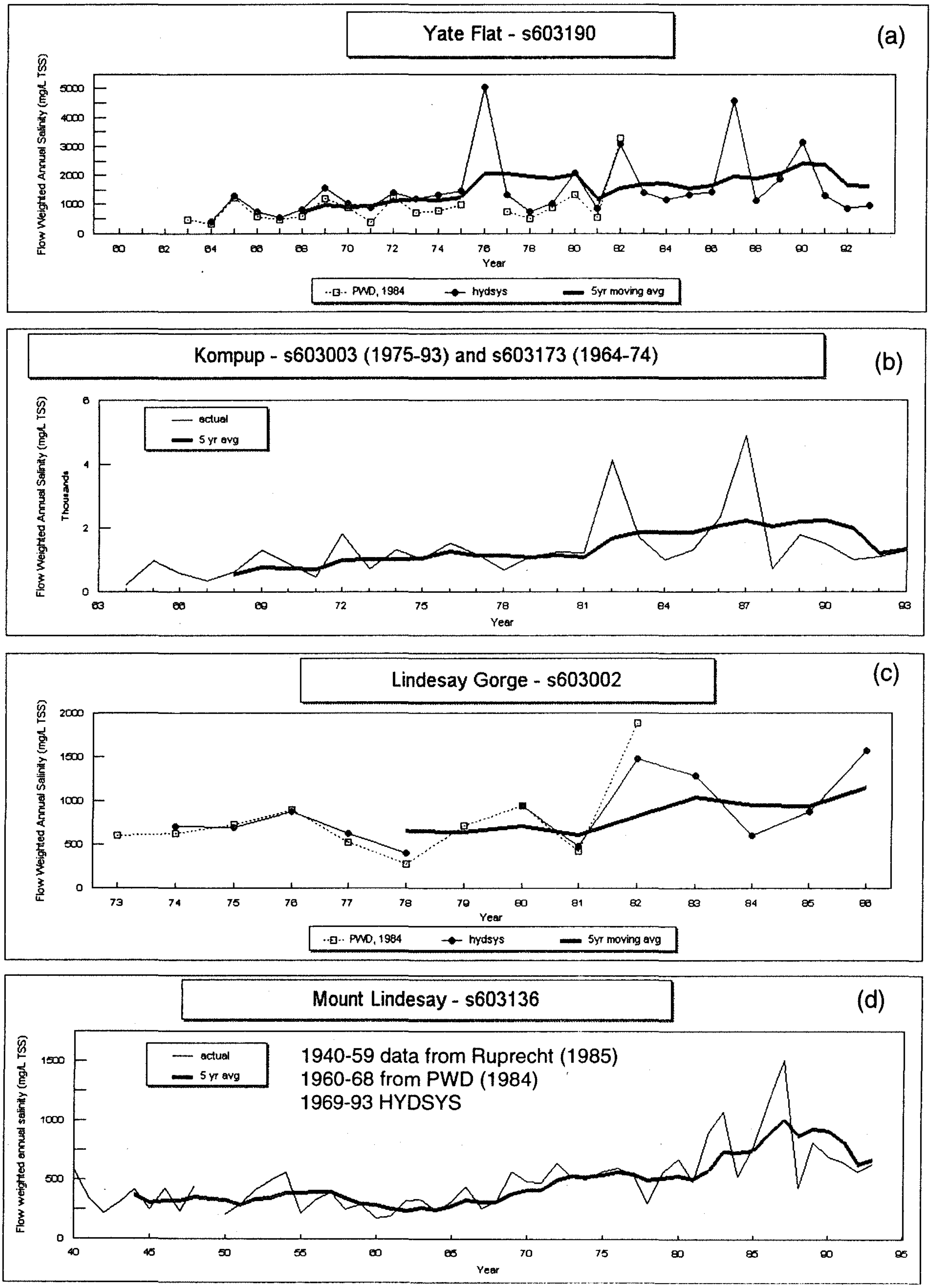


Figure 9 - Flow weighted annual salinity

5.5 Changes in Stream Salt Load and Flow Weighted Annual Salinity

The plots of flow weighted annual salinity (salinity) versus time, at each stream gauging station, appear to have a trend of increasing salinity with time (Fig. 9). This trend becomes decreasing towards the end of the study period but this may simply be climatic. The slope of the 5-year-back-moving average stream salinity illustrates this trend. However, some caution should be taken in using the trends from these graphs as no consideration is given to climatic variation. Up to 1985, the slope showed salinity, at the Kompup gauging station, to be increasing by about 125 $mgL^{-1}yr^{-1}$ while the rate of increase during 1985-90 was less at 75 $mgL^{-1}yr^{-1}$. The period 1990-93 showed a marked decline in salinity of 305 $mgL^{-1}yr^{-1}$ decrease. The rate of increase in salinity at Yate Flat Creek (1975-90) was about 75 $mgL^{-1}yr^{-1}$ and at Kompup the rate was also 75 $mgL^{-1}yr^{-1}$ while at Mt. Lindesay the rate was less at about 25 $mgL^{-1}yr^{-1}$ (Fig. 9a,b,d).

The plots of annual salt load for each gauging station versus time show considerable annual variation (Fig. 10). A general increasing trend with time is noticeable from the five year backwards moving average. However, the period of record at the Lindesay Gorge gauging station is insufficient to determine any trend above the annual variation.

Prior to 1991, stream salinity was determined from water quality samples only (as opposed to continuous monitoring). In some instances the number of samples taken was considered to be insufficient to properly represent stream salinity and salt load. Barrett and Loh (1982) compared the calculated value of flow weighted salinity for different sampling frequencies. Their work showed a general trend of increasing range of flow weighted salinity with both increasing salinity and salinity variability. Collie East Branch had a flow weighted salinity of 2298 mgL^{-1} (in a year of average streamflow volume) and with weekly sampling the range was 84-111% of this value whereas four weekly sampling gave a range of 55-128%. The average salinity at all gauging stations in the Denmark catchment is lower than for Collie East Branch so it can be expected that the range of error from the true flow weighted salinity would be smaller.

The mean value of the water quality (salinity) samples was plotted together with the calculated flow weighted salinity. While the mean salinity was greater than the flow weighted salinity, both followed the same trends. Thus, while the individual values of the calculated flow weighted salinity may not be accurate the trend is confirmed by its similarity to the trend in mean salinity.

Power fitted regression equations were developed between streamflow, salinity and salt load for the initial few years of the data record. The variation of the actual salinity and salt load from the predicted values, given by the regression equations, was considered to be the change in salinity and salt load.

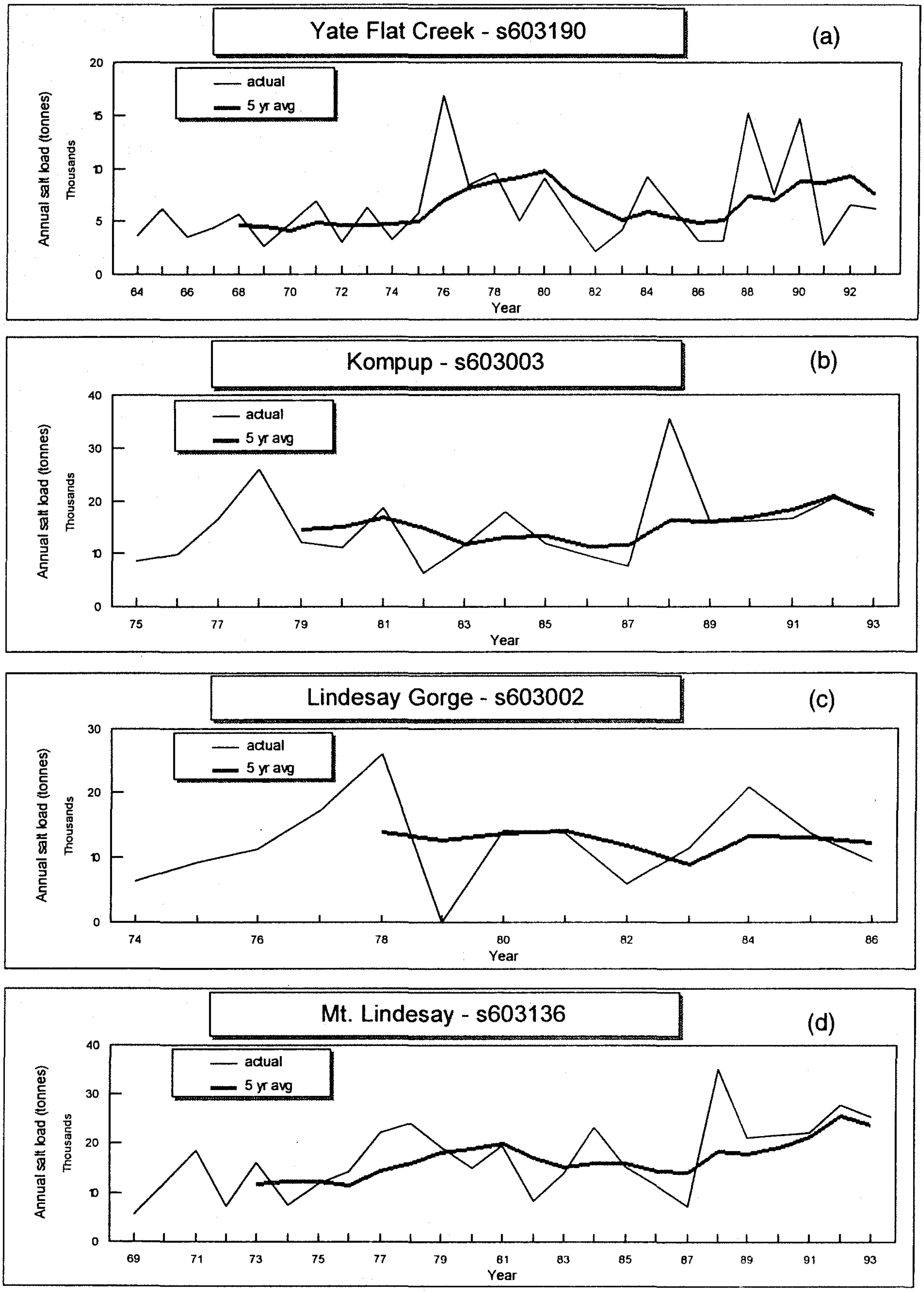


Figure 10 - Annual stream salt load

5.5.1 Yate Flat Creek gauging station (s603190)

The relationships between annual stream salt load, salinity and streamflow were developed using the 1964-72 period (Appendix B). Stream salt load had a significant trend (t-test, 95%) of increase (135 tonnes TSS yr^{-1}) over the period 1964-93 but during 1975-93 the increasing trend (67 tonnes TSS yr^{-1}) was insignificant (t-test, 95%). Most years (1973-93) showed increased salt load relative to the regression period. As the salinity of the stream increased with time so too did the annual variability of stream salinity and salt load. Some years showed significantly increased (t-test, 95%) salt load. The average increase in salt load was 2490 tonnes TSS during 1973-93 whereas the maximum increase during 1964-72 was 1870 tonnes TSS.

The average increase in salinity was 490 mgL^{-1} TSS during 1973-93 with the maximum increase during 1964-72 being 390 mgL^{-1} TSS. There was a significant (t-test, 95%) increasing trend in stream salinity over the period 1964-93. This trend was for an average annual increase of 27 mgL^{-1} TSS but during 1975-93 the rate of increase was insignificant at 16 mgL^{-1} TSS yr^{-1}. The average actual salinity 1964-72 was 955 mgL^{-1} TSS and during 1973-93 was 1605 mgL^{-1} TSS. This difference is in part due to the lower average flow during 1973-93. It is important to note the yearly maximums as while some years may not show a significant increase other years show considerable increase which would impact on the water supply that year, especially for low storage situations such as the current pipehead dam. The maximum salinity during 1964-72 was 1545 mgL^{-1} TSS and for 1973-93 it was 4560 mgL^{-1} TSS. The extent of this increase is well illustrated in figure 9a.

5.5.2 Kompup gauging station (s603003)

The relationships between annual stream salt load, salinity and streamflow were developed using the 1975-83 period (Appendix B). The change in salt load and salinity was an increase for all years 1984 onwards excepting 1985 which decreased slightly (but not significantly) (Fig. 12a,b). Most years the increases were not significant though the average increase in salt load was 2540 tonnes TSS and salinity increased by an average of 290 mgL^{-1} TSS (By comparison the 1975-83 averages were +240 tonnes TSS and +40 mgL^{-1} TSS). Stream salt load had a significant trend (t-test, 95%) of increase (248 tonnes TSS yr^{-1}) over 1975-93. The trend in stream salinity was for a significant increase during 1975-83 (average annual rate of increase, 69 mgL^{-1} TSS) but over 1975-93 the increasing trend (average annual rate of increase, 26 mgL^{-1} TSS) was not significant (t-test, 95%).

The average salinity 1984-93 was 1690 mgL^{-1} TSS and in 1987 the salinity was 4900 mgL^{-1} TSS which is far above the potable limit for fresh water of 500 mgL^{-1} TSS.

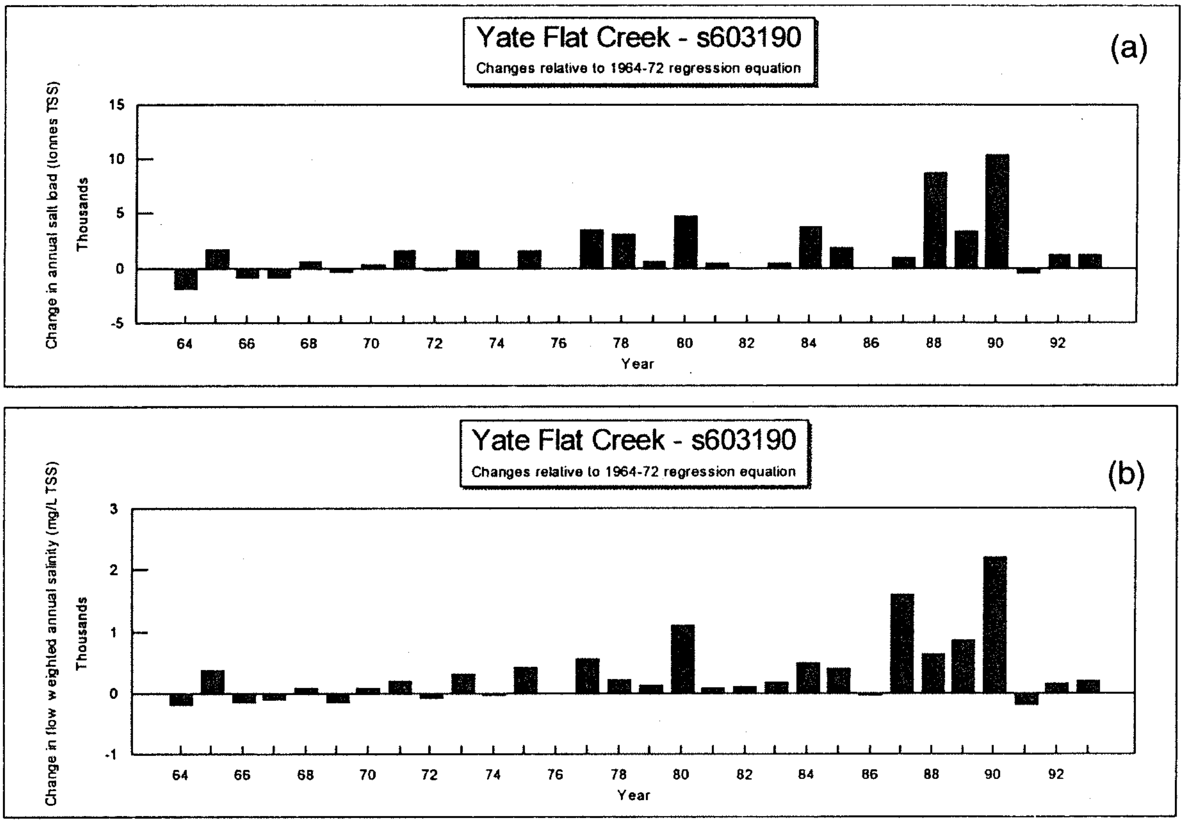


Figure 11 - Changes in Yate Flat Creek annual stream salt load and salinity

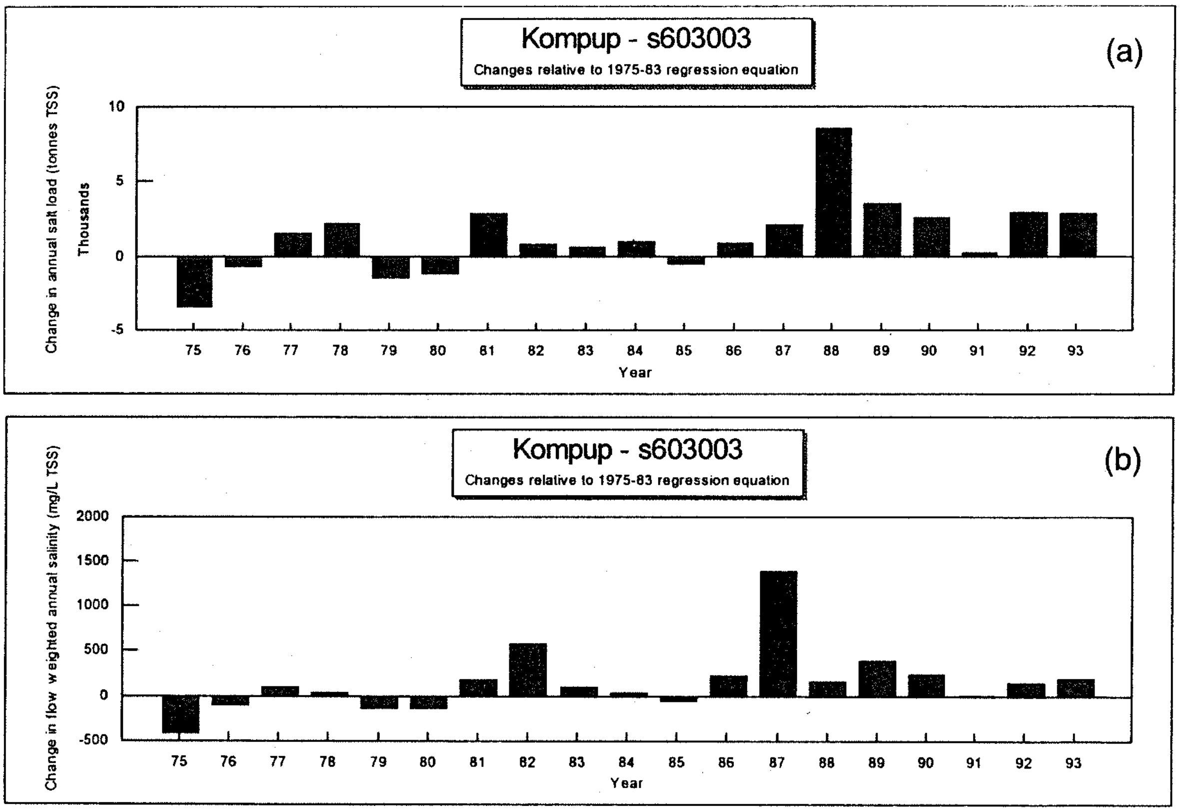


Figure 12 - Changes in Kompup annual stream salt load and salinity

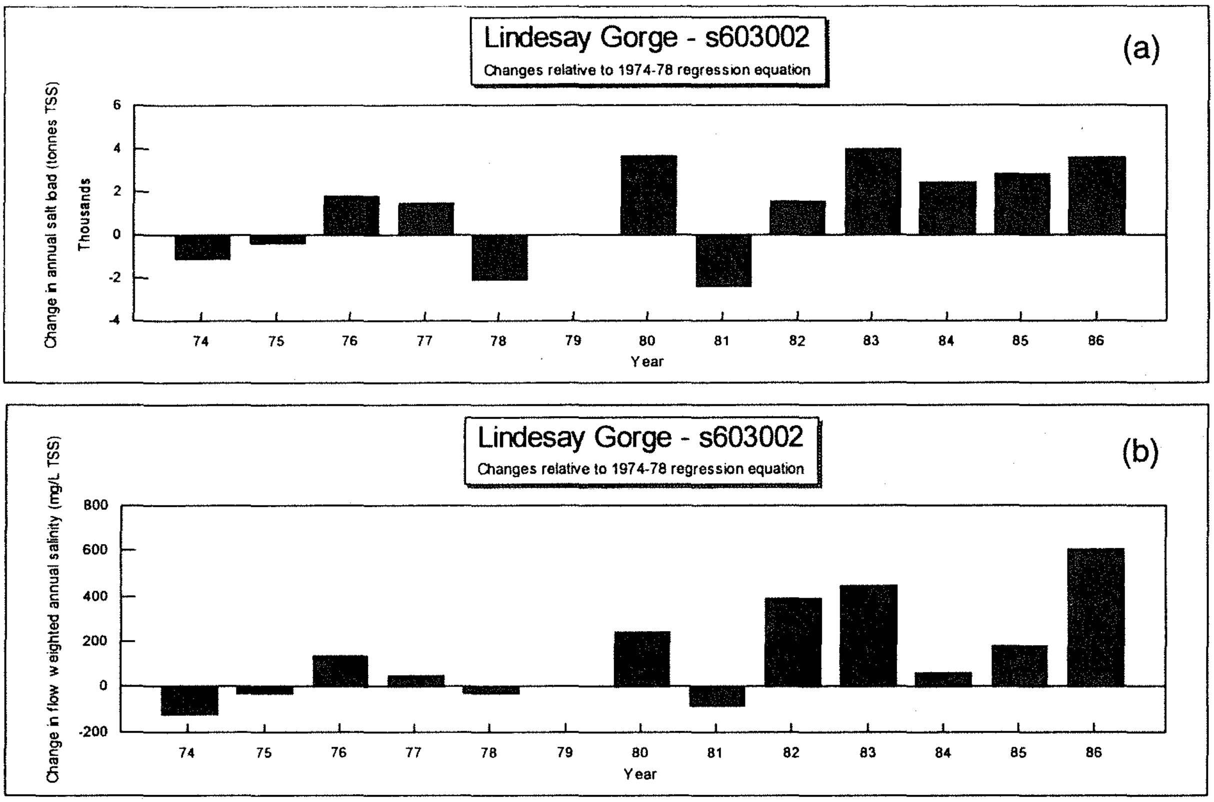


Figure 13 - Changes in Lindesay Gorge annual stream salt load and salinity

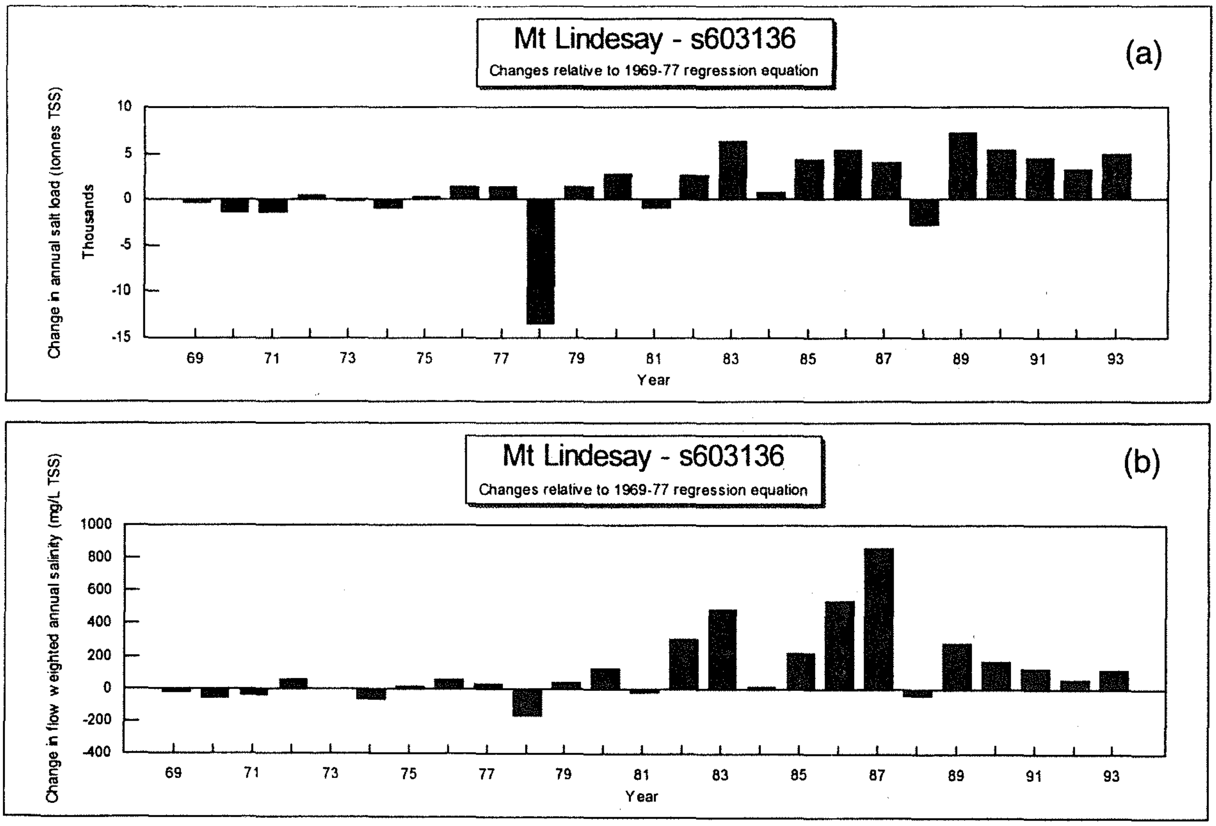


Figure 14 - Changes in Mt. Lindesay annual stream salt load and salinity

5.5.3 Lindesay Gorge gauging station (s603002)

The relationships between annual stream salt load, salinity and streamflow were developed using the 1974-78 period (Appendix B). The plot of changes in annual salt load shows increased salt load in all years from 1980 except 1981 (Fig. 13a). Stream salt load had a significant trend (t-test, 95%) of increase during 1974-86.
Stream salinity increased except in 1981 (Fig. 13b). Low flow years showed the greatest increase in stream salinity. There was a significant trend (t-test, 95%) of salinity increase (average annual rate of increase, 39 mgL^{-1} TSS) during 1974-86.

The average (1980-86) increase in salt load was 2130 tonnes TSS and the average increase in salinity was 270 mgL^{-1} TSS. The average salinity (1974-78) was 660 mgL^{-1} TSS which is just above the limit for fresh water of 500 mgL^{-1} TSS. During 1980-86 the average salinity was 1030 mgL^{-1} TSS.

5.5.4 Mt. Lindesay gauging station (s603136)

Relationships between flow weighted annual salinity, salt load and streamflow were developed using the data for 1969-77 (Appendix B). During this period the average streamflow, salt load and salinity were 46 mm, 12 800 tonnes TSS and 545 mgL^{-1} TSS. The period 1979-93 while having higher average flow of 64 mm and higher salt load of 19 400 tonnes still had higher salinity at 735 mgL^{-1} TSS (Fig 9d) (*i.e.* the increased flow was not sufficient to dilute the increased salt load to the same concentration). The average increase in salinity was calculated as 200 mgL^{-1} TSS. In the years 1978, 81 and 88 the salt load and salinity was calculated as decreasing (Fig. 14b). However, this may be due to the low flows of the 1969-77 period resulting in the developed relationships not being accurate (since extrapolating) for high flows. All other years during 1978-93 were calculated as having increased salinity and salt load.

Stream salt load was calculated as having a significant increasing trend (t-test, 95%) (135 tonnes TSS yr^{-1}) over the whole record (1969-93). This increasing trend was also significant during the shorter period of 1978-93 (554 tonnes TSS yr^{-1}). The average increase in salt load was about 2360 tonnes TSS for 1978-93 while during 1969-77 the maximum variance was about 1570 tonnes TSS. Stream salinity had a significant increasing trend (t-test, 95%) over the period 1969-93 (average annual rate of increase, 14 mgL^{-1} TSS) whereas during 1975-93 this increasing trend was insignificant (t-test, 95%) (average annual rate of increase, 12.5 mgL^{-1} TSS).

6 DISCUSSION

6.1 Rainfall

Annual rainfall in the Denmark region had a decreasing trend during the period 1910 to 1983. Average rainfall at Kompup during 1984-93 was slightly higher than the preceding ten years (1974-83) but still lower than the long term average. If long term average rainfall conditions had prevailed it is likely that groundwater levels would have risen further beneath pasture. Streamflow and stream salt load are also likely to have been greater had long term rainfall conditions prevailed. It is expected that the higher rainfall would affect the magnitude of changes but not the direction of trends.

6.2 Groundwater Levels and Salinity

The M Crane parkland clearing site has data for 1981-95 and shows rising potentiometric levels over this period. There is evidence that the long term trend for the W Crane pastured mid-slope area is of rising groundwater while the groundwater level in the forested area had not risen. The D Drage bore transect has a much shorter data period, 1988-91, which makes it hard to discern trends in groundwater level above seasonal variation. The increasing groundwater levels in the pastured areas of these sites indicate potential for increased saline discharge to streams. At the M Crane site the groundwater level is rising into a zone of higher soil salt storage. This may eventually result in increased salinity of the saline groundwater discharge to the stream. The piezometric level in the D Drage site is already above the salt bulge in the mid-slope to lower slope area and therefore groundwater salinity at this site may not increase much further.

The groundwater table at the M Crane site generally rose over 10 years between 0.84 m (lower slope) and 2.34 m (upper slope). Much of this rise occurred in a group of higher rainfall years. Rainfall near the M Crane site was 14% lower than the long term average (1926-76), during the study period. Bari and Boyd (1992a) considered that the increase to groundwater levels would have been greater had long term average rainfall occurred. The rise in groundwater levels observed in the wetter years may merely be the groundwater table returning to its equilibrium position with respect to long term rainfall conditions and not necessarily indicating hydrologic inequilibrium. Although not part of the Denmark catchment, this site indicates rising groundwater levels in the region despite some trees remaining and below average rainfall that would otherwise act to reduce groundwater levels. The magnitude of rise (1980-91) was less than at the D Drage and W Crane sites which may be due to the greater proportion of remaining trees at the M Crane site.

Although the M Crane parkland site is useful in indicating rising groundwater levels in the region, the D Drage and W Crane sites, with few remaining trees, may better represent the hydrology of the pastured area of the Kompup catchment. Groundwater level at the D Drage and W Crane sites is gradually rising and is already above the salt bulge (at least in the lower slope areas). Therefore, the expectation is that the volume of saline groundwater discharge may increase further due to rising piezometric pressures while the salinity of the groundwater discharge may not increase much further as the rise in groundwater level will not intersect a higher soil salt concentration. The effect of this on stream salinity would be an increase in flow weighted average salinity due to increased volume of saline discharge while base flow salinity will not increase much if the saline discharge is near its peak salinity.

6.3 Streamflow and Salinity

The length of time for soil salt to be leached from the Kompup catchment and for stream salinity to be of similar concentration to atmospheric solute levels (salt from rain and dry fallout estimated by Hingston and Gailitis, 1976) is great. For low rainfall areas the time is estimated to be of the order of 1000 years (Schofield *et al.*, 1988). Based on the average soil salt storage and assuming a constant leaching rate equal to the 1983-93 average salt load less the salt precipitated in rainfall, it is estimated that it would take 1180 years for all the soil salt to be leached out. For use as a water supply the Denmark River would need to have salinity less than 500 mgL^{-1} TSS. Reducing salinity to this level would not require all the salt stored in the landscape to be leached out. The above leaching time calculation is still useful as it indicates the large time scale before significant reductions in stream salinity could occur given the amount of salt stored in the catchment. Hence, waiting for the salt to leach from the catchment is not an appropriate option if salinity trends are required to be reversed in 10-30 years.

6.3.1 Streamflow and Salinity at each Gauging Station

Yate Flat Creek is a sub-catchment of the Kompup catchment. The significant difference between the two catchments is the land usage as Yate Flat Creek has about twice the percentage of area cleared for agriculture relative to Kompup. Generally, stream yield increases with a reduction in forest cover (Moulds *et. al*, 1994; Ruprecht *et. al*, 1991; Bari and Boyd, 1993; Bosch and Hewlett, 1982). The greater stream yield at Yate Flat Creek relative to Kompup can be attributed mainly to the more extensive clearing and possibly also due to the slightly higher average annual rainfall at Yate Flat Creek. By comparison, Mt. Lindesay catchment is only 17% cleared but has lower stream yield yet higher rainfall than Yate Flat Creek. Thus, the greater the extent of clearing the higher the stream yield.

Stream salinity was also higher the greater the extent of clearing. Notably, the bulk of the cleared agricultural land in the Denmark catchment is distant from the coast (*i.e.* lower rainfall areas). Schofield *et. al* (1988) observed that magnitude of increase to stream salinity, subsequent to clearing for agriculture, is proportional to location (*i.e.* rainfall of area) and extent of clearing. The observation of Schofield *et. al* (1988) applies also to the Denmark catchment as stream salinity is greatest in the low rainfall and largely cleared catchments of Kompup and foremostly Yate Flat Creek.

6.3.2 Streamflow and Salt Load of each Sub-catchment

The agricultural area served by the Kompup gauging station contributes less than 40% of the streamflow that ultimately reaches Mt. Lindesay but delivers 80% of the salt load. Thus, this catchment should be the primary focus of efforts to manage stream salinity in the Denmark River. Ferdowsian and Greenham (1992) calculated stream yield and salt export at forty streamflow monitoring sites along the creeks in the Kompup catchment. This information has use in further refining the selection of priority areas to be treated to reduce stream salinity in the Denmark River.

6.3.3 Base flows and base flow salinities

There is no apparent trend with time in base flow as a proportion of total flow. This could be an indication that the major increases in groundwater level have already occurred and thus the volume of groundwater discharge is not increasing greatly relative to the other streamflow components. However, the changing hydrology due to groundwater level rise also affects the other streamflow components (*i.e.* they could increase together).

Ruprecht *et al.* (1985) noted an increasing trend of base flow salinity at Kompup gauging station and anticipated it to eventually stabilise at around the soil salt storage concentration (7600 mgL^{-1} TSS). Kompup catchment contributes about 80% of the stream salt load of the total at Mt. Lindesay gauging station. Thus, the trends in base flow salinity of this area are highly relevant to monitoring trends in salinity of the Denmark River. The deeper more saline groundwater flows are likely to be the predominant component of streamflow late in the flow season (Ruprecht, 1992). Thus, the stream base flow salinity as an indicator of the groundwater salinity would be limited in its extent of increase by the concentration of salt stored in the soil. However, the effect of evaporation may further concentrate this flow giving a stream salinity in excess of the groundwater salinity.

Ferdowsian and Greenham (1992) related base flow salinity to time and rainfall of both the sampling year and the previous year. Their predicted peak for base flow salinity would occur in about the year 2010 with a value of 6300 mgL^{-1} TSS for an average annual rainfall of 740 mm.

Comparison of annual rainfall and streamflow data (Figure 6) with the base flow salinity (Figure 7) reveals that base flow salinity varies inversely with annual rainfall and streamflow. This is evidenced where in any two consecutive years in which the second year has higher streamflow then base flow salinity will be lower in the second year than in the first. The finding of Ferdowsian and Greenham (1992), relating base flow salinity to time as well as rainfall in the sampling year and the previous year, is in accord with this observation.

The long term average rainfall 1910-93 is 792 mm. The years 1985-87 had below average rainfall and saw the rise of base flow salinity to its highest. The following years (1988-89) had above average rainfall and were the start of the declining trend in base flow salinity. The peak of the base flow salinity curve is associated with a period of relatively low annual streamflow (see Fig. 6 and Fig. 7). The base flow salinity curve then declines about 2000 mgL^{-1} TSS but this is associated with a period of relatively higher flow that corresponds to higher rainfall. It can be concluded that the greater part of the increase in base flow salinity has already occurred, as without many further years of data it is not possible to distinguish any residual increasing of base flow salinity from climatic variation. When the base flow salinity of an average rainfall year reaches the expected peak value of 6300 mgL^{-1} TSS (Ferdowsian and Greenham, 1992) then in low rainfall years the actual base flow salinity is likely to exceed this value.

The trend of increasing base flow salinity is in agreement with the observation of rising groundwater levels in pastured areas in the Kompup catchment. Rising groundwater levels dissolve salt previously stored in the soil profile which increases the salinity of the groundwater. This has been observed at Wights catchment in the Wellington Reservoir catchment. Wights catchment was completely cleared in the summer of 1976/77 with the effect of increased groundwater salinity in the valley (J. Ruprecht, pers. comm). As groundwater salinity increases then base flow salinity which is predominantly groundwater discharge will also increase.

6.3.4 Changes in streamflow and stream yield

Piezometric pressures are slowly rising and this will have some increasing effect on base flow (*i.e.* higher discharge flow rate from increased hydraulic gradient) and maybe on quick flow (due to expansion of saturated contributing areas with rising piezometric pressure) which would cause some increase to stream yield. Yet stream yield is not noticeably increasing by any significant amount. This could indicate that the catchment has at least arrived at an approximate (slowly changing) hydrologic equilibrium. Extending the period of record at Kompup gauging station by combining it with the Clear Hills gauging station record reveals that stream yield has increased over the period 1964-93 with much of this increase having occurred by the early 1980s.

6.3.5 Changes in stream salt load and flow weighted annual salinity

Data collection commenced one to two decades after the original change in land use of the catchment from forest to agriculture. Thus, changes to the catchment hydrology are seen as relative to the already altered catchment rather than in comparison to before clearing. The salinity and salt load is calculated to have increased at each of the gauging stations over the study period. As the period of data is fairly short, the increasing trend of salinity is not directly obvious although it is apparent that salinity has increased relative to the earlier record.

Flow weighted annual salinity, at a particular location, is inversely proportional to annual streamflow. While salinity is observed to be increasing at each gauging station the greatest observed increases occur in low flow years. Towards the end of the study period streamflow was relatively higher. During this period, it appeared that the rate of salinity increase had declined. Consideration of the higher streamflows suggests that the reduced rate of salinity increase is a climatic response and not necessarily a shift in the long term trend of salinity changes.

It is well established that the magnitude of salinity response to clearing is affected by the extent of clearing (Schofield *et. al*, 1988). This is illustrated by comparing the Kompup (32% cleared) and Yate Flat Creek (60% cleared) catchments. Stream salt load per hectare for Yate Flat Creek is twice that at Kompup and stream yield is also significantly greater at Yate Flat Creek. The net result is that Yate Flat Creek has flow weighted salinity 200 mgL^{-1} TSS greater than Kompup. Thus, prevention of further clearing in the Denmark River catchment will have limited the potential maximum salinity of the river.

Stream salinity response occurs some years after clearing hence the current trends of increasing salinity are a legacy of clearing prior to Catchment Clearing Control legislation. Partial deforestation in 1976 of Lemon catchment in the Wellington Reservoir catchment saw immediate groundwater rises but the change in stream salinity was not significant till 1988 (*i.e.* 12 years later) (Ruprecht and Schofield, 1991). Due to this delayed response of stream salinities to clearing, it is expected that stream salinities continue to increase after clearing has stopped. Not only is there a delay before the salinity increase occurs but the cleared area will take even longer to establish a new hydrologic equilibrium and stop increasing in salinity. During 1975-93, the trend in stream salinity at each gauging station was for an insignificant rate of increase (t-test, 95%). As the rate of salinity increase at Kompup gauging station was significant over 1975-83 but not over 1975-93 it is possible that the trend has been affected by climatic factors. Thus, further years of data are necessary to determine if stream salinity in the Denmark River has stopped increasing. The evidence of the success of the clearing controls will be the cessation of salinity increases.

Much of the agricultural clearing in the Denmark River catchment has taken place since the 1950s. In high rainfall areas stream salinities may increase after clearing before reaching a new equilibrium in about 60 years whereas in low rainfall areas the time to equilibrium would be substantially greater (Schofield *et al.*, 1988). Salinity of the Denmark River is still increasing (albeit at an insignificant rate) and has potential to increase further (*i.e.* the observations of Schofield *et al.* (1988) indicate that stream salinity in the low rainfall area of the Denmark River catchment is expected to reach a new equilibrium considerably more than 60 years beyond 1950).

The potential is for increased quantities of saline discharge owing to the rising groundwater levels in pastured areas. As the base flow salinity appears to be near or at its peak and the proportion of baseflow as a fraction of total flow does not appear to be changing - the increase to flow weighted annual stream salinity may be relatively minor. Following this reasoning it would be anticipated that stream salinity would peak in concert with the peak in baseflow salinity (*i.e.* the equation of Ferdowsian and Greenham (1992) estimates baseflow salinity to peak around 2010). This estimate of 2010 for the peaking of stream salinity does not agree with the general observation of Schofield *et al.* (1988) that the new equilibrium in stream salinity would be considerably beyond 2010.

The Mt. Lindesay gauging station is the most downstream flow monitoring site in this study and a possible location for a future reservoir. Therefore, the salinity at this location on the Denmark River is relevant to the development of any future water resource. The limit that determines fresh water according to water resources classification is 500 mgL^{-1} TSS (Steering Committee, 1989). The exceedance of this limit at Mt. Lindesay averaged 45 mgL^{-1} TSS during 1969-77 but the trend of increasing salinity with time saw the exceedance increase to 235 mgL^{-1} TSS (1978-93). This decline in quality is real since the average streamflow for 1978-93 was greater than for 1969-77 (*i.e.* the higher salinity was not a result of lower flows) (Fig. 8d, 9d). Apart from the increasing average salinities the maximum annual salinity 1969-77 was 645 mgL^{-1} TSS in 1972 whereas the maximum annual salinity 1978-93 was much greater at 1510 mgL^{-1} TSS in 1987 (the second year in two successive low rainfall years). Thus, the Denmark River has declined in quality from being marginal in 1972 (*i.e.* having salinity in the range 500-1000 mgL^{-1} TSS) to being brackish (>1000 mgL^{-1} TSS) in 1987. While a large storage capacity reservoir may avoid serious problems from high salinity years the salinity of the Denmark River is sufficiently high to warrant remedial catchment management programmes.

Flow weighted stream salinity at Yate Flat Creek averaged 955 mgL^{-1} TSS during 1964-72 with a maximum of 1542 mgL^{-1} TSS. However, stream salinities by 1973-93 were significantly higher averaging 1769 mgL^{-1} TSS with a maximum of 5401 mgL^{-1} TSS. As the change to stream salinity is large this will obviously effect salt sensitive species. Further, the maximum salinity during the year may be unbearable to some of the aquatic organisms. Davis *et. al* (1993) conducted a survey of salinity tolerances of fauna in wetlands and lakes which found that some freshwater species did not have tolerances to salt and were only found at salinities less than 1000 mgL^{-1} TSS. As the streams of the Denmark River basin were formerly fresh, some of the stream flora and fauna may have low salt tolerance. The current trend of increasing stream salinity is likely to affect the occurrence of these low salt tolerant species.

Although clearing controls are expected to limit the potential maximum salinity, this limit is still greater than desirable. Possible measures to reduce salinity in this Low Rainfall Zone include protection of remnant vegetation, reforestation, forest regeneration and high water use agricultural systems. In administering the Catchment Clearing Control legislation of 1978 it was accepted that there would be limited use of areas of native vegetation left on farmland (remnants) for stock grazing and shelter (Pettit and Froend, 1994). 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. Pettit and Froend (1994) found that the majority of remnants in the Wellington catchment are in very poor condition. True *et. al* (1992) found that the remnant vegetation in the Kent River Water Reserve was in decline due to the rising salinity in the catchment and grazing by domestic stock. 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 (Pettit and Froend, 1994). The potential loss of these areas of remnant vegetation would negate the clearing bans and add to the problem of increasing stream salinity in the Denmark River. Therefore, a policy on remnant vegetation protection and management should be developed and implemented.

6.4 Streamflow, salinity and reforestation

Bari and Boyd (1992b) in a study of the partially reforested catchment of Mairbeding Creek, in the Wellington Reservoir catchment, found that after eight years the reforestation was partially successful in lowering the groundwater table across the valley floor but had not noticeably reduced saline groundwater discharge to the stream. The catchment was 55% cleared of which 18% was re-planted with trees. By comparison, 76% of the cleared area at Padbury Road catchment was reforested with pines and eucalypts which resulted in a continuous reduction in salt load from the catchment (Bari, 1992). Bari and Boyd (1994) reported that the effect of reforestation on reducing groundwater level was dependant upon the percentage of cleared area replanted, stem density and crown cover. Schofield *et. al* (1989) estimated from regression equations that 46% of the cleared area would require to be reforested in order to reduce groundwater levels by 200 $mmyr^{-1}$. These equations were developed for sites with annual rainfall of about 725 $mmyr^{-1}$ which is similar to the rainfall conditions of the Kompup catchment.

The area replanted in the Denmark catchment was 0.17% (40 ha) of the Kompup catchment in 1991, a further 0.25% (60 ha) in 1992 and another 0.28% (65 ha) in 1993. It is not expected that the reforestation, being immature (hence limited crown cover) and small in area, will have yet produced a noticeable effect on stream salt load and salinity.

7 CONCLUSIONS

7.1 Rainfall

(i) There was a decreasing trend of rainfall in the Denmark region over the period 1910 to 1993. It is not yet possible to determine if this trend has ceased.

7.2 Land Use

(i) The dates of major agricultural clearing in the Denmark catchment are between 1946 and 1957 and between 1965 and 1973. Catchment Clearing Control legislation was introduced in 1978 and the area of land cleared has since stabilised.

(ii) About 17% of the catchment was cleared for agriculture by 1984. Most of the clearing 80% is upstream of the Kompup gauging station. Yate Flat Creek catchment is about 60% cleared and Kompup 32% cleared.

7.3 Groundwater Levels and Salinity

(i) Groundwater levels generally rose during 1981-95 at the M Crane parkland clearing site. The increase to potentiometric levels varied from 0.84 m in the valley area to

2.34 m in an upslope location. Groundwater salinity near the streamline increased from about 8500 mgL^{-1} TSS (1981) to 9000 mgL^{-1} TSS (1995).

(ii) Between April 1980 and April 1991 the groundwater level at the W Crane mid-slope pasture site rose by about 1.9m. The long term trend of groundwater level in native forest on the other side of the valley appears to be for no change. Groundwater salinity data was only available for 1988-91 and no trend was noticeable.

(iii) Groundwater levels at the D Drage site rose during the period 1989-91 and groundwater salinity fluctuated but had no net change.

7.4 Streamflow

(i) Yate Flat Creek contributes less than 20% of streamflow but about 40% of stream salt load to Mt. Lindesay. The catchment area between Kompup and Yate Flat Creek contributes about 20% of the flow and 40% of the salt load. Lindesay Gorge-Kompup contributes about 30% of streamflow and about 9% of stream salt load. Mt. Lindesay-Lindesay Gorge catchment produces about 30% of flow and 14% of salt load.

(ii) The five year back moving averages of streamflow show no particular trend with time. Combining the record of Kompup and Clear Hills gauging station reveals a trend of increasing stream yield (despite decreasing rainfall) most of which had occurred by the early 1980s.

7.5 Stream Salt Load and Salinity

(i) During 1975-93, Yate Flat Creek had an average flow weighted annual salinity of 1823 mgL^{-1} TSS, Kompup was 1617 mgL^{-1} TSS and Mt. Lindesay was 709 mgL^{-1} TSS.

(ii) The flow weighted annual stream salinity and stream salt load at each gauging station had an increasing trend with time over the study period. These trends were significant (t-test, 95%) at each gauging station except Kompup whose trend of increasing salinity was not significant over the period 1975-93 but was significant during 1975-83. The trends at Yate Flat Creek (stream salinity and salt load) and Mt. Lindesay gauging station (stream salinity) were also insignificant over the shorter period 1975-93.

7.6 Base Flow and Salinity

(i) There was no apparent trends with time in the percentage of base flow as a fraction of total flow.

(ii) Base flow salinity at Kompup gauging station increased from about 1250 mgL^{-1} TSS in the 1960s and peaked in 1987 at 6500 mgL^{-1} TSS but declined to 4100 mgL^{-1} TSS by 1993.

8 RECOMMENDATIONS

- As the Denmark River has potential as a future water resource it is important to continue to monitor the quantity and quality of streamflow. Thus, continuous recording of stage, conductivity and temperature should be maintained at Mt. Lindesay (s603136), Kompup (s603003) and Yate Flat Creek (s603190) gauging stations. Stream yield calculations also require rainfall data so monitoring of rainfall should continue.

- There is a large number of groundwater bores in the upper reaches of the Denmark catchment (above Kompup gauging station). Some of these were drilled by the Water Authority but have not been monitored since their drilling. Between 1988 and 1991 the W. A. Department of Agriculture monitored these bores. To develop catchment management strategies for the Denmark River catchment it is necessary to monitor the catchment hydrology which requires data on groundwater level and salinity. Assessing trends in groundwater level and salinity gives an indication of the saline groundwater discharge to the stream which affects the stream salinity. Therefore, monitoring of the M Crane, W Crane and D Drage sites ought be continued/resumed.

- When assessing the response of groundwater levels to land use change it is important to maintain some bores for the use as a control. Control sites have value in enabling distinguishing between groundwater changes resultant from land use changes and those caused by climatic variation. The forest bores at the W Crane site are useful for comparing with the trends in groundwater under pasture on the adjacent hillslope. It is therefore necessary to continue to monitor the bores at this site as they are useful as a control for this and other sites of similar rainfall. Any monitoring of groundwater under reforestation will also require control bores located in sites which remain as pasture.

- Some reforestation is being carried out by private landholders. There may occur instances where reforestation (current or future) has existing groundwater bores (WAWA or other agency) in its midst. Alternatively, new bores may be drilled if the area of reforestation is sufficiently large that it is considered likely to have significant enough impact to warrant monitoring its effect on reducing groundwater levels. The groundwater monitoring results would indicate the level of success the reforestation had in reducing discharge of saline groundwater to the stream.

- A review of the existing monitoring programme is necessary to determine if the data collected is adequate (quality- accuracy, frequency) and appropriate (*i.e.* location) for calculating the changes in stream salinity. This review should also assess data requirements necessary for monitoring the impact of any reforestation on groundwater levels.

- Continue with the development and implementation of the Integrated Catchment Management programme begun in 1988. Actions to reduce stream salinity should include remnant vegetation protection, reforestation and high water use agriculture systems. The management strategy should focus mainly on the Intermediate and Low Rainfall Zones.

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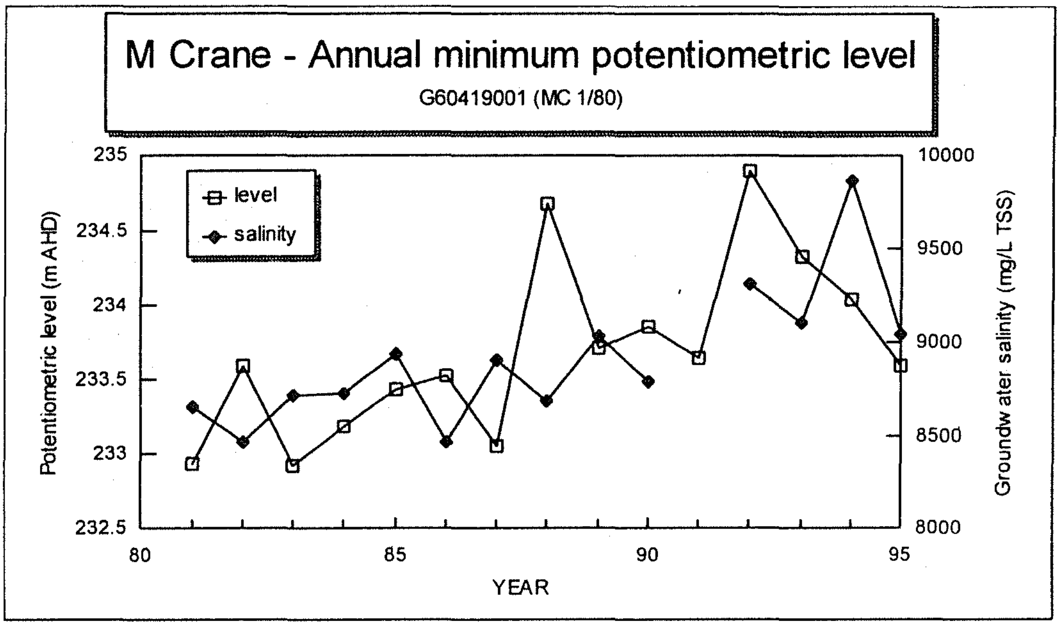
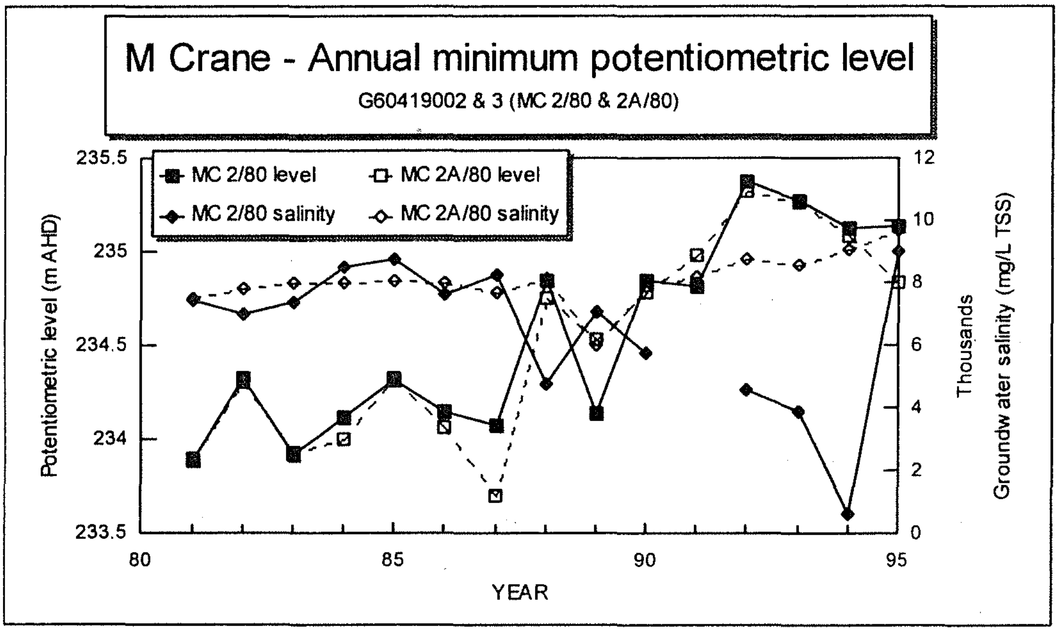
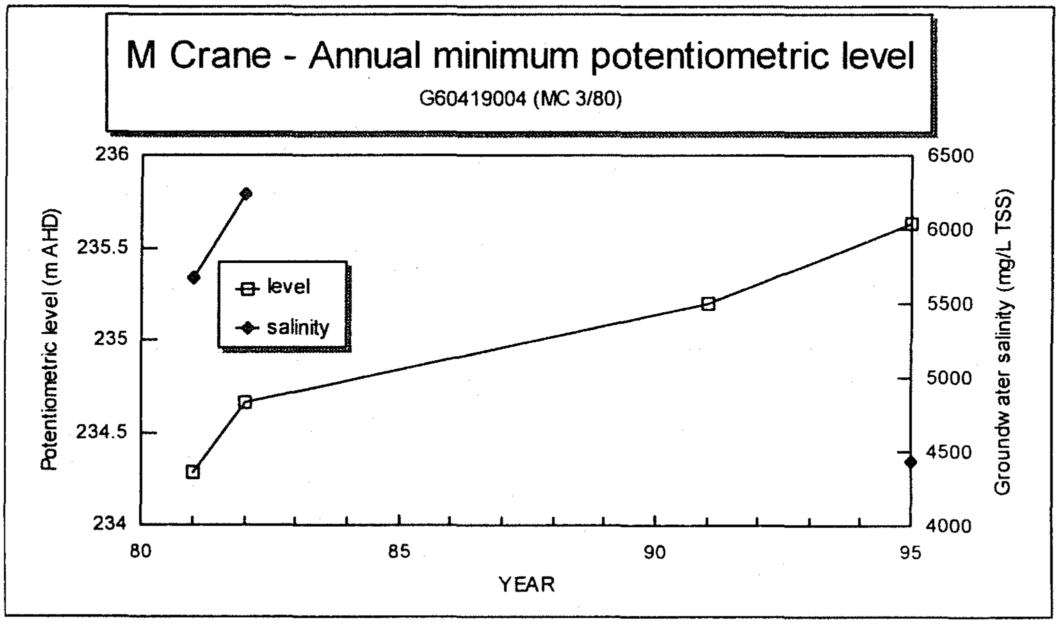
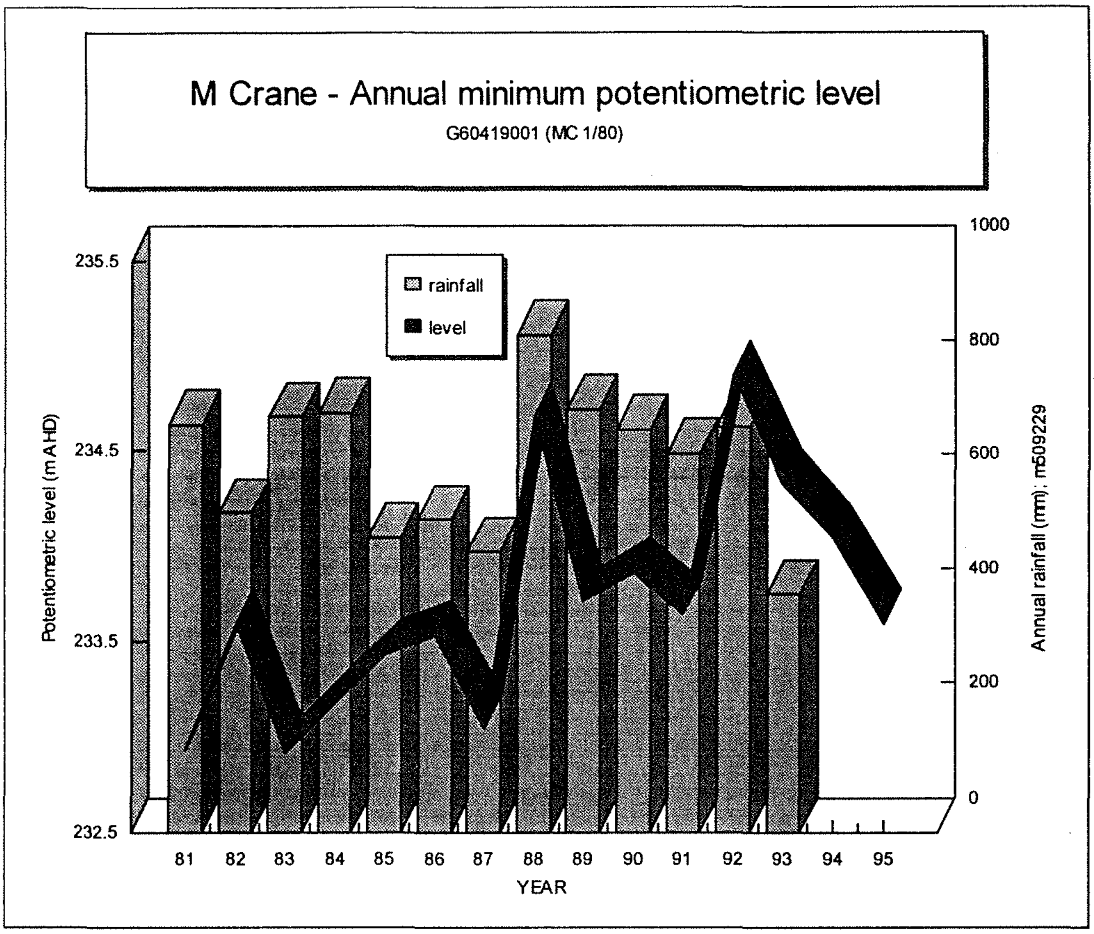
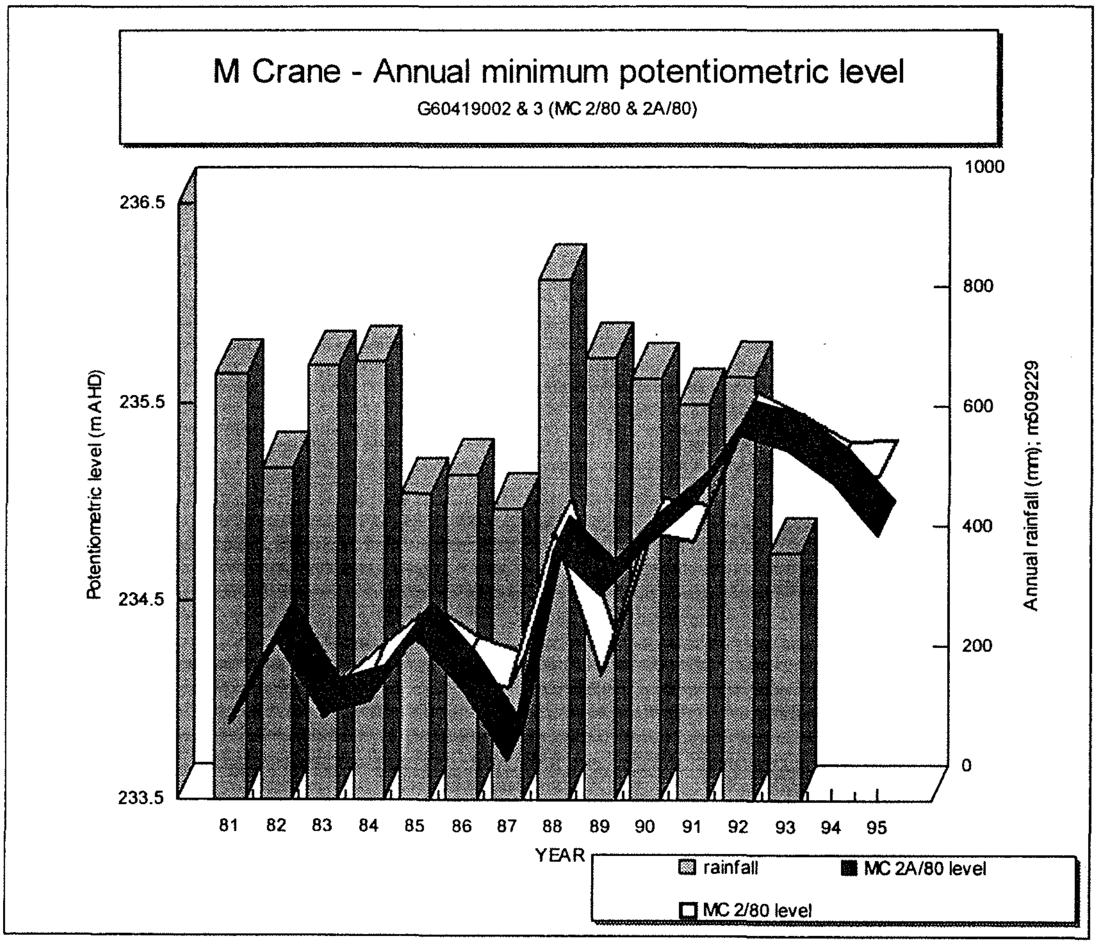
Appendix A - Groundwater levels and salinity

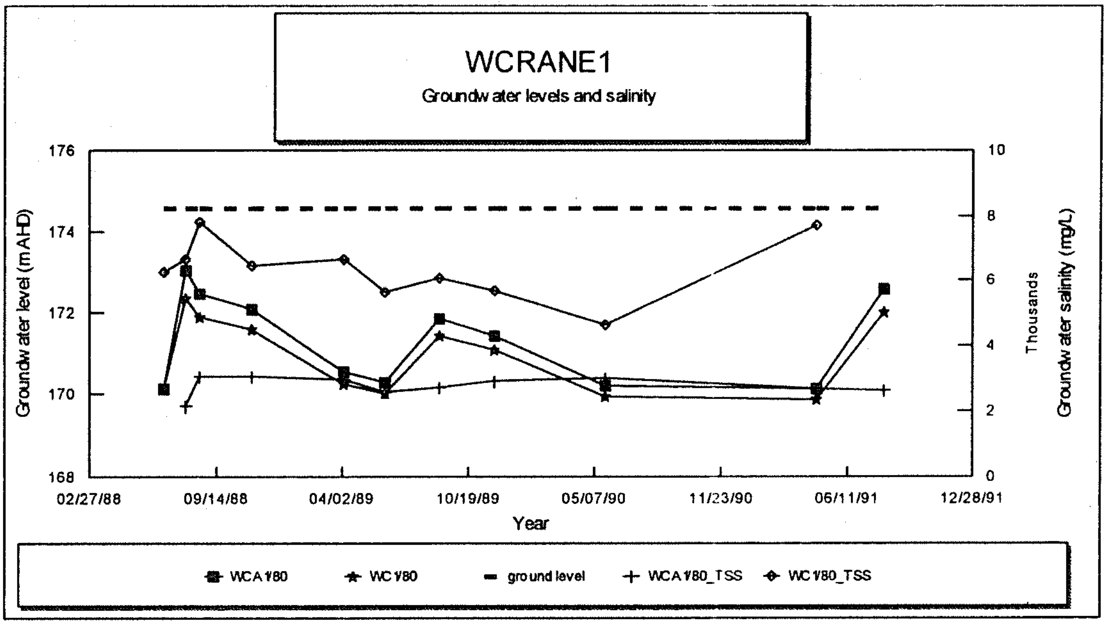

M Crane - Annual minimum potentiometric level
G60419001 (MC 1/80)
level
salinity
Potentiometric level (m AHD)
Groundwater salinity (mg/L TSS)
235
234.5
234
233.5
233
232.5
10000
9500
9000
8500
8000
80
85
90
95
YEAR

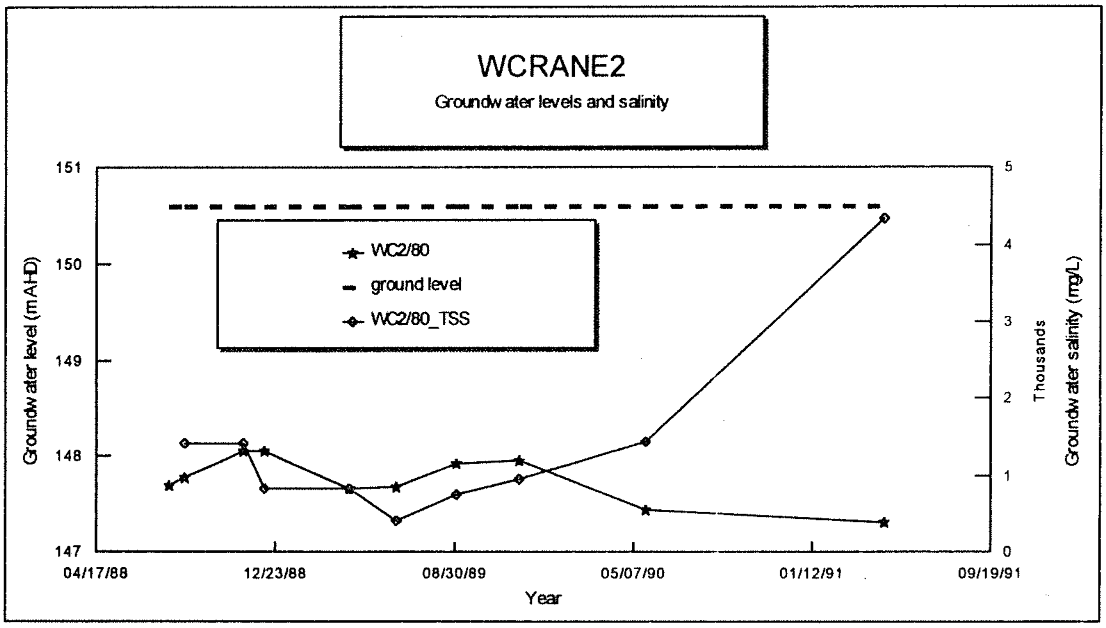

M Crane - Annual minimum potentiometric level
G60419002 & 3 (MC 2/80 & 2A/80)
MC 2/80 level
MC 2A/80 level
MC 2/80 salinity
MC 2A/80 salinity
Potentiometric level (m AHD)
Thousands
Groundwater salinity (mg/L TSS)
235.5
235
234.5
234
233.5
12
10
8
6
4
2
0
80
85
90
95
YEAR

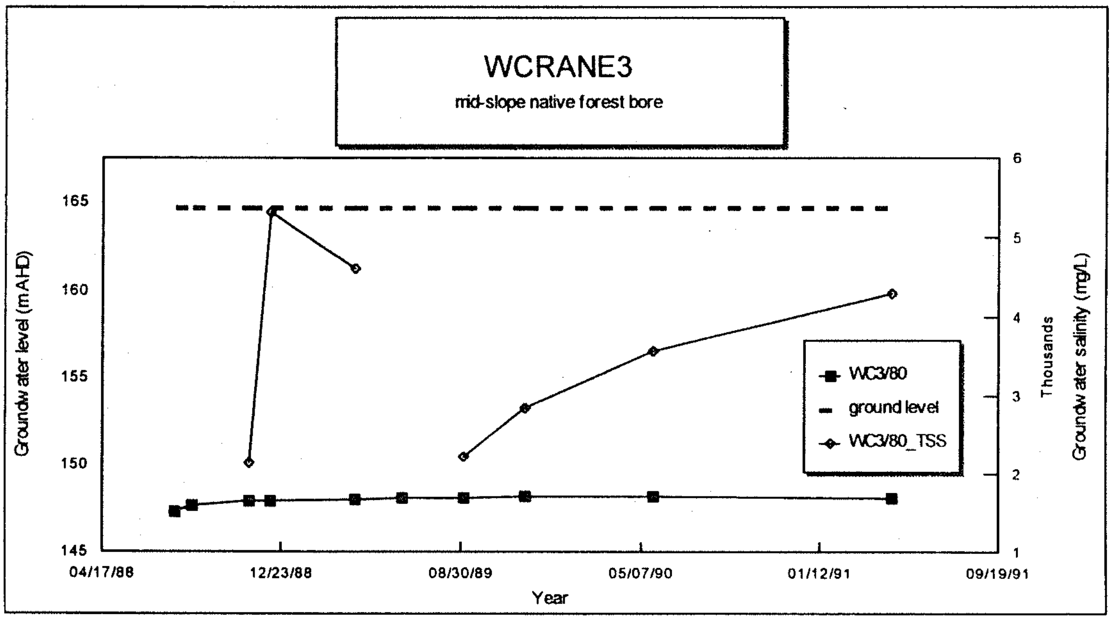

M Crane - Annual minimum potentiometric level
G60419004 (MC 3/80)
level
salinity
Potentiometric level (m AHD)
Groundwater salinity (mg/L TSS)
236
235.5
235
234.5
234
6500
6000
5500
5000
4500
4000
80
85
90
95
YEAR

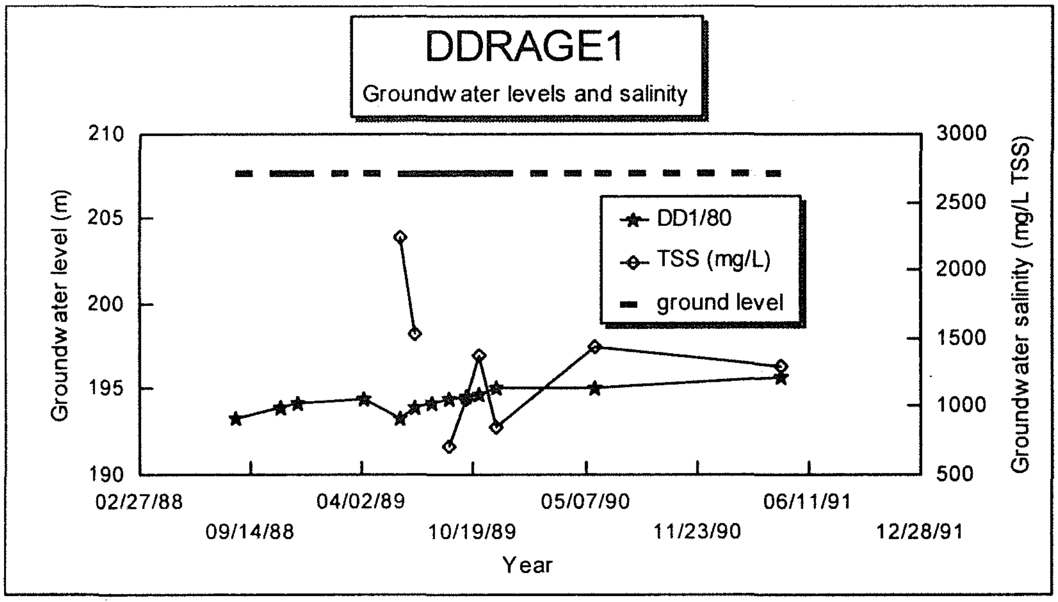

M Crane - Annual minimum potentiometric level
G60419001 (MC 1/80)
▨ rainfall
■ level
Potentiometric level (m AHD)
235.5
234.5
233.5
232.5
Annual rainfall (mm); m509229
1000
800
600
400
200
0
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
YEAR

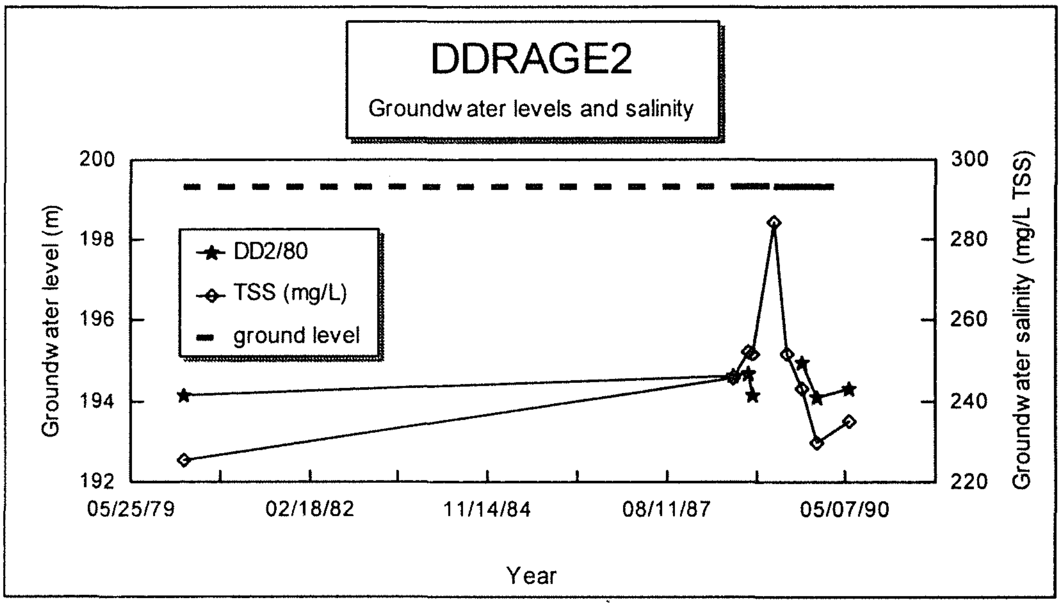

M Crane - Annual minimum potentiometric level
G60419002 & 3 (MC 2/80 & 2A/80)
Potentiometric level (m AHD)
236.5
235.5
234.5
233.5
Annual rainfall (mm); m509229
1000
800
600
400
200
0
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
YEAR
▨ rainfall
■ MC 2A/80 level
☐ MC 2/80 level

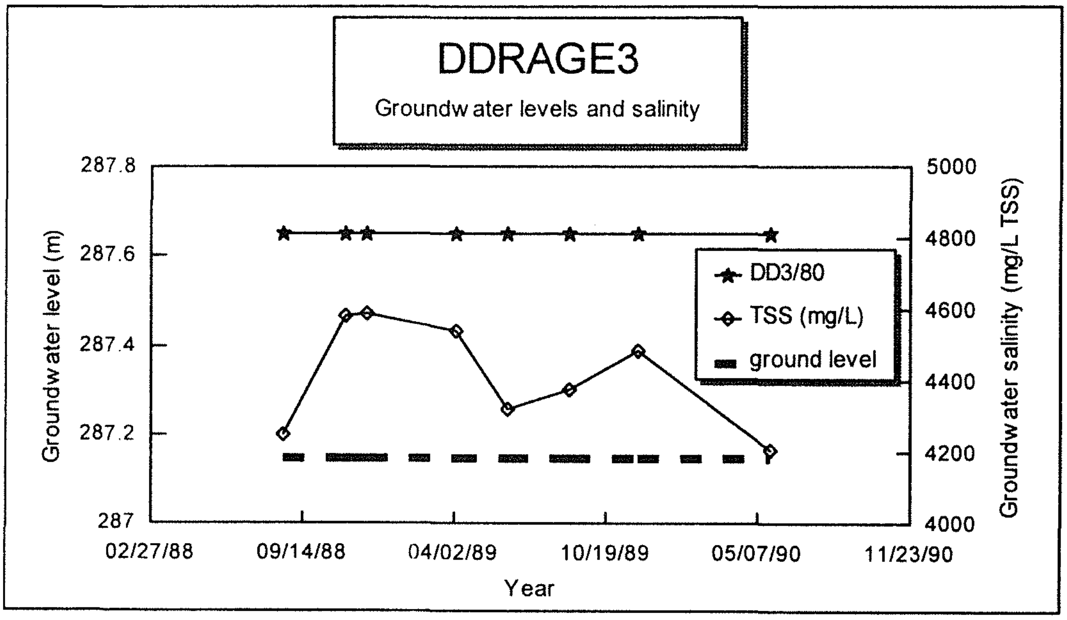

WCRANE1
Groundwater levels and salinity
Groundwater level (mAHD)
176
174
172
170
168
02/27/88
09/14/88
04/02/89
10/19/89
05/07/90
11/23/90
06/11/91
12/28/91
Year
10
8
6
4
2
0
Thousands
Groundwater salinity (mg/L)
WCA1/80
WC1/80
ground level
WCA1/80_TSS
WC1/80_TSS


WCRANE2
Groundwater levels and salinity
Groundwater level (mAHD)
151
150
149
148
147
04/17/88
12/23/88
08/30/89
05/07/90
01/12/91
09/19/91
Year
5
4
3
2
1
0
Thousands
Groundwater salinity (mg/L)
WC2/80
ground level
WC2/80_TSS

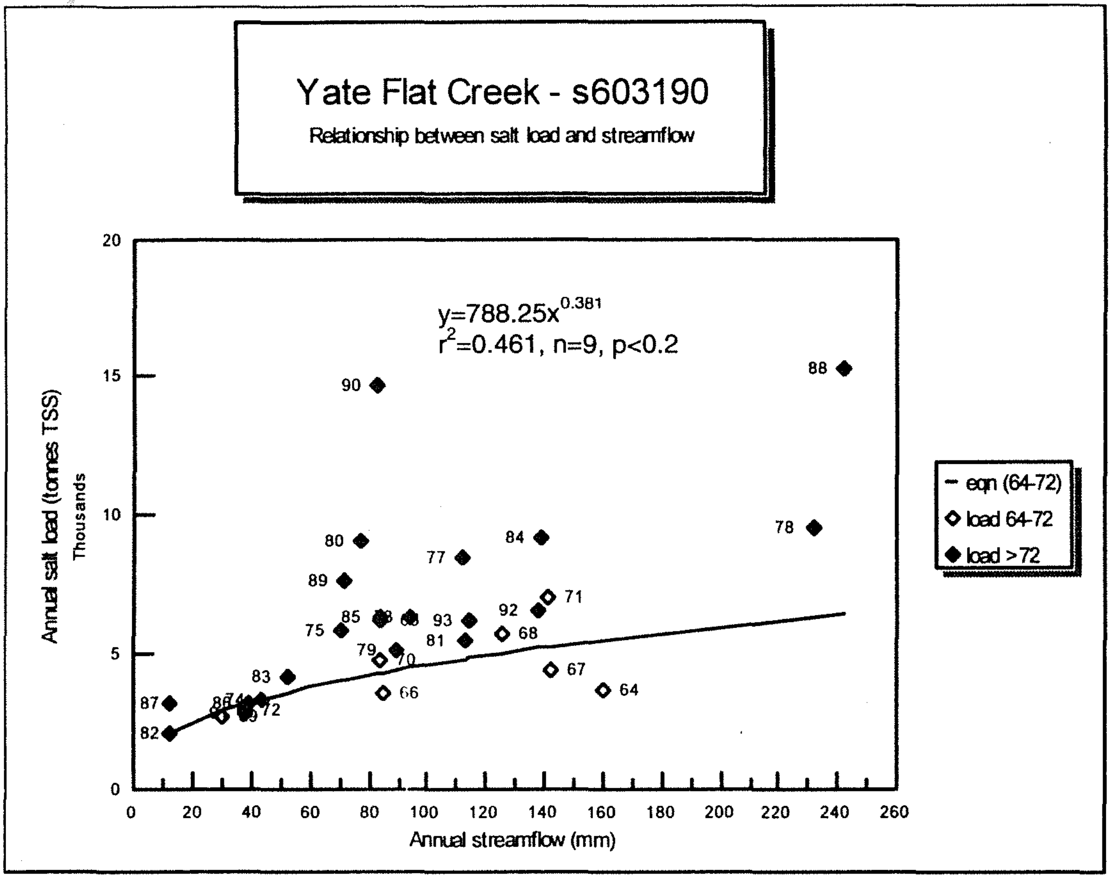

WCRANE3
mid-slope native forest bore
Groundwater level (mAHD)
165
160
155
150
145
04/17/88
12/23/88
08/30/89
05/07/90
01/12/91
09/19/91
Year
6
5
4
3
2
1
Thousands
Groundwater salinity (mg/L)
WC3/80
ground level
WC3/80_TSS

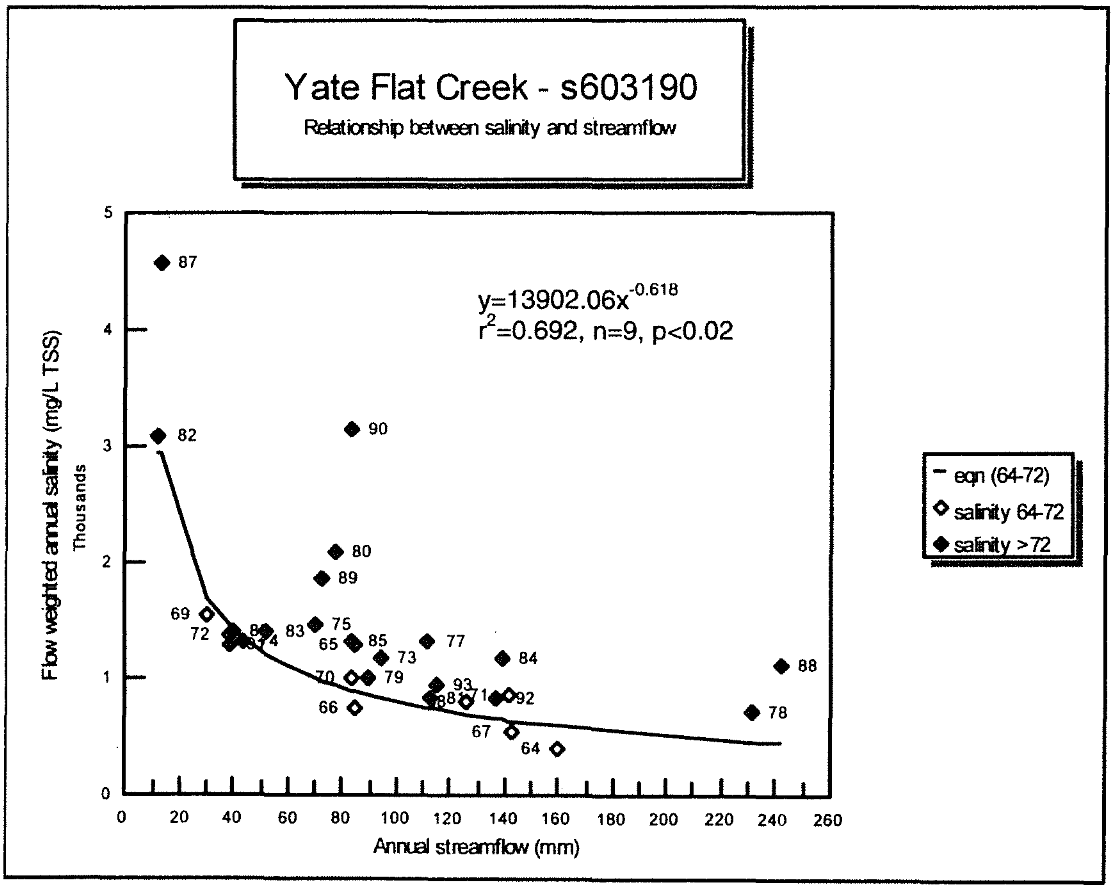

DDRAGE1
Groundwater levels and salinity
Groundwater level (m)
210
205
200
195
190
Groundwater salinity (mg/L TSS)
3000
2500
2000
1500
1000
500
DD1/80
TSS (mg/L)
ground level
02/27/88
09/14/88
04/02/89
10/19/89
05/07/90
11/23/90
06/11/91
12/28/91
Year

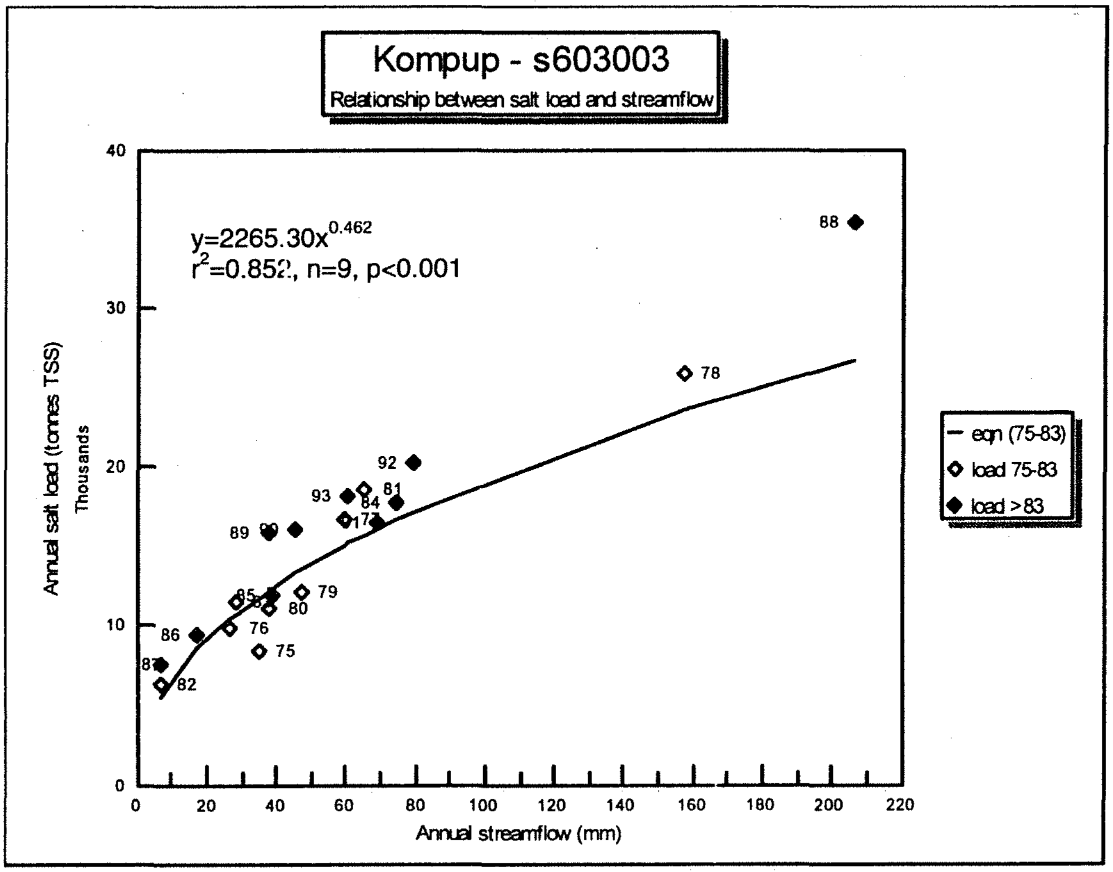

DDRAGE2
Groundwater levels and salinity
Groundwater level (m)
200
198
196
194
192
Groundwater salinity (mg/L TSS)
300
280
260
240
220
DD2/80
TSS (mg/L)
ground level
05/25/79
02/18/82
11/14/84
08/11/87
05/07/90
Year


DDRAGE3
Groundwater levels and salinity
Groundwater level (m)
287.8
287.6
287.4
287.2
287
Groundwater salinity (mg/L TSS)
5000
4800
4600
4400
4200
4000
DD3/80
TSS (mg/L)
ground level
02/27/88
09/14/88
04/02/89
10/19/89
05/07/90
11/23/90
Year

Appendix B - Streamflow Relationships

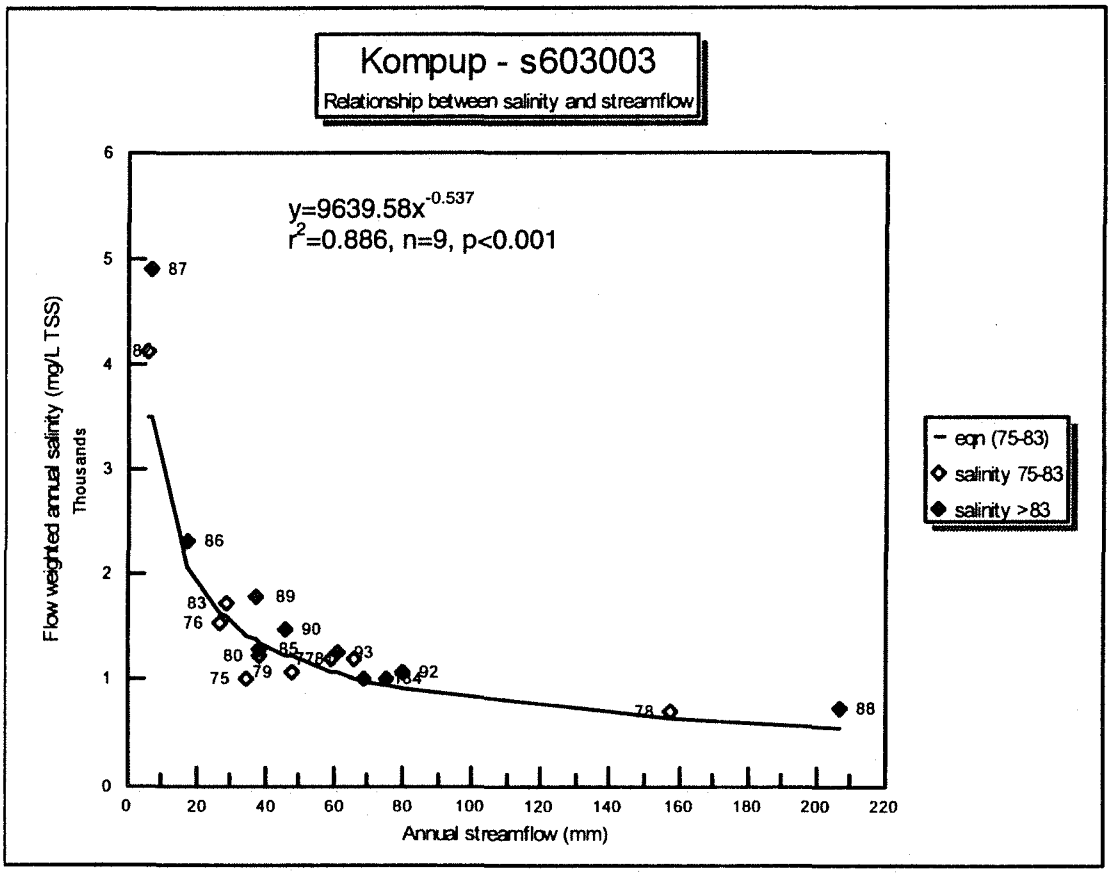

Yate Flat Creek - s603190
Relationship between salt load and streamflow
y=788.25x^0.381
r²=0.461, n=9, p<0.2
Annual salt load (tonnes TSS)
Thousands
0
5
10
15
20
Annual streamflow (mm)
0 20 40 60 80 100 120 140 160 180 200 220 240 260
eqn (64-72)
load 64-72
load >72
90
88
80
84
78
77
89
71
85
93
92
75
68
81
79
70
67
83
66
64
87
86
74
72
82


Yate Flat Creek - s603190
Relationship between salinity and streamflow
y=13902.06x^-0.618
r²=0.692, n=9, p<0.02
Flow weighted annual salinity (mg/L TSS)
Thousands
0
1
2
3
4
5
Annual streamflow (mm)
0 20 40 60 80 100 120 140 160 180 200 220 240 260
eqn (64-72)
salinity 64-72
salinity >72
87
82
90
80
89
69
72
74
83
75
65
85
77
73
84
88
70
79
93
71
92
66
78
67
64



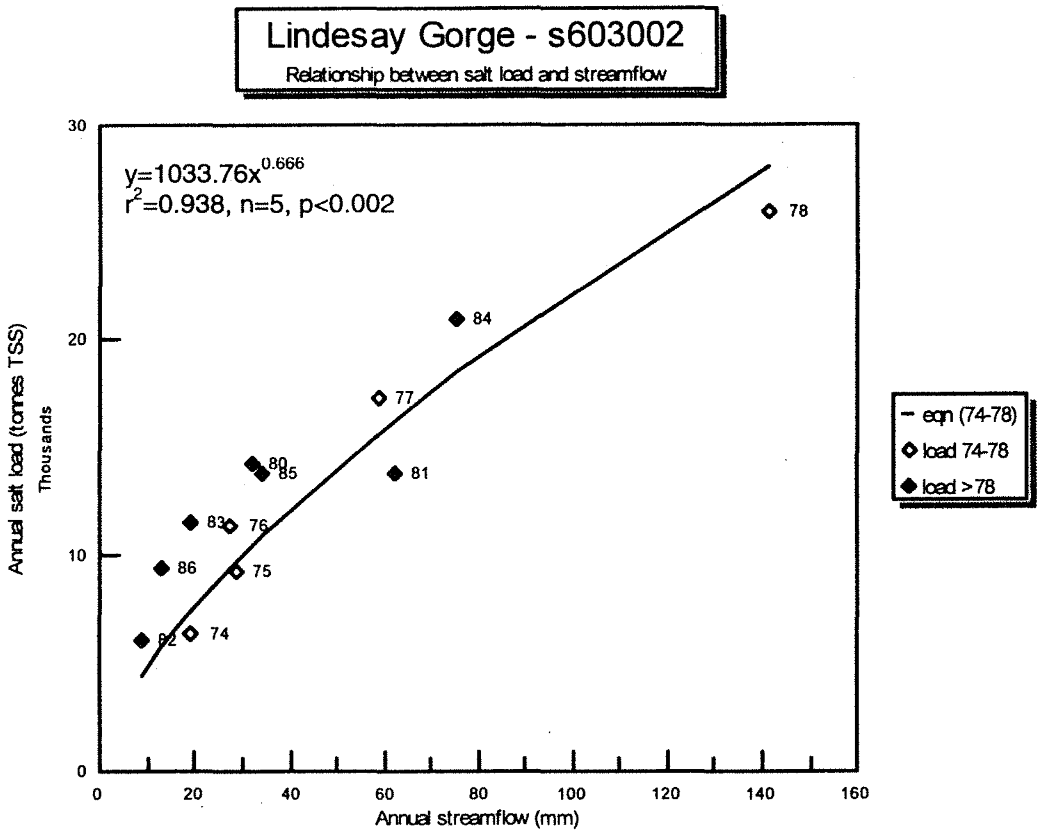
Kompup - s603003

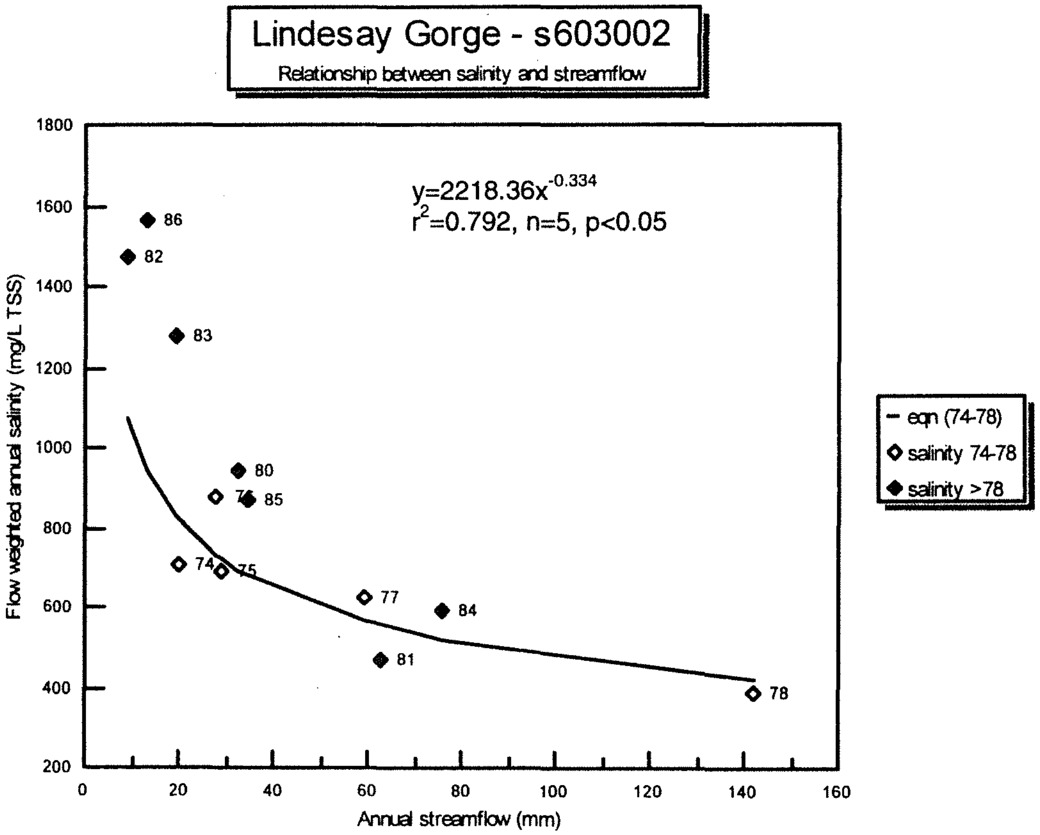
Relationship between salt load and streamflow

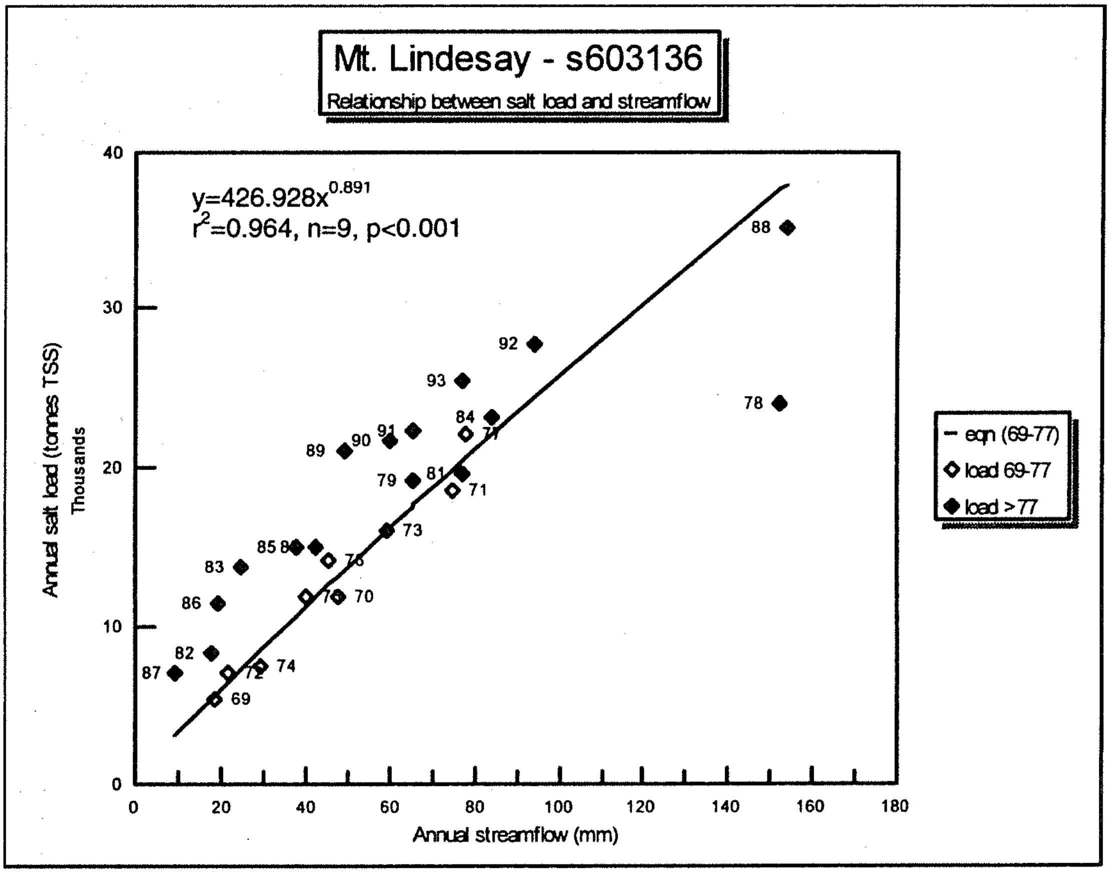


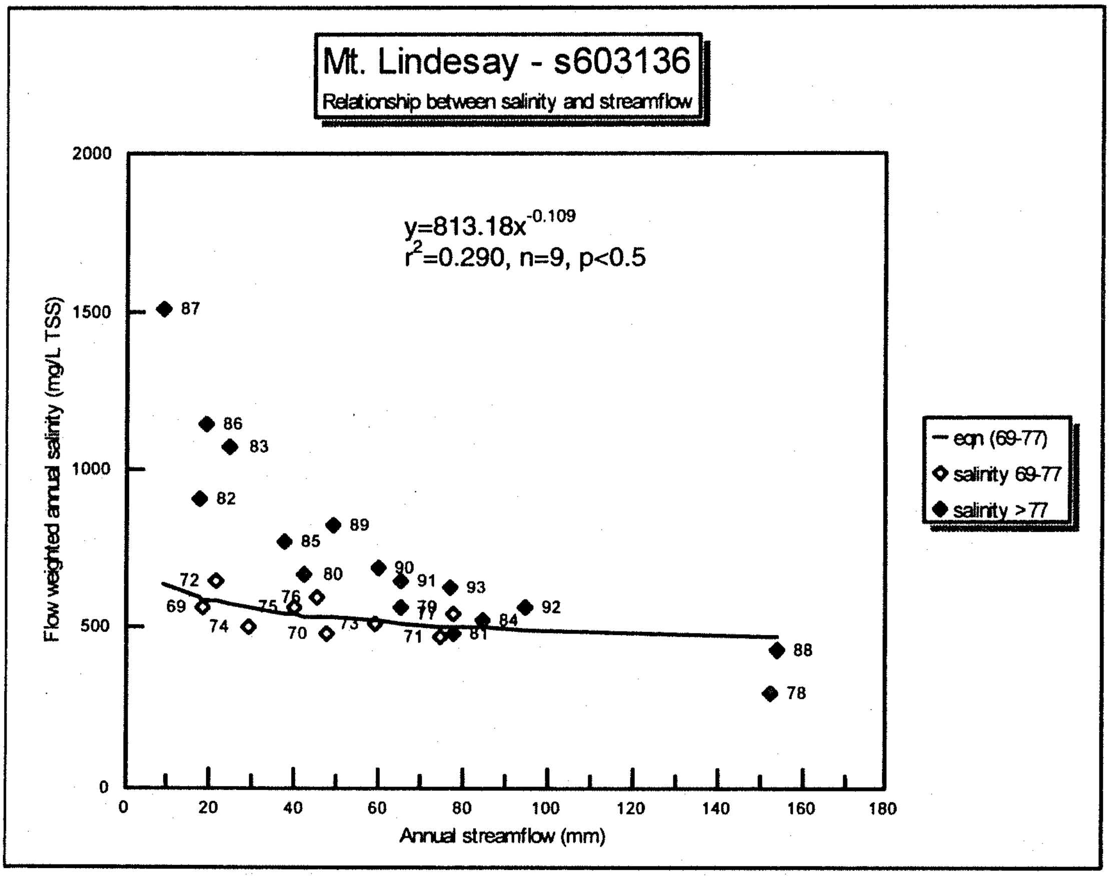
Kompup - s603003

Relationship between salinity and streamflow


Lindesay Gorge - s603002
Relationship between salt load and streamflow
y=1033.76x^0.666
r²=0.938, n=5, p<0.002
Annual salt load (tonnes TSS)
Thousands
30
20
10
0
0
20
40
60
80
100
120
140
160
Annual streamflow (mm)
78
84
77
80
85
81
83
76
86
75
82
74
eqn (74-78)
load 74-78
load >78


Lindesay Gorge - s603002
Relationship between salinity and streamflow
y=2218.36x^-0.334
r²=0.792, n=5, p<0.05
Flow weighted annual salinity (mg/L TSS)
1800
1600
1400
1200
1000
800
600
400
200
0
20
40
60
80
100
120
140
160
Annual streamflow (mm)
86
82
83
80
76
85
74
75
77
84
81
78
eqn (74-78)
salinity 74-78
salinity >78


Mt. Lindesay - s603136
Relationship between salt load and streamflow
y=426.928x^0.891
r²=0.964, n=9, p<0.001
Annual salt load (tonnes TSS) Thousands
Annual streamflow (mm)
0
10
20
30
40
0
20
40
60
80
100
120
140
160
180
88
92
93
78
84
71
91
90
89
79
81
71
73
85
84
83
76
75
70
86
82
87
72
74
69
— eqn (69-77)
◇ load 69-77
◆ load >77


Mt. Lindesay - s603136
Relationship between salinity and streamflow
y=813.18x^-0.109
r²=0.290, n=9, p<0.5
Flow weighted annual salinity (mg/L TSS)
Annual streamflow (mm)
0
500
1000
1500
2000
0
20
40
60
80
100
120
140
160
180
87
86
83
82
89
85
80
90
91
93
72
76
69
75
74
70
73
79
77
71
81
84
92
88
78
— eqn (69-77)
◇ salinity 69-77
◆ salinity >77

Appendix C - Streamflow Data

Yate Flat Creek gauging station (s603190)

s603190 Year	Streamflow (mm)	Salinity (mg/L TSS)	Salt Load (tonnes TSS)	Rainfall (mm)
64	160	407	3688	849
65	84	1288	6151	821
66	84	740	3547	673
67	142	548	4418	728
68	125	802	5694	713
69	30	1545	2644	518
70	83	1002	4738	781
71	141	873	6972	994
72	38	1389	2980	626
73	94	1176	6273	861
74	43	1332	3261	730
75	70	1460	5797	698
76	59	5041	16892	729
77	112	1331	8416	716
78	231	727	9532	889
79	89	1010	5090	731
80	77	2085	9072	708
81	112	847	5397	728
82	12	3077	2133	653
83	52	1400	4151	641
84	138	1165	9143	867
85	83	1335	6313	812
86	39	1415	3126	637
87	12	4564	3203	643
88	242	1113	15279	871
89	72	1867	7597	828
90	83	3138	14714	733
91	38	1279	2760	674
92	137	844	6557	827
93	114	952	6179	722

Kompup gauging station (s603003)

s603003 Year	Streamflow (mm)	Salinity (mg/L TSS)	Salt Load (tonnes TSS)	Rainfall (mm)
75	35	1025	8416	758
76	27	1536	9784	715
77	59	1199	16661	729
78	157	700	25887	854
79	47	1085	12071	667
80	38	1236	11145	711
81	65	1213	18665	835
82	7	4112	6348	494
83	28	1714	11442	654
84	75	1011	17806	802
85	39	1303	11879	703
86	17	2326	9520	602
87	7	4901	7637	611
88	207	729	35397	880
89	38	1779	15779	807
90	46	1491	16017	675
91	69	1017	16471	677
92	80	1083	20253	794
93	61	1270	18182	628

Lindesay Gorge gauging station (s603002)

s603002 Year	Streamflow (mm)	Salinity (mg/L TSS)	Salt Load (tonnes TSS)	Rainfall (mm)
74	19	706	6364	636
75	28	696	9227	819
76	28	878	11283	767
77	59	626	17195	824
78	142	393	25951	940
79				736
80	32	946	14205	755
81	62	475	13803	902
82	9	1476	6007	535
83	19	1284	11456	685
84	75	597	20934	952
85	34	869	13752	708
86	13	1563	9376	651

Mt. Lindesay gauging station

s603136 Year	Streamflow (mm)	Salinity (mg/L TSS)	Salt Load (tonnes TSS)	Rainfall (mm)
60		173		876
61		192		864
62		326		856
63		336		810
64		230		1029
65	43	318		870
66	48	446		759
67	100	261		836
68	70	320		733
69	18	570	5497	722
70	47	480	11912	949
71	75	472	18553	929
72	21	645	7187	603
73	59	519	16123	884
74	29	501	7554	649
75	40	568	11907	848
76	45	602	14279	800
77	78	543	22207	857
78	152	300	23964	983
79	65	561	19212	774
80	42	674	14968	775
81	77	483	19591	941
82	17	911	8273	563
83	25	1073	13852	706
84	84	524	23202	889
85	37	776	15141	709
86	19	1144	11445	628
87	9	1508	7173	694
88	154	435	35108	933
89	49	821	21091	862
90	60	695	21800	701
91	65	650	22286	749
92	94	563	27895	839
93	77	633	25562	589