WATER AUTHORITY
of Western Australia

WATER RESOURCES DIRECTORATE

Denmark River Yield and Salinity Study

Report No. WH 8
November 1985

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Hydrology Branch

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J.K.Ruprecht, R.A.Stokes and R.B.Pickett

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ABSTRACT

A hydrological study of the Denmark River Basin in the south of Western Australia was undertaken to predict stream water yields and salinities as a consequence of agricultural clearing and to determine the implications for the development of a major reservoir.

Aerial photographs and Landsat imagery were used to develop a history of clearing between 1946 and 1984. Approximately 18% of the Mt Lindesay Catchment (525 km^2) was cleared prior to 1984, with 34% cleared in the upper reaches above the gauging station at Kompup (234 km^2). This headwater area currently produces about 37% of the streamflow and 72% of the stream salt load as measured at the Mt Lindesay gauging station.

An annual rainfall-runoff simulation produced mean and median streamflows of 38 x 10^6 m^3 and 32 x 10^6 m^3 respectively over the 1940 to 1983 period. These and the predicted annual salinity statistics compared favourably with the historical record. Once the full hydrological effects of clearing have developed by early next century it is predicted that the 10%, 50% and 90% probabilities of non-exceedance of streamflow will be 12, 32, and 82 x 10^6 m^3 respectively with associated salinities of 1080, 730 and 460 mg L^{-1} TSS (Total Soluble Salt). This will mean that about 62% of monthly salinities will be greater than 800 mg L^{-1} and 38% greater than 1000 mg L^{-1}.

A monthly simulation of reservoir water and salinity for a storage size of between 100% and 300% of mean annual inflow (MAI) and for demands between 60% and 90% MAI indicated significant reductions in the probabilities of monthly draw salinities. Monthly draw salinities above 800 mg L^{-1} were reduced to less than 20% and to less than 2% above 1000 mg L^{-1} for most storage sizes. In operation these would be improved upon through scouring and the use of multi-level offtakes.

ACKNOWLEDGEMENTS

Streamflow, daily rainfall, pluviograph and stream water quality data were collected and processed by the Hydrographic staff of the Hydrology Branch of the Water Authority. Rainfall and evaporation data were made available through the Commonwealth Bureau of Meteorology.

Catchment clearing information was made possible by the supply of aerial photographs from the Department of Lands and Surveys. The 1984 Landsat imagery was interpreted with the assistance of Geoff Spencer and Bill Holman from the Department of Lands and Survey. The clearing information was also processed by by Colin Pearce of the Department of Conservation and Land Management. Detailed catchment analysis was undertaken on the Land Information Systems Support Centre's (LISSC) Intergraph system.

Finally, useful discussions on approaches to the study and interpretation of results were made by Mr I. Loh and Mr G. Hookey.

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1. INTRODUCTION

1.1 Background

The town of Denmark on the south coast of Western Australia is supplied with water from a pipehead dam of about 420 000m^3 capacity on the Denmark River, approximately 6km north of the town. The catchment area upstream of the dam is 567 km^2 of which approximately 25% is alienated and 95 km^2 (17%) was cleared for agriculture by 1984.

The salinity in the pipehead dam has been deteriorating in recent years, particularly since 1978. Maximum salinities have increased from less than 900 mg L^{-1} total soluble salts (TSS) in 1980 to more than 1400 mg L^{-1} TSS in 1983. These salinities prompted the development of an alternative source, in 1984, on Scotsdale Brook for substitution or dilution during periods of high run-of-river salinity in the Denmark River.

The potential yield of a major reservoir on the Denmark River was thought to be approximately 30 x 10^6 m^3 (PWD, 1979). The salinity of the draw from such a development will depend upon the amount and salinity of the streamflow from the catchment and the size and operation of the reservoir.

1.2 Study Objectives

The aim of this report is to develop predictions of the effects of agricultural clearing on the magnitude and timing of water and salt yields from the Denmark catchment and to evaluate the likely water supply salinities for a range of reservoir sizes and demands.

These were to be first estimates to determine catchment management strategies and the need for more detailed hydrology studies.

2. CATCHMENT DESCRIPTION

2.1 Location and Climate

The Denmark River Basin lies between latitudes 34° 30' and 35° 00' South and between longitudes 117° 00' and 117° 30' East in the South of Western Australia (Figure 1). The catchment area to the pipehead dam is 567 km^2. Most of the area is within the shires of Denmark and Plantagenet, and the principal towns are Mt Barker and Denmark.

The south coast region experiences a "Mediterranean" type climate (Kopper Classification Cab.) with warm, mostly dry summers and cool, wet winters (Dick, 1975). Average annual rainfall decreases from 1000 mm at the pipehead dam to 700 mm at the northern boundary of the catchment (Public Works Department 1980). Approximately 75% of this rainfall occurs between May and October.

Pan evaporation averages 1270 mm yr^{-1} across the catchment with about 80% of this occuring between October and April. The average annual temperature is approximately 15° C.

2.2 Landforms and Soils

The main drainage rises on the dissected lateritic plateau on the southern edge of the Yilgarn block approximately 50 km from the southern coast (Figure 2). The laterite plateau covers 55% of the catchment (Table 1), with 20% consisting of dissected plateau. Swampy flats with poor drainage covers 10% of the catchment, primarily in the west and north-west. There is a small area of higher relief around a granite massif in the south east, the peak of which (Mt Lindesay) has an elevation in excess of 450m. The remainder of the catchment varies in elevation from 80m in the south to 240m in the north.

TABLE 1 LANDFORMS AND SOILS OF DENMARK RIVER BASIN

Landforms/Soils	% Area
Swampy flats; shallow drainage lines with leached sands and podzolic soils	10
Laterite Plateau; uplands with sands and ironstone gravels over mottled clays	55
Dissected Plateau; hilly country with yellow mottled soils and gravels	20
Incised Valleys; moderate to steep slopes, yellow podzolic soils and red earths	15

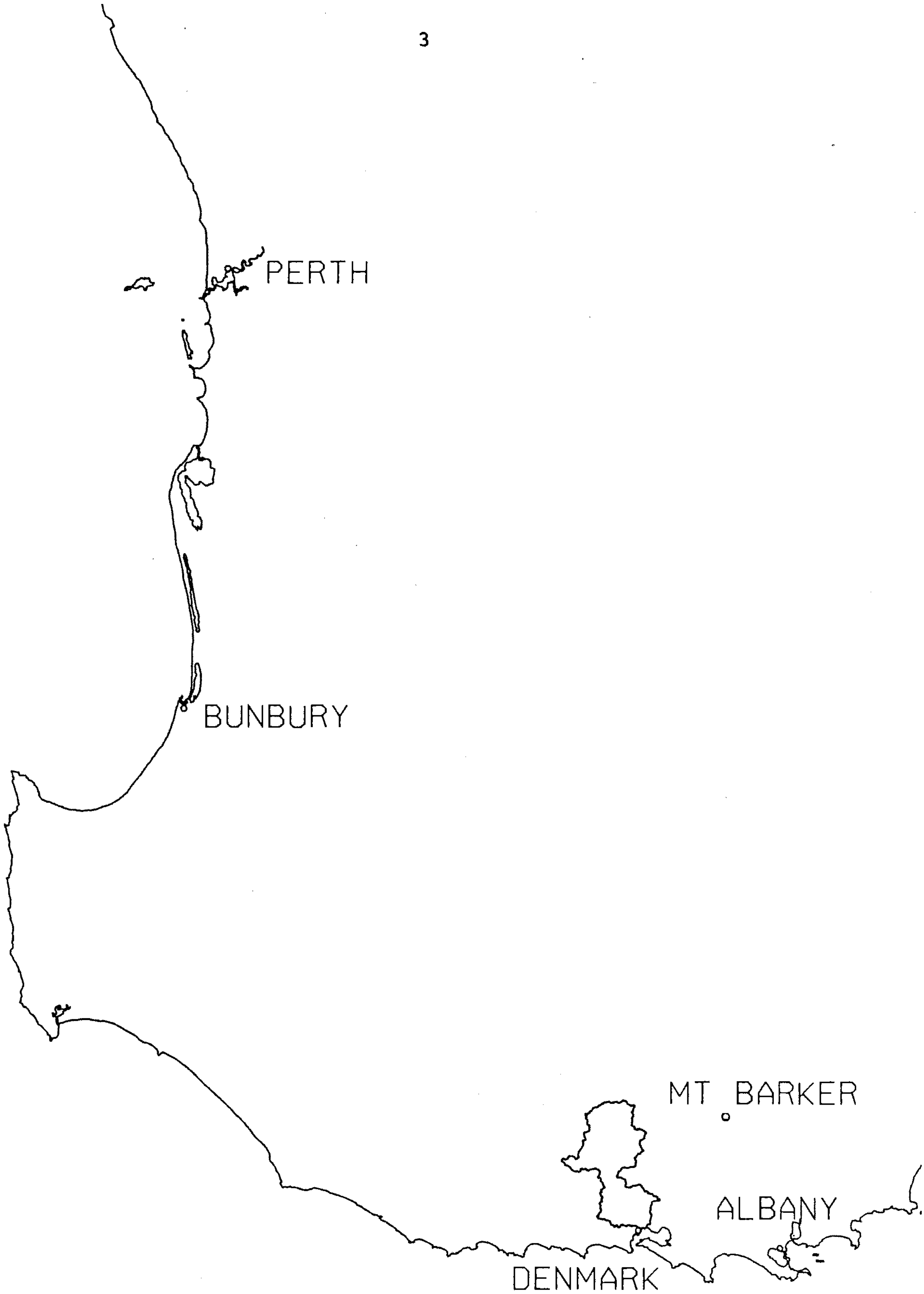

FIGURE 1 DENMARK RIVER BASIN LOCATION MAP

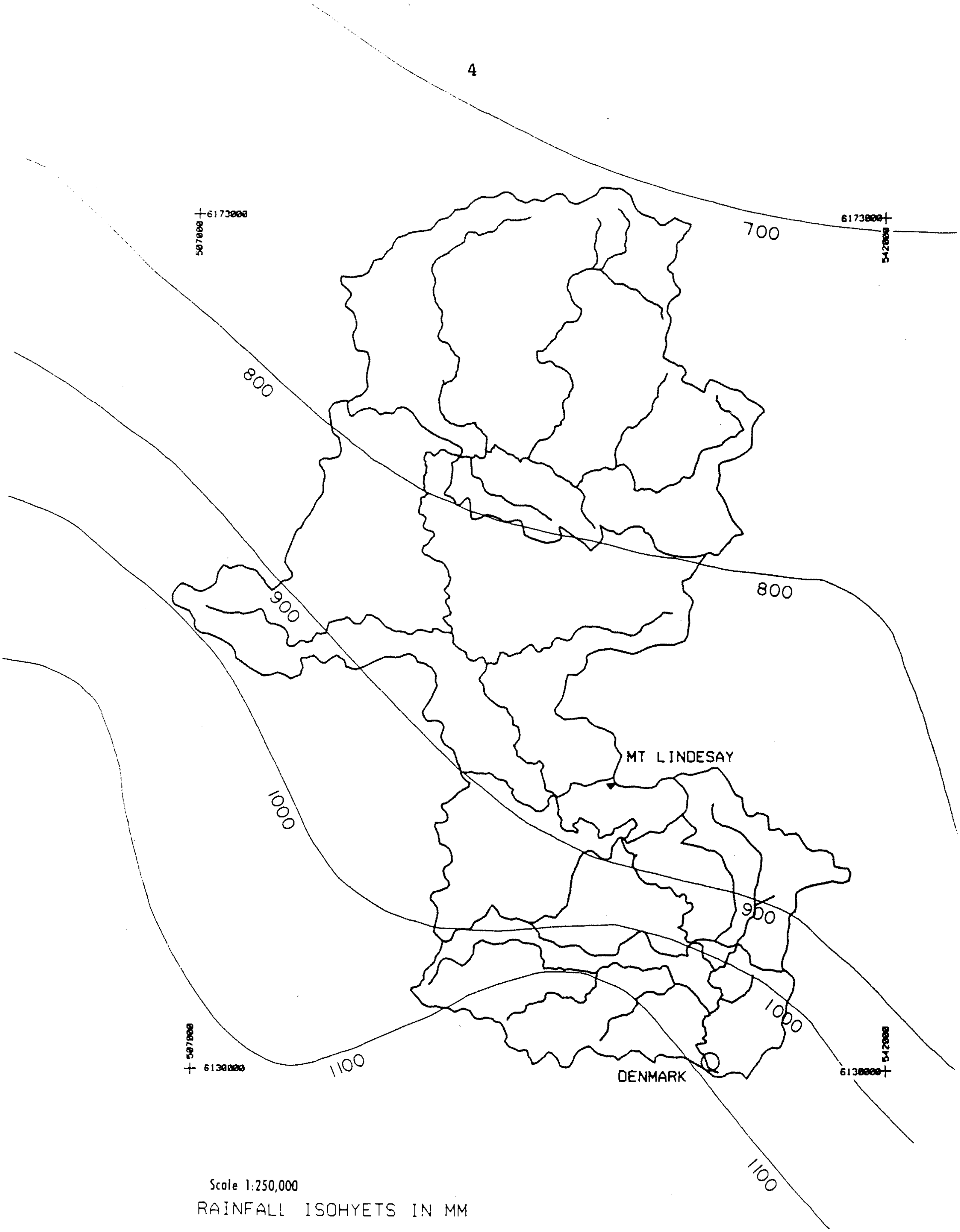

FIGURE 2 DENMARK RIVER CATCHMENT

2.3 Vegetation and Landuse

The natural vegetation of the area is predominantly forest with a wide range of forms and diversity of species. The dominant species over most of the catchment are jarrah (E. marginata) and marri (E. calophylla). On better drained soils such as the incised valleys and dissected plateaus there is relatively good quality jarrah/marri forest. In contrast the vegetation on the swampy leached sands is a low forest of jarrah. In the lower, wetter reaches of the Denmark River Basin there are isolated stands of karri (E. diversicolor).

Approximately 17% of the catchment area to the pipehead dam has been cleared for agriculture prior to 1984. Most of this (84%) is in the drier upper reaches where the landuse is grazing and some grain production. Below Mt Lindesay the dominant agricultural practices are dairying and beef production. The remainder of the area is designated State Forest.

3. HISTORICAL INFORMATION

3.1 Rainfall

3.1.1 Aim

The aims of this section are to describe the availability and reliability of the rainfall data; the production of daily catchment rainfall (for yearly totals); and to describe features of these catchment rainfalls particularly their representativeness through time.

3:1.2 Availability of Data

Rainfall data has been recorded in the Denmark area since July 1897, however consistent daily data was not produced until 1910. Initially the rainfall data was recorded by the Bureau of Meteorology but from the early 1970's the Public Works Department began collecting rainfall data on gauged catchments. This has resulted in a greatly improved rainfall network (Figure 3). A detailed list of the rainfall stations between 1897 and 1984 and are relevant to the Denmark River Basin, (Table 2) shows that the rainfall station with the longest record is that of the Denmark Post Office which has run from 1897 to the present day.

Prior to 1937 there were only limited rainfall data available, however from 1968 the number of stations producing daily data had increased from 8 in 1968, to 19 stations in 1977 (Figure 4). The record produced from the pluviographs, introduced in the 1970's, was initially poor but had improved considerably by 1980.

3.1.3 Individual Rainfall Stations

To test the validity of the individual rainfall stations, two rainfall stations were identified for analysis because of this long record of approximately 86 years. These were Denmark Post Office (009 531), which is located south of the catchment in a high rainfall region, and Pardellup Prison Farm (009 591) which is located north east of the catchment in a low rainfall region (Figure 3).

Figures 5 and 6 show the annual rainfall measured at each station over the period 1910 to 1983 for 009 531 and 009 591 respectively. Both these figures highlight the high annual rainfalls recorded from 1915 to 1930 and the low annual rainfalls recorded from 1965 to 1983. By looking at the record before and after 1955 the comparative high rainfall at the beginning of the century compared to the latter is more apparent. Prior to 1955 there had been 7 years when the rainfall recorded was greater than the 90th percentile, while since 1955 there have been no rainfall events greater than the 90% probability of non-exceedence value. Prior to 1955 there had been no rainfall events with a 10% probability of non-exceedence, while since 1955 there have been 5 rainfall

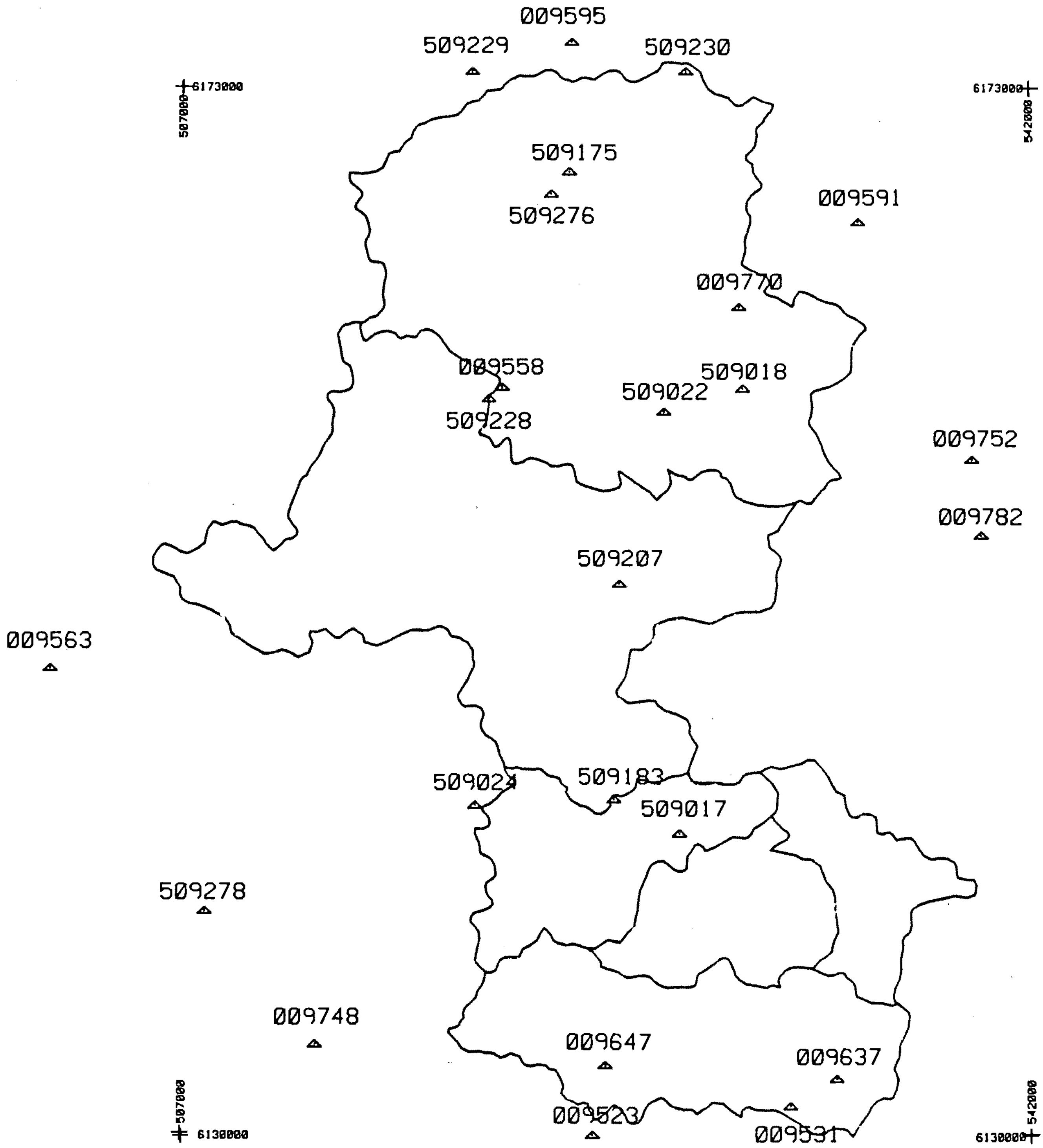

FIGURE 3 RAINFALL STATION SPATIAL COVERAGE

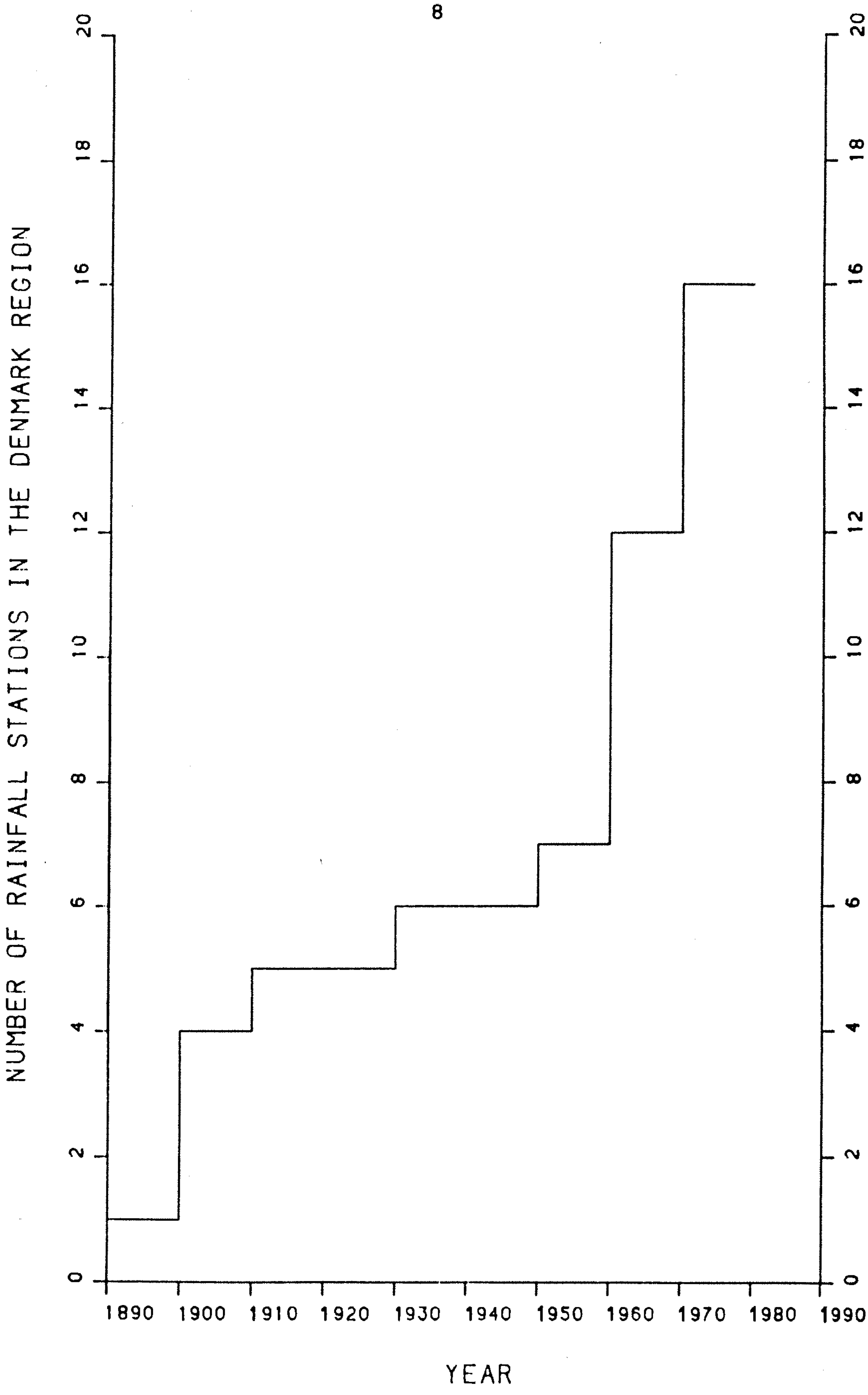

FIGURE 4 RAINFALL STATIONS TEMPORAL COVERAGE

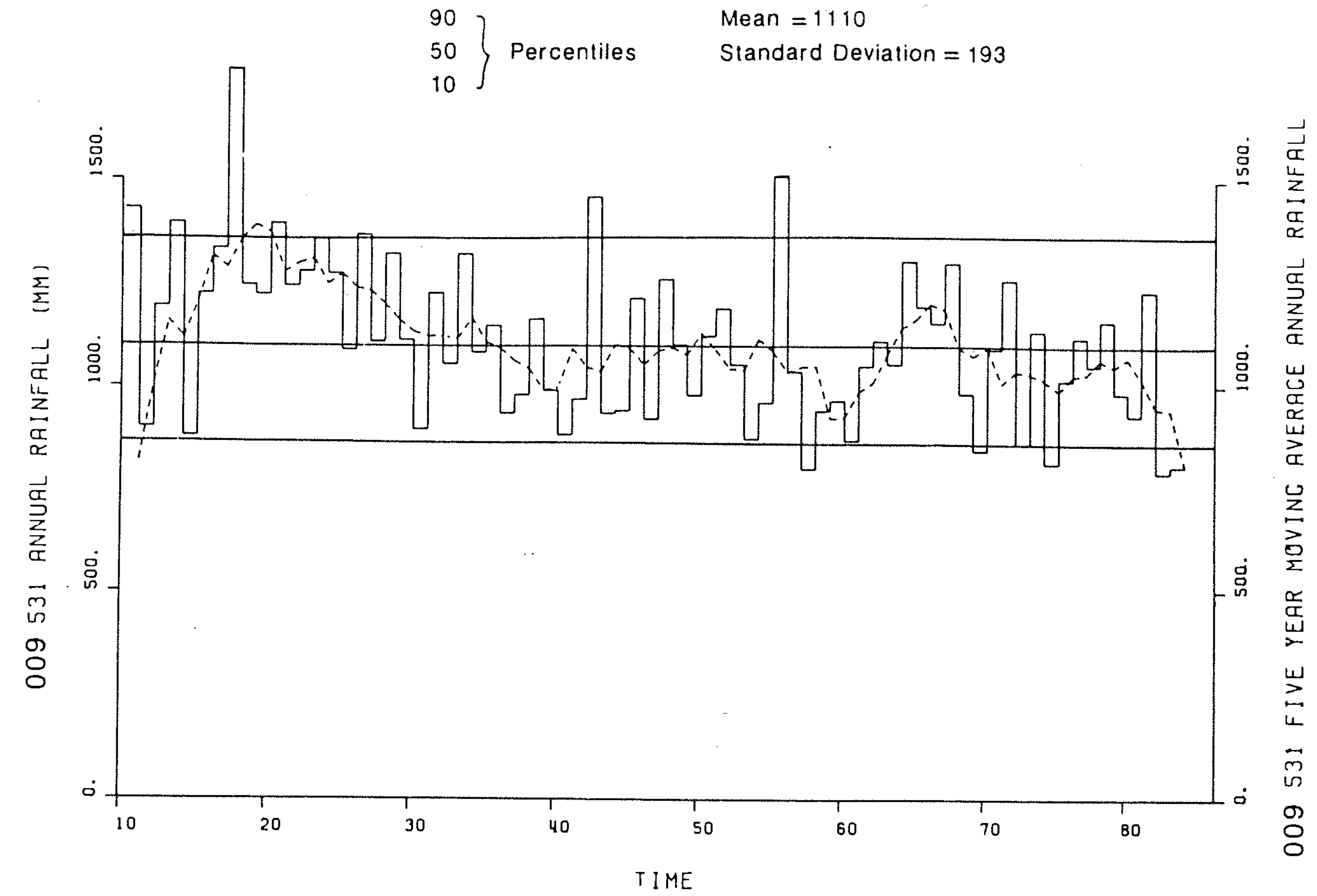

FIGURE 5 DENMARK P.O. (009 531) ANNUAL RAINFALL

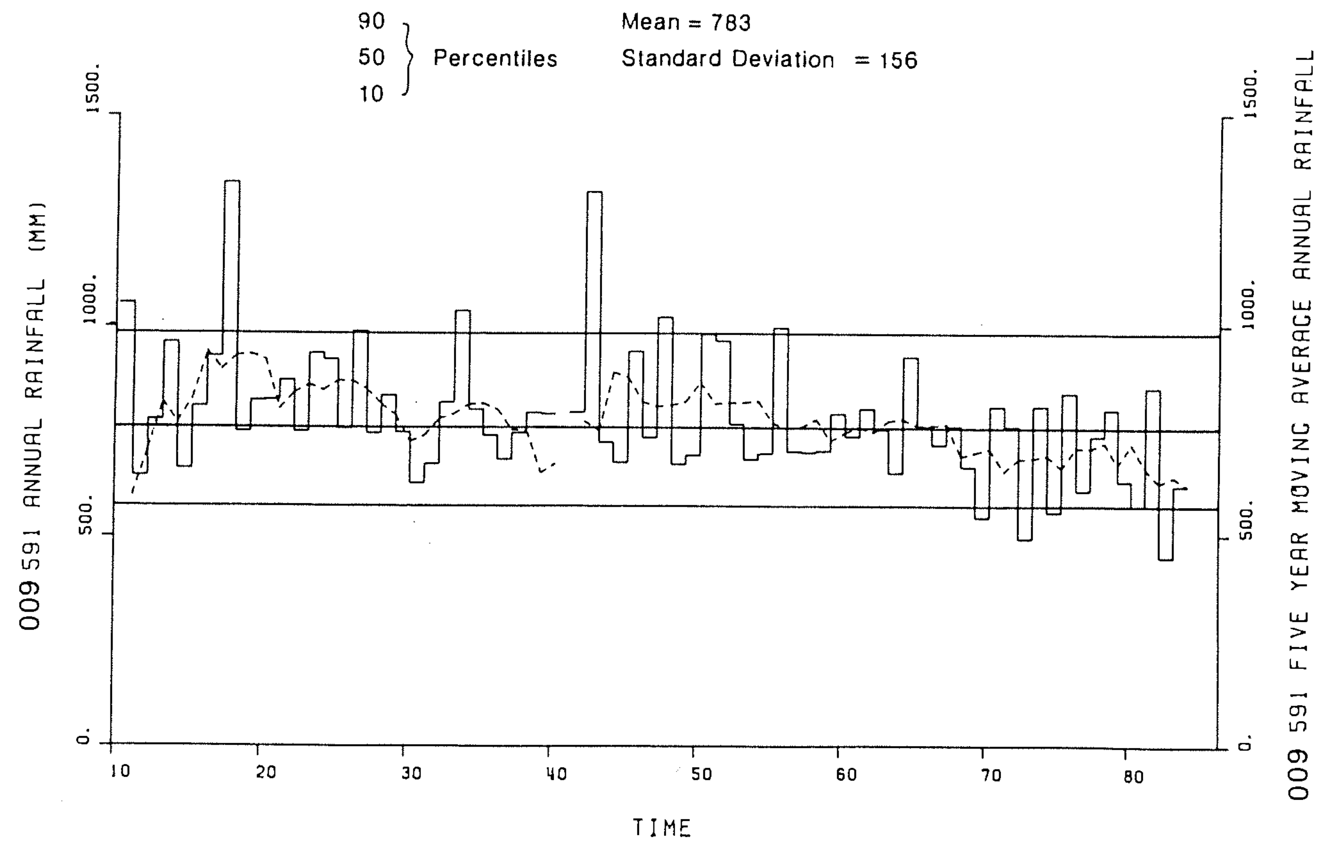

FIGURE 6 PARDELLUP PRISON FARM (009 591) ANNUAL RAINFALL

TABLE 2 RAINFALL STATIONS IN THE DENMARK RIVER REGION

STATION NUMBER	NAME	PERIOD OF RECORD	NO. YEARS	AVE RAINFALL FROM ISOHYET
009 523	ILLALAGI	1912-	73	1200
009 531	DENMARK P O	1897-	88	1100
009 558	IAWAKIA	1937-1983	47	795
009 563	KENT RIVER	1912-1952	41	1100
009 591	PARDELLUP PRISON FARM	1899-	86	730
009 595	PEERILLUP	1915-	70	715
009 637	DENMARK RESEARCH STATION	1974-	11	1050
009 647	DENMARK (4)	1956-	29	1140
009 752	DENBARKER	1966-1982	17	780
009 770	MT BARKER	1968-1973	6	760
009 782	BARLINA	1968-	17	800
009 784	KORDABUP DOWNS	1969-	16	1070
509 017	MT LINDESAY	1974-1977	4	890
509 018	BLUE CREEK	1970-1976	7	770
509 022	WOONANUP	1972-	13	780
509 024	HAREWOOD	1974-	11	930
509 175	PERILLUP	1973-1974	2	740
509 183	LINDESAY GORGE	1973-	12	890
509 207	BLUE LAKE	1976-	9	830
509 228	KOMPUP	1974-	11	800
509 229	BOUNDARY RD	1974-	11	730
509 230	RIDDLESDEN	1974-1977	4	710
509 276	BILAMA	1976-1977	2	750

events which were less than the 10% probability for both rainfall stations. To test the consistency of the rainfall data a double mass curve of 009 531 versus 009 591 was produced (Figure 7). This plot highlights two changes to the relationship between these stations. The first change occurred in the late 1930's and the second occurred in 1950. Possible reasons for the changes in the relationship could be a physical relocation of the rainfall station or an alteration to the station habitat (eg adjacent vegetation). The gradient of the double mass curve (Figure 7) is approximately 1.4, and compares favourably with interpolating between isohyets which gives a value of 1.5.

The statistics for the two rainfall stations, shown in Table 3, were divided into three sections, these were the complete period from 1910 - 83 and two sub-sections of 1910-39 and 1940-83. The means for the individual stations over the complete historical record are 1110 mm and 783 mm for 009 531 and 009 591 respectively. By comparing the means of the two sub-sections the long term reduction in rainfall is

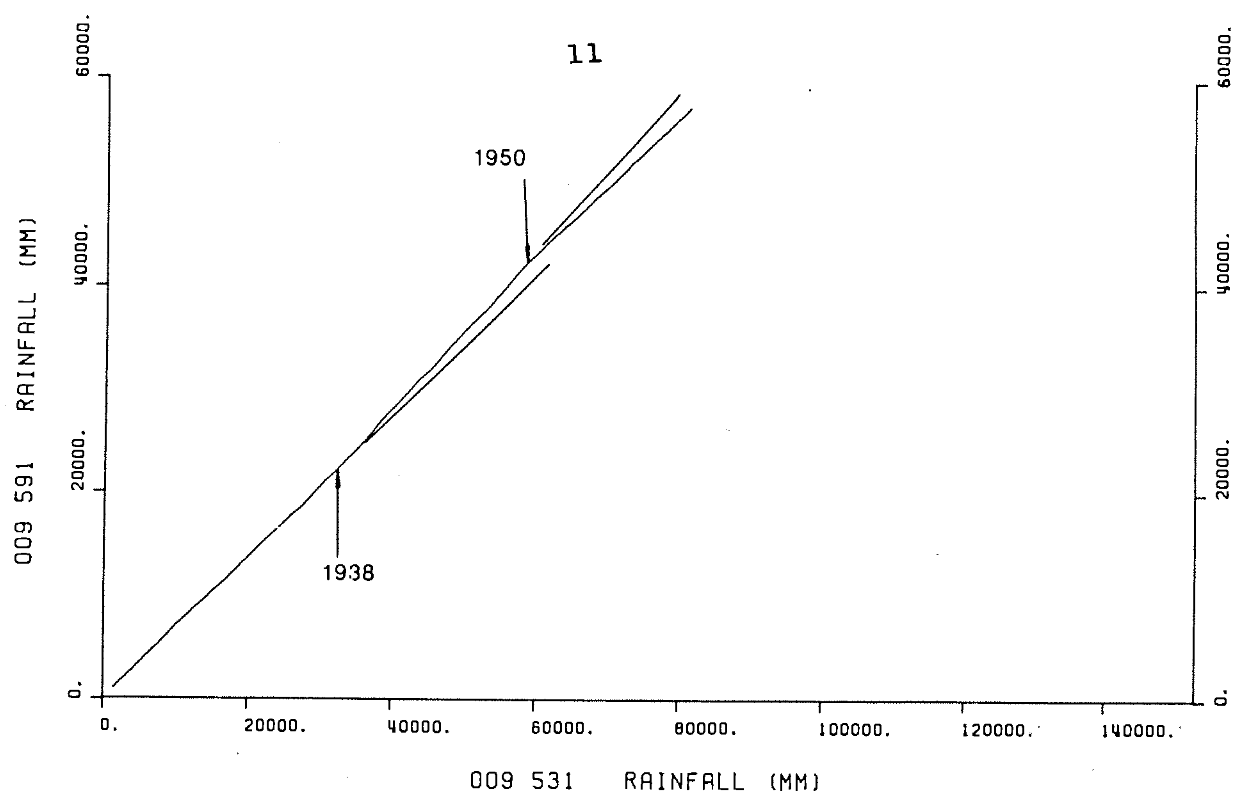

FIGURE 7 DOUBLE MASS CURVE 009 591 VS 009 531

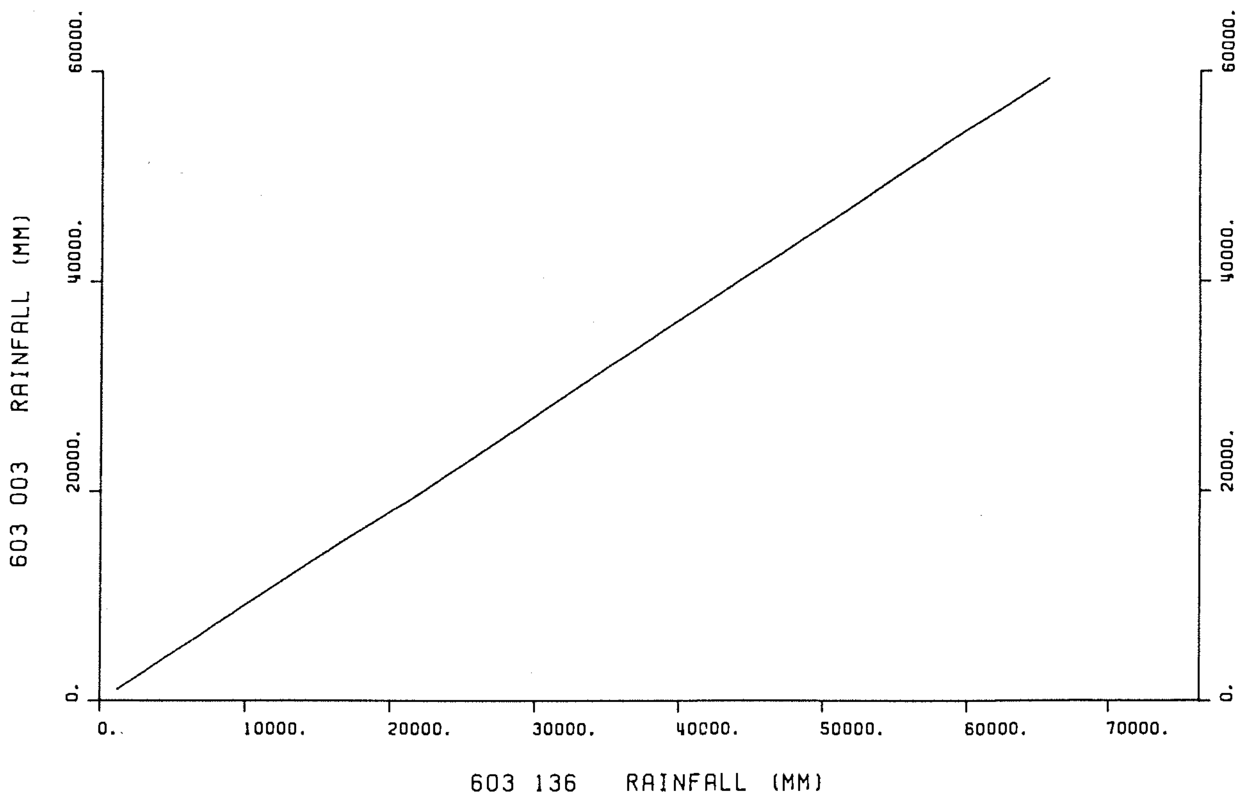

FIGURE 8 DOUBLE MASS CURVE - KOMPUP VS MOUNT LINDESAY

noticeable. The mean annual rainfalls for the period 1910-39 compared to 1940-83 have reduced 13.5% and 9.7% for 009 531 and 009 591 respectively.

3.1.4 Calculation of Daily Catchment Rainfalls

For the Denmark River catchment the three sub-catchments studied were Kompup catchment associated with gauging station 603 003; Lindesay Gorge catchment associated with gauging station 603 002; and Mt Lindesay catchment associated with gauging station 603 136 (Figure 3). For each sub-catchment a catchment rainfall was produced using the Thiessen weight method, with isohyetal correction factors.

3.1.5 Catchment Rainfalls

Using the Thiessen method catchment rainfalls were produced for Kompup, Lindesay Gorge and Mt Lindesay sub-catchments. The annual rainfalls for the three catchments are plotted with respect to time in Figures 9, 10 and 11. These graphs include the five year moving average to dampen the year to year variability in the annual rainfalls. From these diagrams there is an apparent trend of decreasing rainfall with time in the Denmark region. To further emphasise this point, no annual rainfall has exceeded the 90% probability of non-exceedance since 1955 for all three catchments studied whilst in the period 1955 to 1984 the 10% probability has been exceeded three times for all three catchments. A very preliminary check on the catchment rainfalls was to compare the values from the Thiessen network method to those obtained from an isohyetal map calculation (see Table 5).

The differences between the two means can be explained by the different periods over which the means were calculated. For the catchment rainfalls the period of record is from 1910 to 1983 (74 years) while for the isohyetal map calculation the period of record is 1926 to 1980 (55 years). From the plots of annual rainfall against time it can be seen that the period 1910 to 1926 (17 years) was above the mean annual rainfall for 12 out of the 17 years, therefore it would be expected that the mean catchment rainfalls would be above the mean isohyetal map rainfalls

To test the consistency of the rainfall data, a double mass curve of the annual rainfalls, as derived by the Thiessen method, for the Kompup catchment versus the Mt Lindesay catchment (see Figure 11) was produced. This double mass curve plot depicts a linear relationship over the complete record of 1910 to 1984. This compares to the individual rainfall station double mass curve which highlighted a number of changes in the observed relationship between stations. The double mass curve of the catchment rainfalls confirms that any trend in decreasing rainfall is over the entire catchment and not just confined to the lower rainfall areas like the Kompup catchment. Overall the double mass curves highlight the spatial variability of individual raingauge stations and the uniformity of the catchment rainfalls as a result of the Thiessen method.

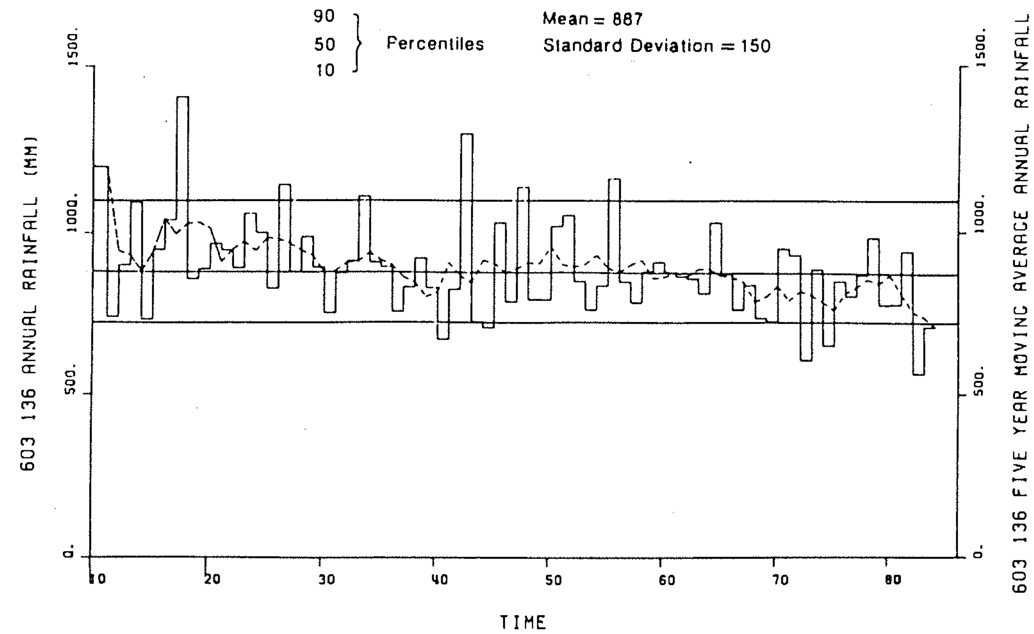

FIGURE 9 MOUNT LINDESAY CATCHMENT RAINFALL

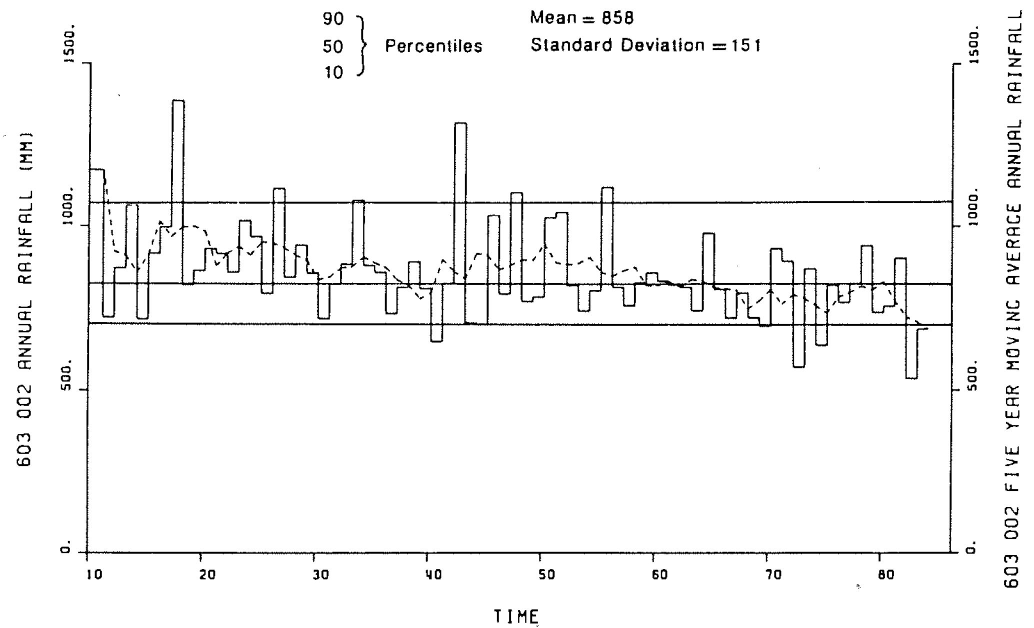

FIGURE 10 LINDESAY GORGE CATCHMENT RAINFALL

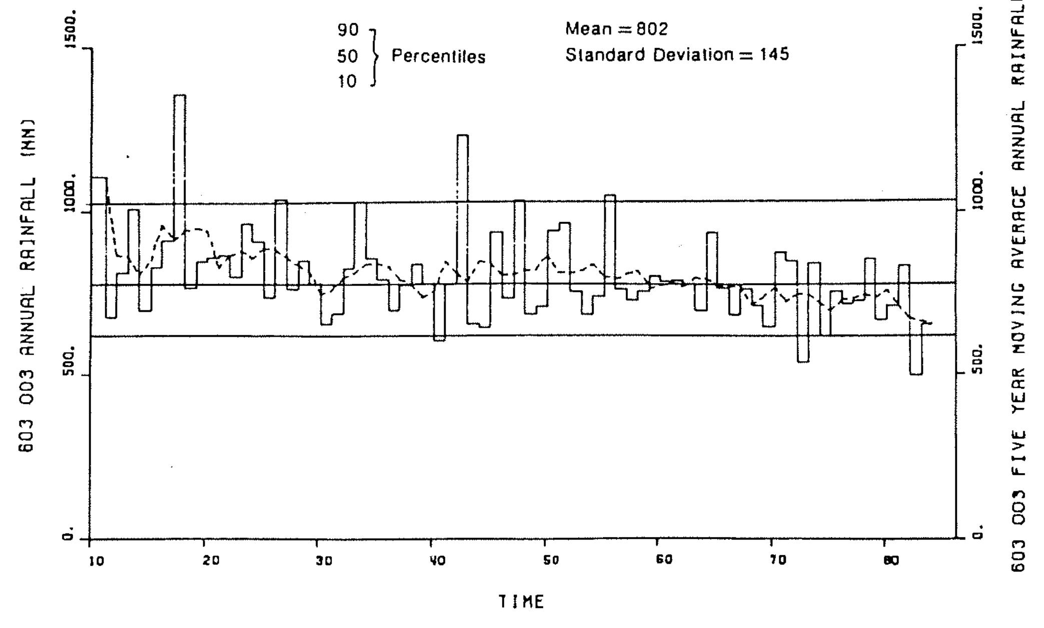

FIGURE 11 KOMBUR CATCHMENT RAINFALL

3.1.6 Discussion and Summary

There is a good coverage of rainfall stations from about 1918 when there were five rainfall stations covering the catchment area. However, the quality of this record is not consistent. During the late 60's and 70's the rainfall coverage improved due to the addition of Public Works Department pluviographs. At present there are eight rainfall stations which cover the Mt Lindesay catchment, with another six operating in the general vicinity.

Catchment rainfalls were produced for Kompup, Lindesay Gorge and Mt Lindesay by the Thiessen method which introduces an areal factor or influence for each station. These catchment rainfalls were compared using the double mass curve technique.

The rainfall analysis indicated a decrease of average annual rainfall of between 9% and 12.5% over the 1910-1939 and 1940-1983 periods. This trend is similar to that reported by Pittock (1983) which indicated a rainfall decrease of about 10% over south western Australia between 1913-1945 and 1946-1978. Pittock attributed this to a probable variation in climate associated with a global warming trend. The decrease of rainfall over the south west was considered to be consistent with the changes in rainfall generation processes associated with global warming.

The evidence for and mechanisms of a continued lower rainfall have not been conclusively established for the south west. However there is enough evidence to warrant caution in using the total rainfall record with the associated higher overall average rainfall. Therefore it was decided to use the statistics of the second half of the record as these might be more likely, on present understanding, to represent future rainfall statistics.

TABLE 3 RAINFALL STATISTICS FOR 009 531 AND 009 591

DENMARK POST OFFICE - 009 531

	1910-1983	1910-1939	1940-1983	% (1)
MEAN	1110	1200	1050	13.5
MAXIMUM	1759	1759	1508	14.3
MINIMUM	788	878	788	11.4
STD. DEV.	193	190	170	10.5
10% P OF NE	863	903	827	8.8
50% P OF NE	1102	1227	1043	16.7
90% P of NE	1360	1397	1280	8.6

PARDELLUP PRISON FARM - 009 591

	1910-1983	1910-1939	1940-1983	% (1)
MEAN	783	828	752	9.7
MAXIMUM	1341	1341	1318	1.7
MINIMUM	449	625	449	39.2
STD. DEV.	156	146	155	5.8
10% P of NE	572	663	548	20.1
50% P of NE	756	797	734	8.3
90% P of NE	984	1032	972	6.1

Notes : (1) Percentage reduction from period 1910-39 to period 1940-83
(2) P of NE = Probability of non-exceedence

TABLE 4 RAINFALL STATISTICS FOR MT LINDESAY CATCHMENT

PERIOD	1910-83	1910-39	1940-83	% (1)
MEAN	887	940	851	10%
MAX	1408	1408	1294	8%
MIN	563	733	563	30%
STD DEV	150	144	144	-
10%	722	752	686	9%
MEDIAN	872	906	841	7%
90%	1097	1112	1040	7%

Note : See note for Table 3

TABLE 5 COMPARISON OF CATCHMENT RAINFALLS FROM THIESSEN METHOD AND ISOHYETAL METHOD

	SIMULATED CATCHMENT MEAN ANNUAL RAINFALLS	ISOHYETAL MAP MEAN RAINFALL	% (1)
MT LINDESAY	887	853	3.8
LINDESAY GORGE	858	823	4.1
KOMPUP	802	765	4.6

Note : See note for Table 3

3.2 Soil Salt Storage and Groundwater

3.2.1 Backgound

Extensive storages of soil salt (in excess of 1000 tonnes per hectare for rainfall less than 600mm per annum) are known to exist in the clay subsoils of the south west (Johnston et al, 1980). Soil salt storage has been shown to vary inversely with rainfall (Figure 14). In higher rainfall areas relatively little salt accumulates in the soil because there is an approximate balance between the input through rainfall and dryfall and the output in streamflow. However, in drier areas, such as the upper Denmark, salt accumulates because there is comparatively little streamflow as the landscape water balance is dominated by evapotranspiration.

Stream water salt loads have been shown (Loh and Stokes, 1981 and Stokes and Loh, 1982) to be predominantly derived from the high salt storage clay sub-soils after clearing. More than 80-90% of yearly salt loads may be from the deeper soils and groundwater.

For the purposes of predicting stream water salinity it is necessary to estimate soil salt storage and groundwater salinities.

3.2.2 Soil Salt Storage

The Denmark River Basin lies to the east of the Manjimup Woodchip Licence Area (MWLA) for which Johnston et al (1980) presented the magnitude and variability of soil salt storage. The rainfalls, evaporation, landscapes and vegetation of the MWLA are similar to those of the Denmark Basin. Therefore the results from the MWLA will be used for comparison with soil salt storage results from the Denmark.

In 1980 a small soil salt storage, groundwater level and salinity investigation was carried out in and near the Denmark River basin upstream of the gauging station at Kompup (see Figure 12). A total of 19 cores were obtained at 5 sites and soil salt and water storages determined. The site averages of soil solute storage are listed in Table 6 and the average total soil salt storage (kg m^{-3}) and concentration (mg l^{-1}) are shown plotted against the rainfall for the site in Figures 13 and 14. The site averaged results from the MWLA are also shown for comparison.

Considerable variations of salt storages were found between cores at the same site over distances of a few hundred metres. This is also a feature noted by Johnston et al (1980). Site averages are a more useful measure of the variation of soil salt across a region.

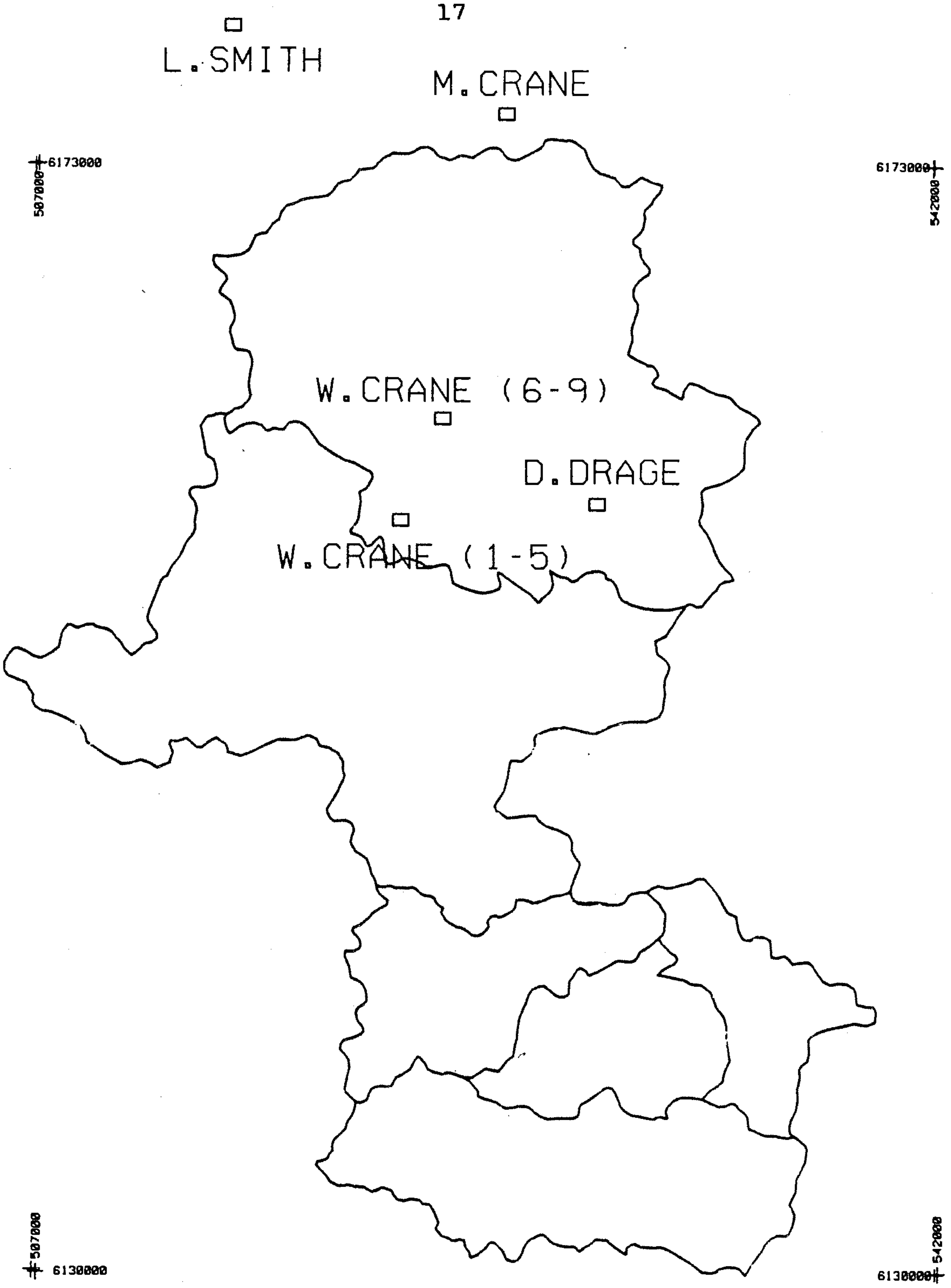

FIGURE 12 BORE LOCATION MAP

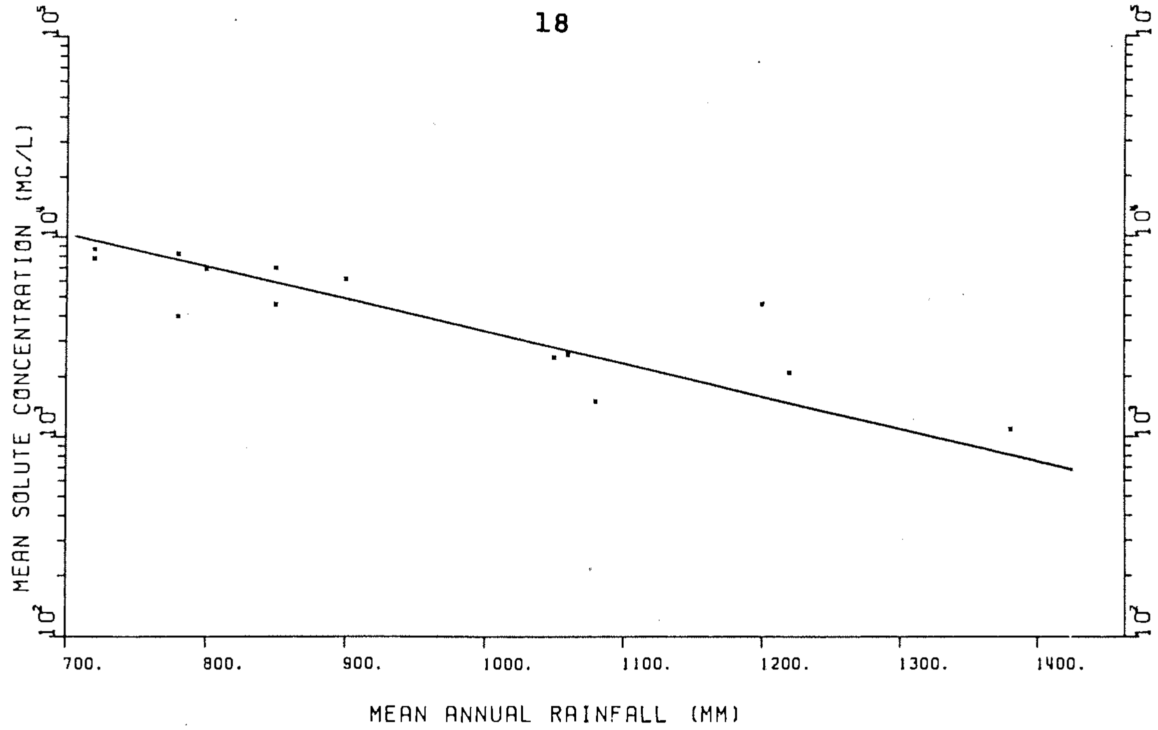

FIGURE 13 RELATIONSHIP BETWEEN SALT STORED IN THE SOIL PROFILE AND ESTIMATED ANNUAL RAINFALL

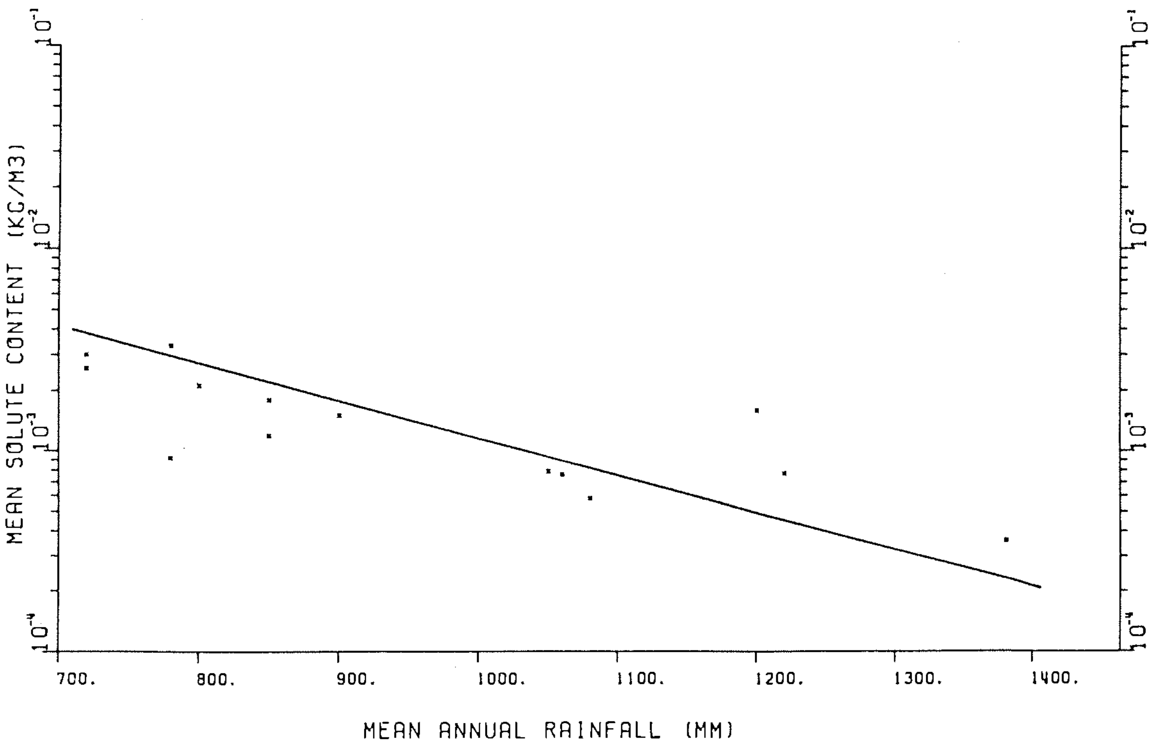

FIGURE 14 RELATIONSHIP BETWEEN AVERAGE SALT CONTENT IN THE SOIL PROFILE AND ESTIMATED ANNUAL RAINFALL

Logarithmic regressions of soil salt content (T; kg m^{-3}) and concentration (C; mg l^{-1}) against average rainfall (R; mm) fitted to the data with the results:-

$\log T = 1.12 - 0.001R, \quad r^2 = 0.61$

$\log C = 4.74 - .0012R, \quad r^2 = 0.72$

In general the data from the Denmark area is consistent with that from the more extensive study in the MWLA. Therefore it is possible to be more confident in selecting representative soil salt storages for all rainfall zones across the Denmark from the MWLA data augmented with the more limited Denmark data. This is particularly the case for areas with rainfalls above 800 mm for which there is no data in the Denmark region.

TABLE 6 SOLUTE STORAGE, AVERAGE SOLUTE AND AVERAGE SOLUTE CONCENTRATIONS IN SOIL

RAINFALL (mm)	BOREHOLE NEST	NUMBER OF PROFILES	AVERAGE PROFILE DEPTH (m)	AVERAGE SOLUTE CONTENT (kg/m^3)	AVERGE SOLUTE STORAGE (kgm^{-2})	AVERAGE SOLUTE CONCENTRATION (mgl^{-1})
720	LSMITH	5	17.7	3.00	57.2	8670
720	MCRANE	3	14.2	2.57	39.2	7800
780	DRAGE	3	19.4	0.92	16.9	3966
780	WCRANE6-9	4	16.0	3.30	54.8	8198
800	WCRANE1-4	4	20.1	2.10	42.8	6864

NOTE. Profile averaged over borehold group

3.2.3 Stream Baseflow Salinities

Stream baseflow salinities, particularly from late spring into summer, are likely to be good indications of groundwater salinities. This is because the deeper, more saline groundwater systems are the predominant component of streamflow in the late part of the flow season when surface runoff and flow from the shallow, fresher groundwaters have decreased or ceased (Stokes and Loh, 1982).

To investigate magnitudes and trends in baseflow salinities as a result of clearing, the record of flow and salinity at the Clear Hills (603 173) and its replacement Kompup (603 003) gauging stations were used. Plots of salinity and flow through time and of salinity against flow were produced for each year since 1962. From these plots approximate asymptotic salinities towards the end of the flow season were estimated.

The result of this analysis is shown in Figure 15 where the base flow salinity is plotted through time. A logarithmic concentration (S; mg L^{-1}) versus linear time (t; years starting at 1) was fitted:-

$$\log S = 3.11 + 0.04t \text{ with } r^2 = 0.875$$

This relationship and the 90% confidence limits are shown in Figure 15. The rate of increase of baseflow salinity has accelerated substantially at Kompup since the early 1960's when the yearly increase was of the order 120 mg L^{-1}. By the 1980's this had increased to be in excess of 400 mg L^{-1}. However, it is expected that the baseflow salinity will eventually stabilize at around the soil salt storage concentration.

3.2.4 Groundwaters

The level of groundwaters in relation to valley inverts will partly determine the delay time between clearing and the development of soil salinisation and the discharge of groundwaters to streams. Groundwater hydraulic gradients will also determine the rate at which groundwater discharge will increase relative to recharge to groundwater (the output to input ratio). It might be expected for example that more incised streams, in steeper terrain would develop groundwaters which respond in a shorter time span.

Loh and Stokes (1981) reported depths to groundwater of more than 10m for areas of less than 800 mm annual rainfall on the Collie catchment. Rates of groundwater rise in this rainfall zone have been found to be about 0.8 m yr^{-1} (Peck 1983). Therefore the delay between clearing and groundwater discharge would be (10/0.8) 12 years.

The topography of parts of the upper Denmark appear to be somewhat more incised, steeper and the valleys less broad than for similar rainfall zones on the Collie. Three hillslope sections from the Denmark region depicting slopes and groundwater levels for an incised, a less incised and an upland area are shown in Figures 16, 17 and 18.

Although there has been very recent or partial clearing on all three transects it is likely that the groundwater levels are representative of forested areas in the Denmark region. Groundwater levels in the valleys are expected to be less than 5m below the invert and in some instances to be above the level of the invert potentiometrically. Therefore in this region groundwaters probably respond relatively quickly to clearing and contribute to streamflow well within 15 years.

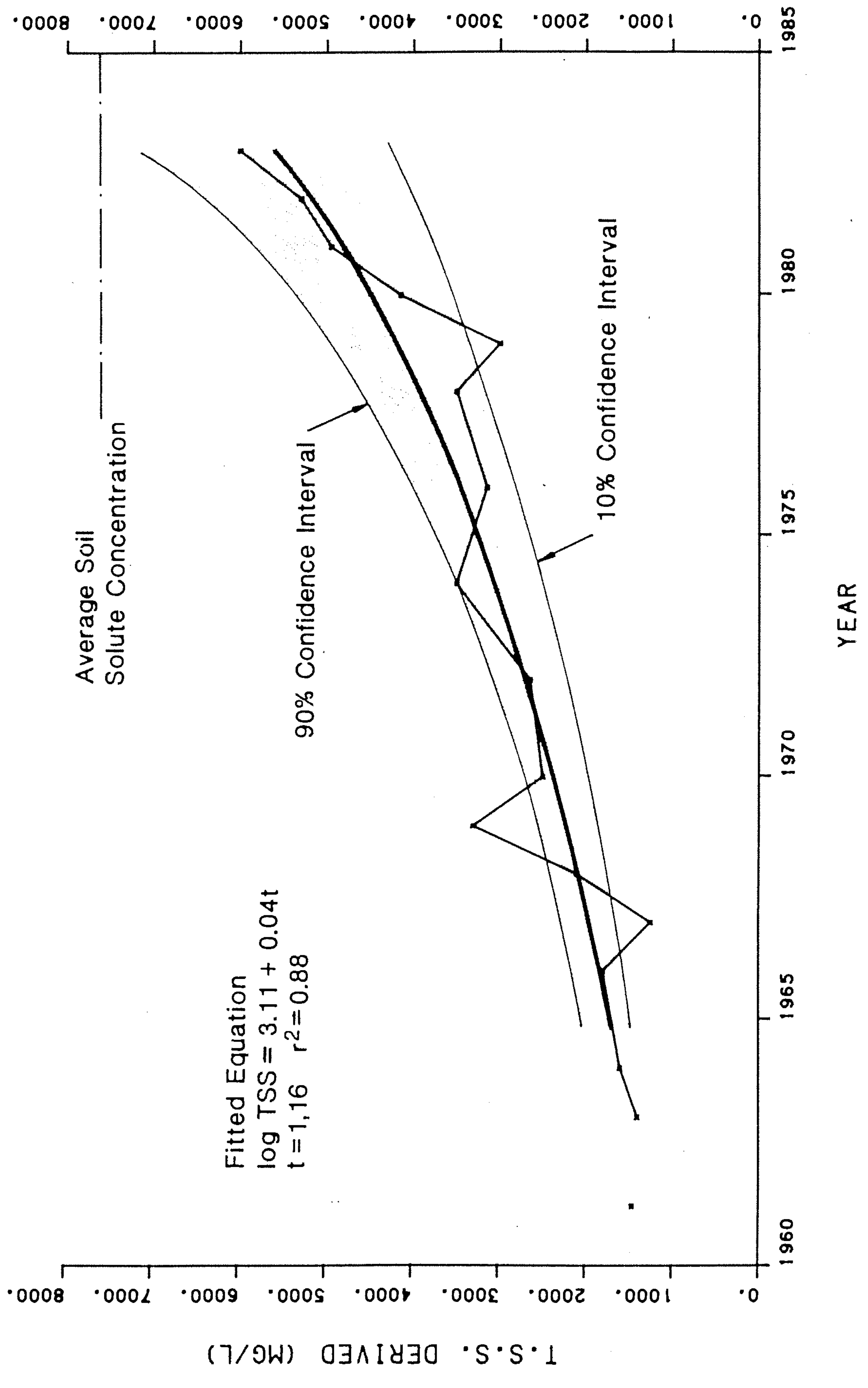

FIGURE 15   RELATIONSHIP BETWEEN BASEFLOW SALINITY AND TIME

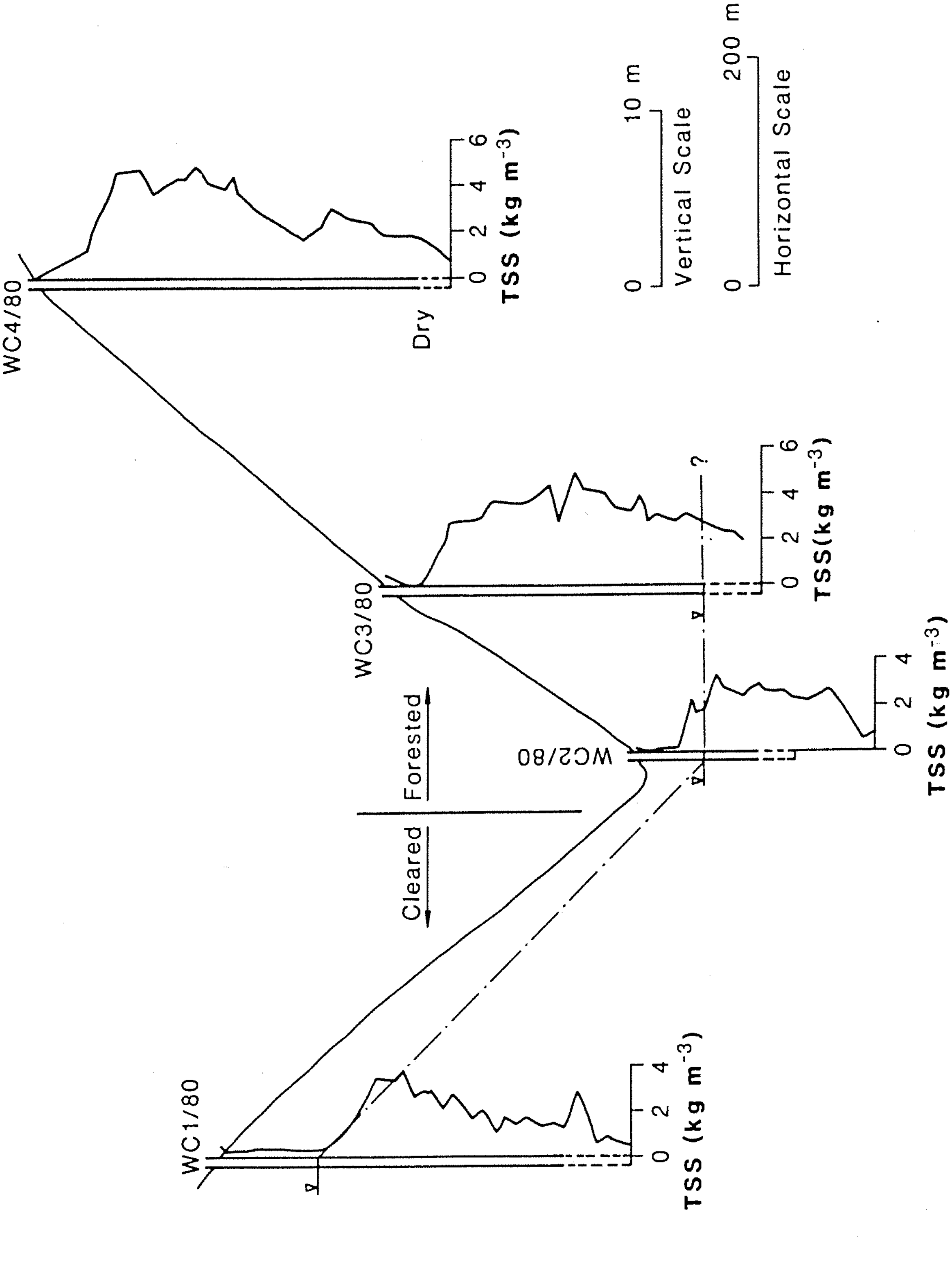

FIGURE 16 INCISED HILLSLOPE BORE TRANSECT

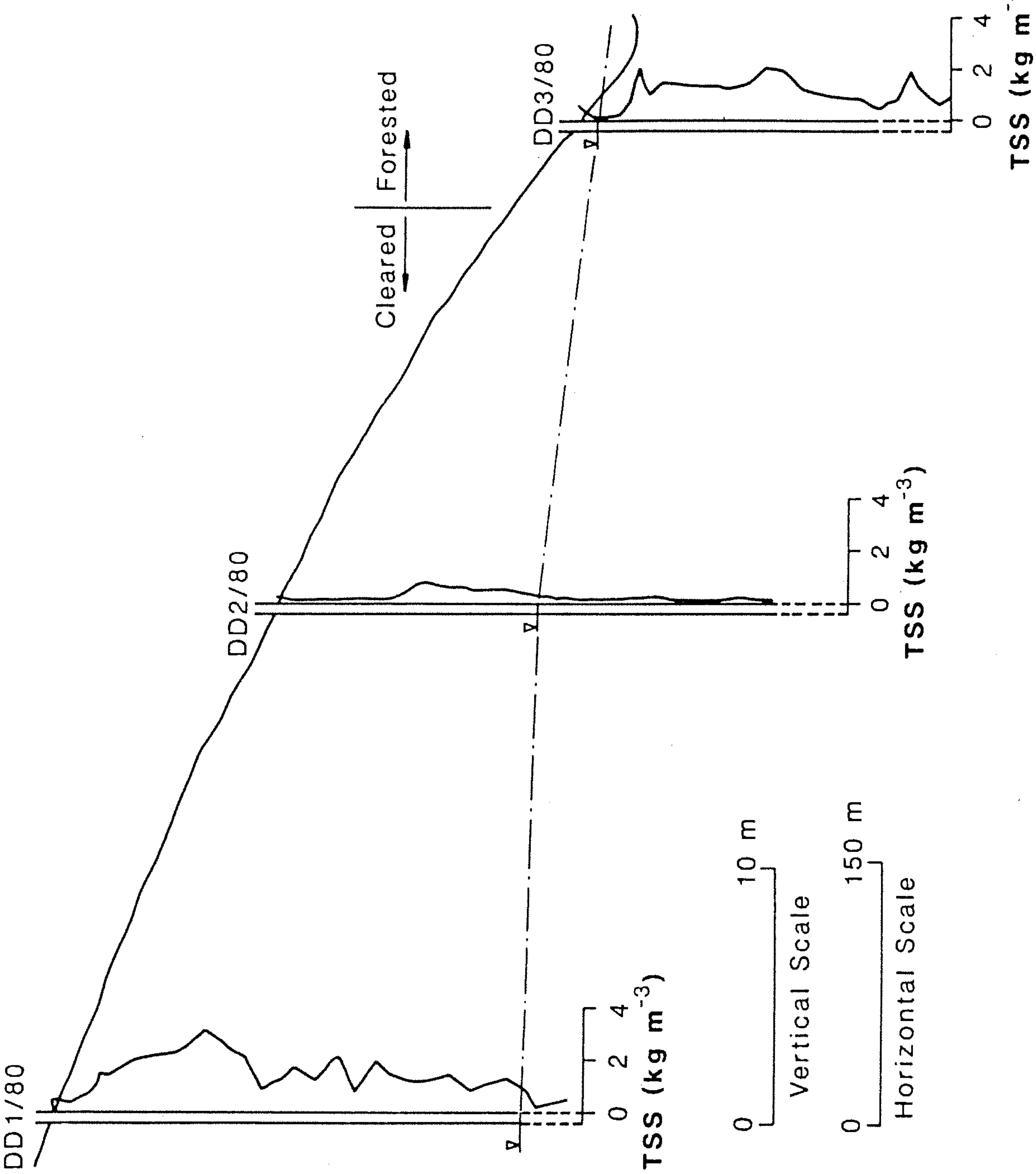

FIGURE 17 LESS INCISED MIDSLOPE BORE TRANSECT

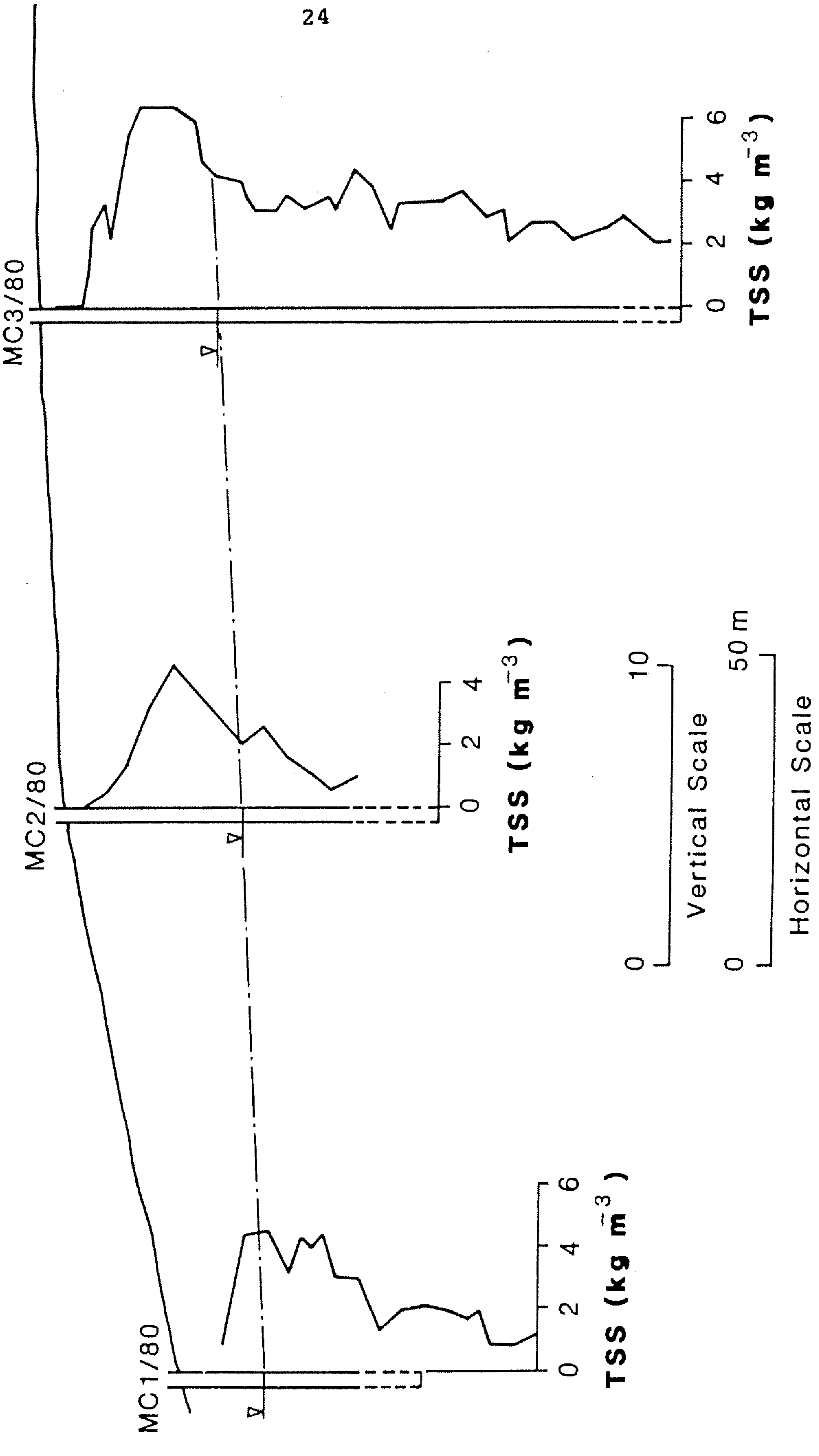

FIGURE 18 UPLAND AREA BORE TRANSECT

3.3 Streamflow

3.3.1 Availability of Data

The Denmark River Basin has had 8 gauging stations in operation for varying periods of time since 1940; a table of the gauging stations is shown in Table 7 and a summary of the period of operation is depicted in Figure 19, and the location of these stations is shown in Figures 20a and b. Currently 4 gauging stations are operating in the Denmark River Basin. These are Mt. Lindesay (603 136), Kompup (603 003), Lindesay Gorge (603 002) and Yate Flat (603 190).

3.3.2 Water Yield

The annual streamflow volumes for Mt Lindesay, Lindesay Gorge, Kompup and Yate Flat catchments are shown in Figures 21 and 22. These diagrams highlight the increasing variability of the streamflow in the latter years of record, with the maximum and minimum flows occuring in the last 7 years. Over the period 1973 to 1983 (11 years) the average percentage of the streamflow from the Kompup catchment was 37%, while for the area between Lindesay Gorge and Kompup the percentage was 34%. For the area between Mt Lindesay and Lindesay Gorge the percentage was 29%. These percentages vary considerably from year to year. The very high flows of 1978 were mostly from the Lindesay Gorge to Kompup catchment, while the low flows of 1982 and 1983 were substantially from the Mt Lindesay to Lindesay Gorge catchment and the Kompup catchment respectively. Overall the distribution of streamflow contributions from the catchments detailed is not constant. This highlights the spatial variability of rainfall over a relatively large catchment and the varying responses of different catchment vegetation, landuse, topography and soil zones.

The Kompup catchment and the Yate Flat sub-catchment streamflow volumes are shown in Figure 22. Over the period when the two sub-catchment gauging stations were operating the mean percentage contributions were 17% and 9% respectively for the Perillup Brook and Yate Flat sub-catchments. During the low flow years of 1969 and 1972 the Perillup Brook sub-catchment had negligible streamflow whilst the Yate Flat Catchment contributed greater than 70% in both years.

Figure 23 illustrates the contribution of each of the sub-catchments, which have had streamflow volumes recorded, against the corresponding streamflow for Kompup. This figure highlights the close correlation (r^2 = .86) between the Kompup and Clear Hills catchments.

TABLE 7 DENMARK RIVER BASINS GAUGING STATIONS

NUMBER	NAME	AREA (km^2)	PERIOD OF RECORD	MEDIAN RUNOFF (mm)	PERCENT CLEARED 1984 (%)
603 014	DENMARK RIVER AT PIPEHEAD DAMSITE	567	1940-60	63.1	18.5
603 136	DENMARK RIVER MOUNT LINDESAY	525	1960-84	47.8	18.1
603 002	DENMARK RIVER LINDESAY GORGE	466	1973-84	38.6	18.0
603 003	DENMARK RIVER KOMPUP	235	1972-84	43.8	34.2
603 173	DENMARK RIVER CLEAR HILLS	225	1962-78	45.3	34.2
603 172	AMURI CREEK AMARILLUP SWAMP	18.9	1962-77	86.2	NA
603 177	PERILLUP BROOK	65.6	1962-73	45.3	13.6
603 190	YATE FLAT CREEK WOONANUP	56.7	1963-84	63.1	60.8

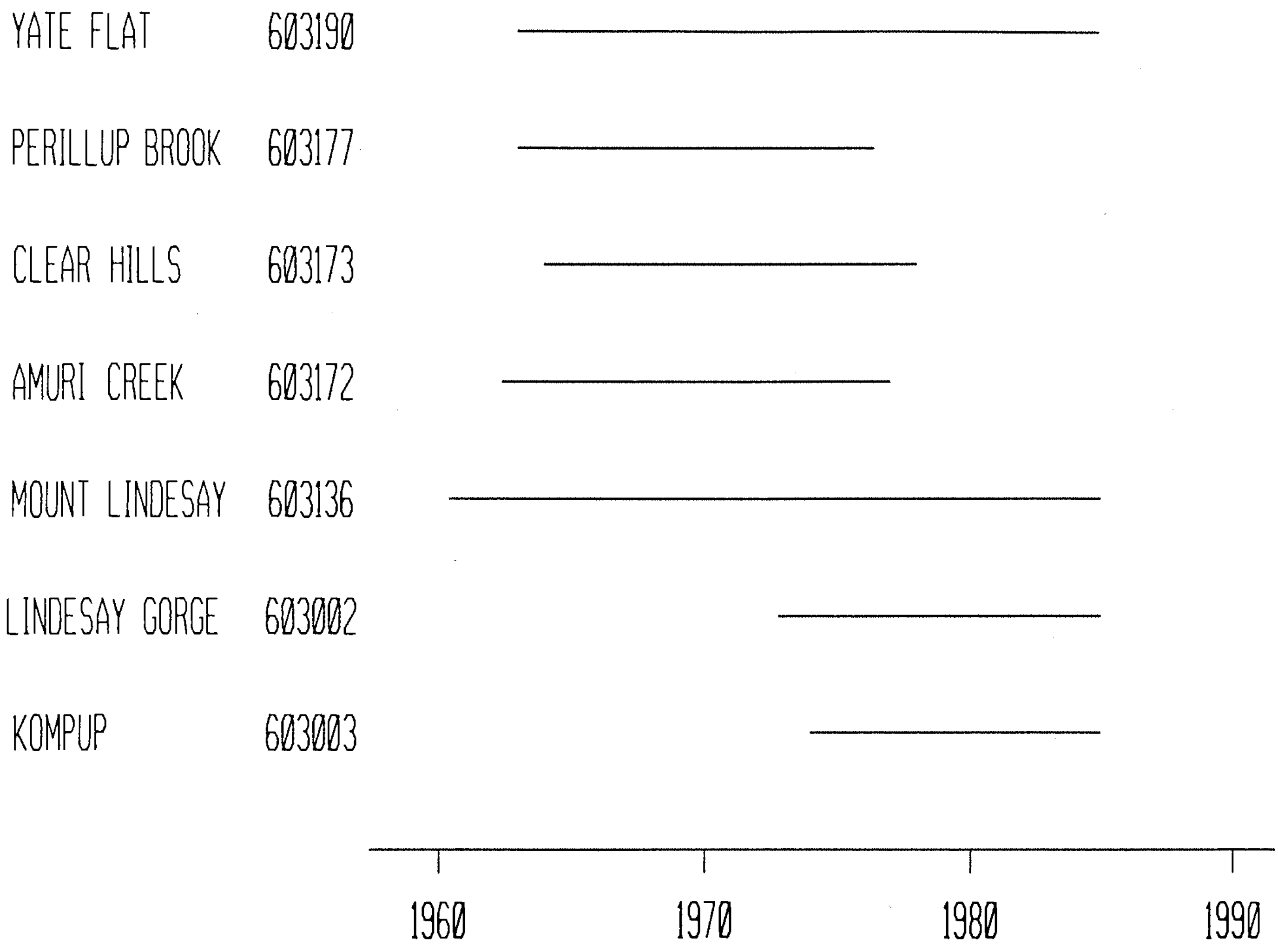

FIGURE 19 STREAMFLOW RECORD AVAILABILITY

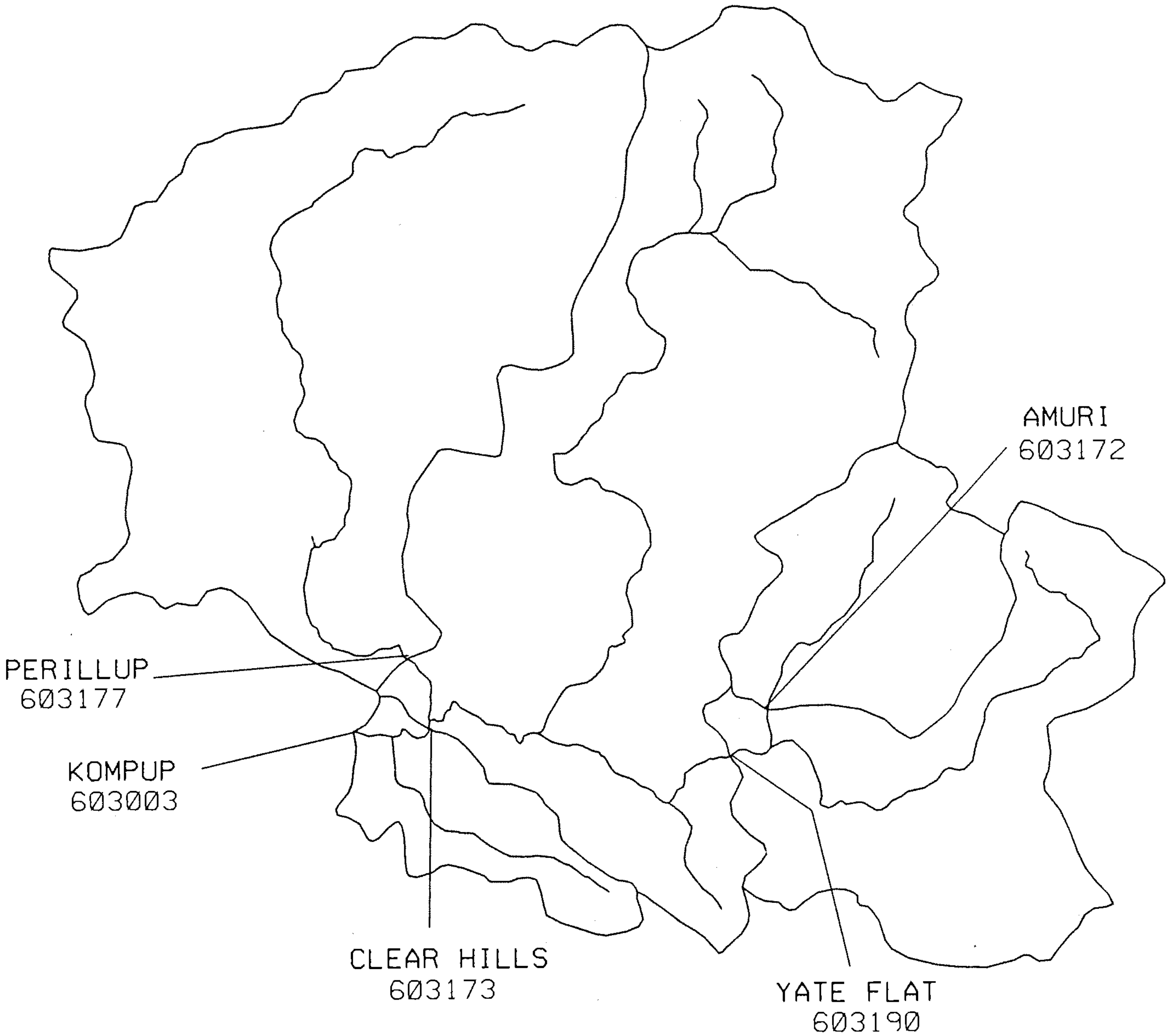

FIGURE 2Ø a STREAMFLOW GAUGING STATION - KOMPUP CATCHMENT

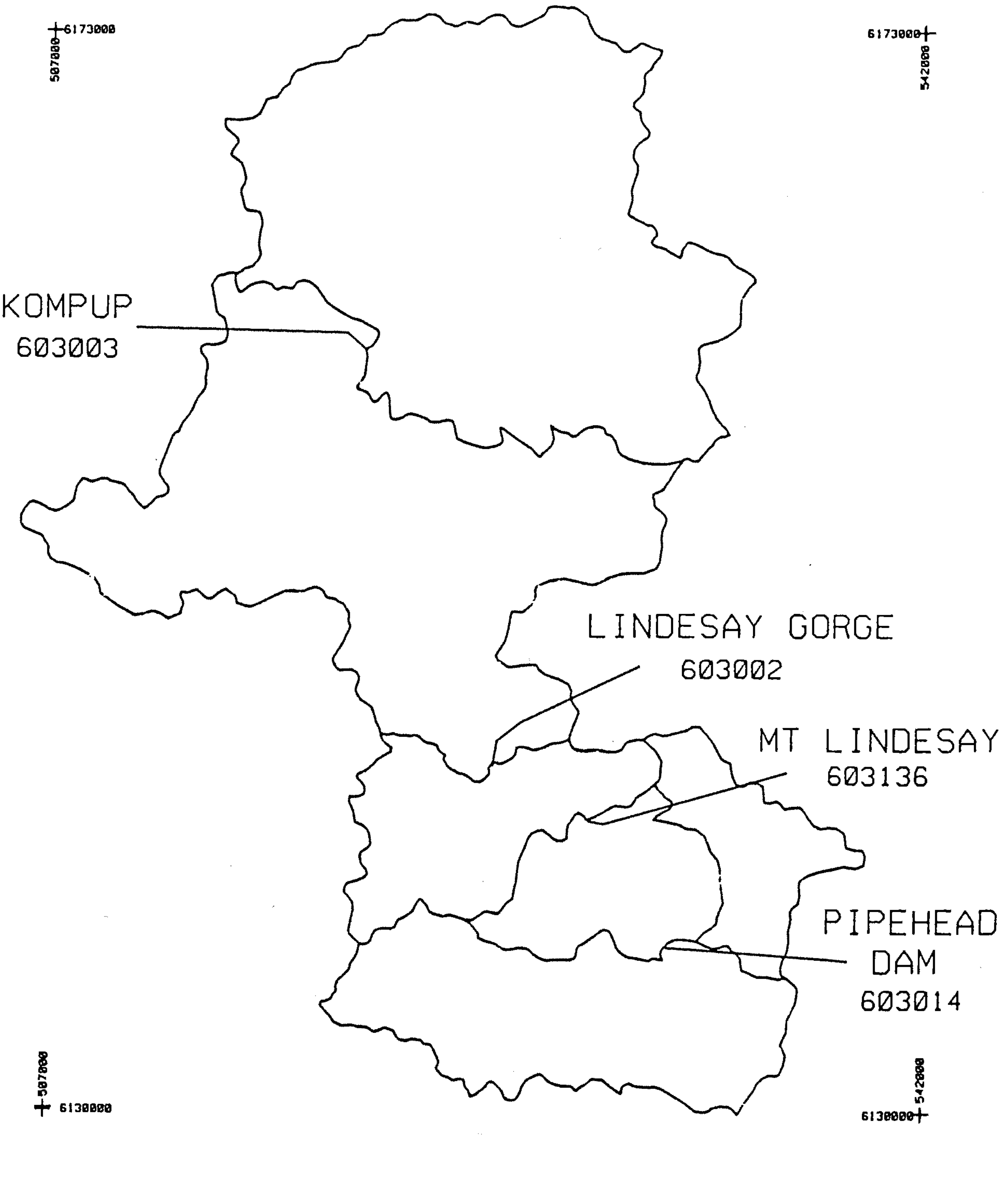

FIGURE 20 b DENMARK RIVER
STREAMFLOW GAUGING STATIONS

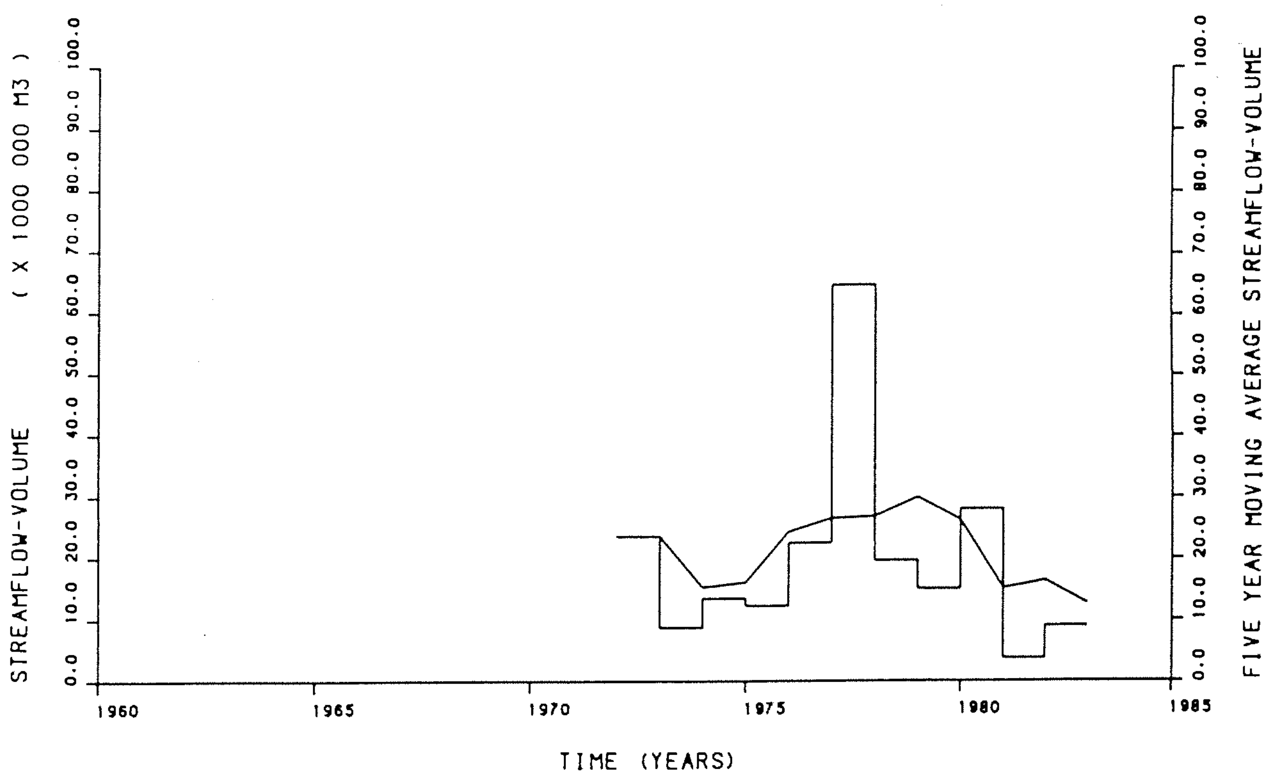

FIGURE 21 a LINDESAY GORGE ANNUAL STREAMFLOW

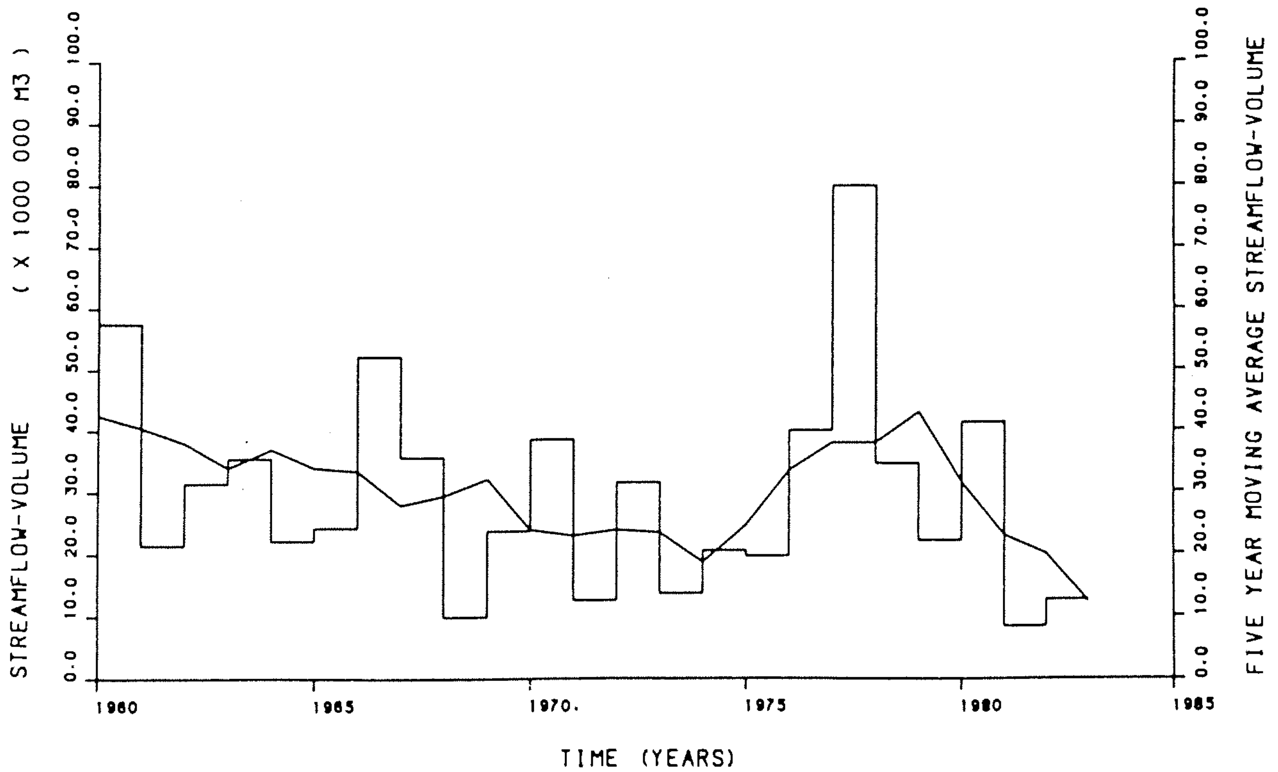

FIGURE 21 b MOUNT LINDESAY ANNUAL STREAMFLOW

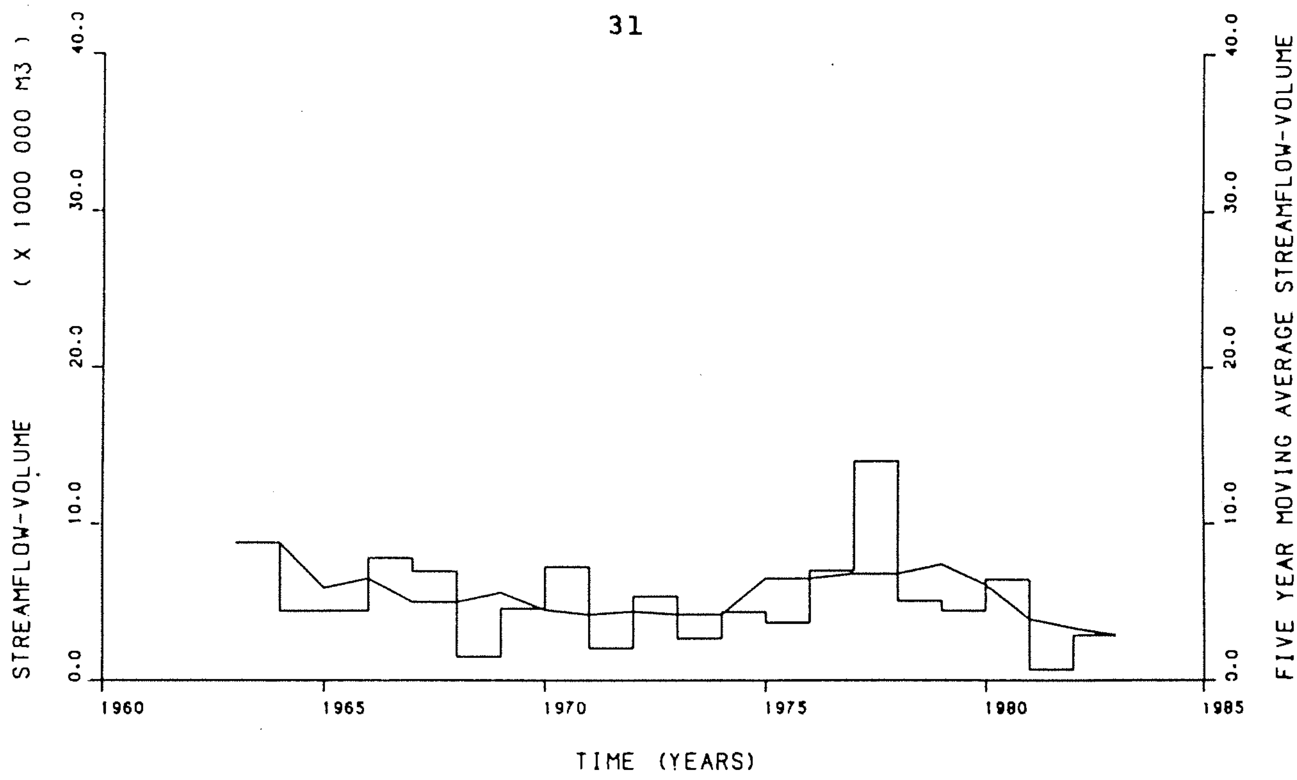

FIGURE 22 a YATE FLAT ANNUAL STREAMFLOW

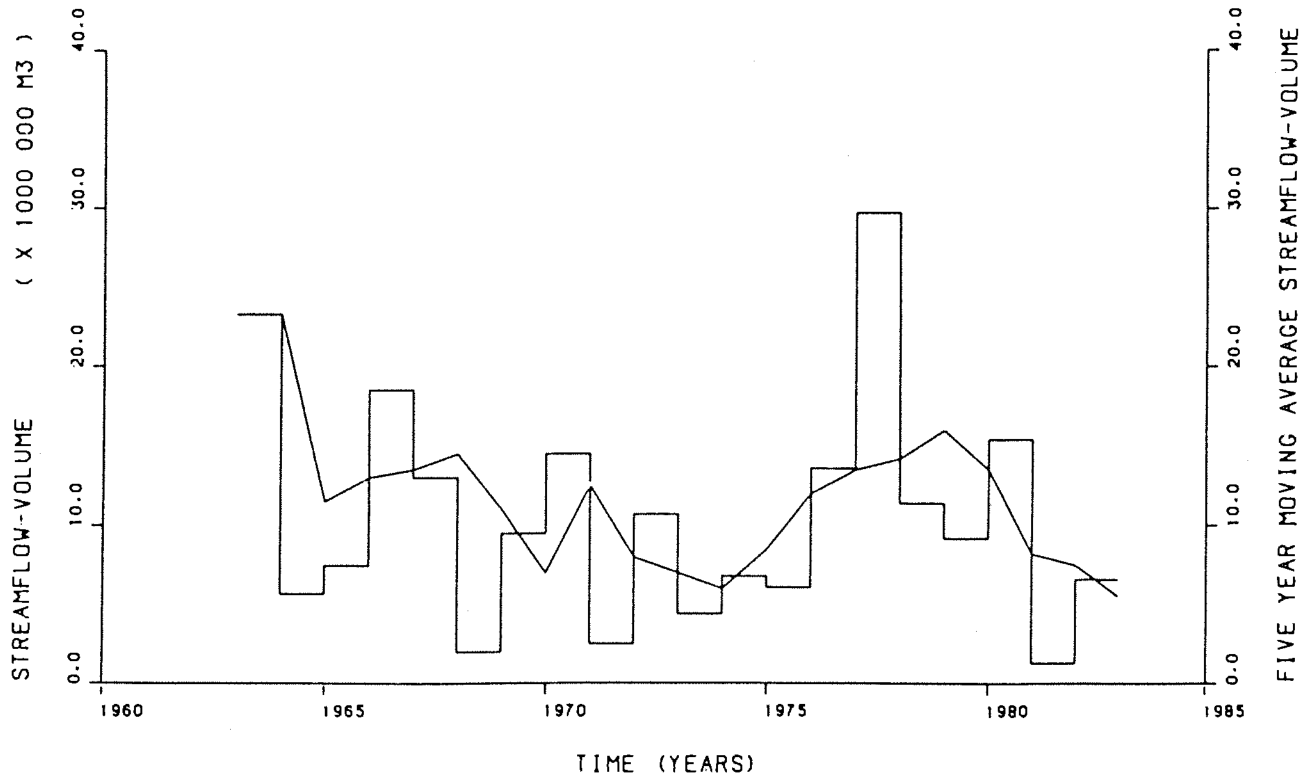

FIGURE 22 b KOMPUP ANNUAL STREAMFLOW

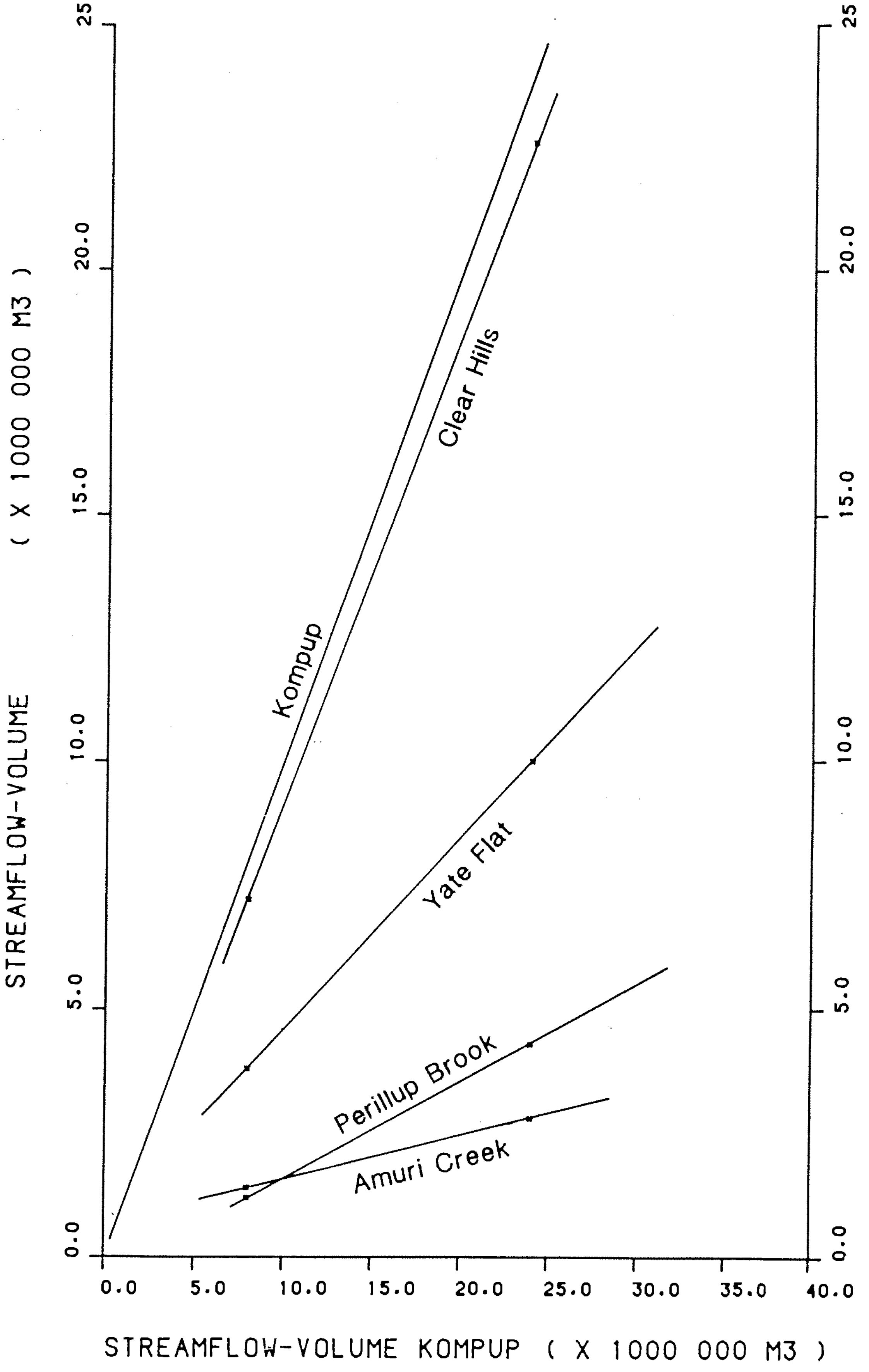

FIGURE 23 STREAMFLOW - SUB-CATCHMENTS VERSUS KOMPUP CATCHMENT

Figure 24 shows the relationship between rainfall and runoff for the Mt Lindesay catchment. This diagram emphasises the scatter in the relationship between annual streamflow and annual rainfall, particularly in a catchment of area greater than 500 km^2. In particular, the 1978 runoff is very high for the amount of rainfall which fell during the year.

Figure 25 depicts the ranking of the streamflows recorded from Mt Lindesay over the period 1940-1983. The streamflow shows a typical positive skewness which indicates an approximate log-normal probability distribution. Another point of note is the five major flows are substantially above the remaining flows and there is an apparent discontinuity at this point between the streamflows. However these is some uncertainty over the 1940-1960 figures as they were transposed from the Denmark River pipehead dam to Mt Lindesay, particularly with medium to high flows, and were based on a daily stage reading.

3.3.3 Forested Catchment Runoff

In the low rainfall areas (less than 900 mm annual rainfall) under forested conditions, 90-95% of the streamflow occurs in the wet months of April to October. This streamflow is generated primarily from the ephemeral aquifer which develops seasonally in the shallow soils close to the streamline above the pallid clay zone. In these low rainfall areas the evapotranspiration is high and nearly all water which infiltrates into the subsoil is returned to the atmosphere through transpiration by the deep-rooted native forests. The deeper groundwaters are generally localised and occur more than 5m below the valley inverts and therefore do not discharge to the stream system. The absence of groundwater inflow normally results in streams of this area ceasing to flow 1-2 months prior to the higher rainfall streams.

Generally the streamflows are small, this is confirmed in Table 8, where the streamflow for Lindesay Gorge averages only 4.8% of the annual rainfall. There is also generally large variability in the streamflow, which is substantiated in Table 8 where the Lindesay Gorge - Kompup Catchment has the largest coefficient of variation for both runoff and the runoff to rainfall ratio.

The 900-1100 mm rainfall zone represents a transition between the high and low rainfall regions. Streams within this zone have variable hydrological characteristics which depend on whether the groundwater system contributes to the surface hydrology (Department of Conservation and Environment, 1980). Local topography, hydrogeology and rainfall characteristics contribute to these differences.

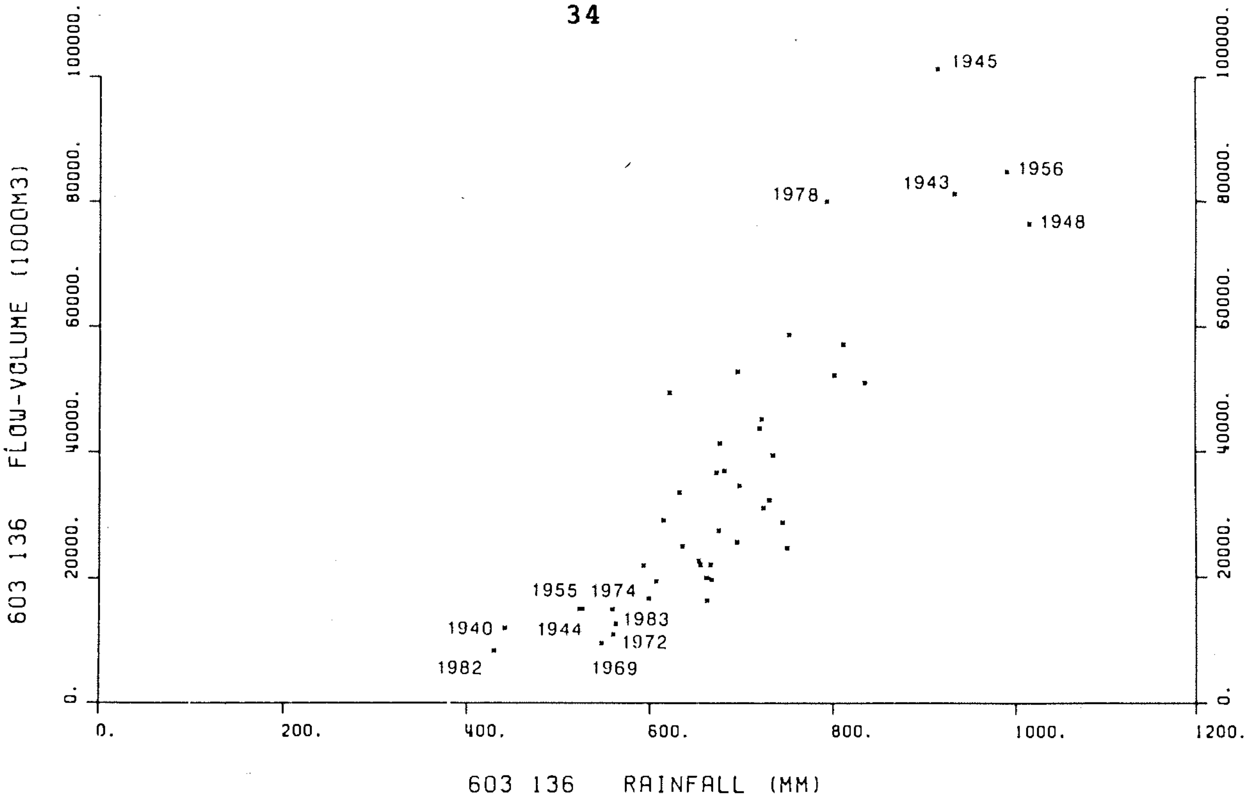

FIGURE 24 FLOW VERSUS RAINFALL FOR MOUNT LINDESAY 1940-1983

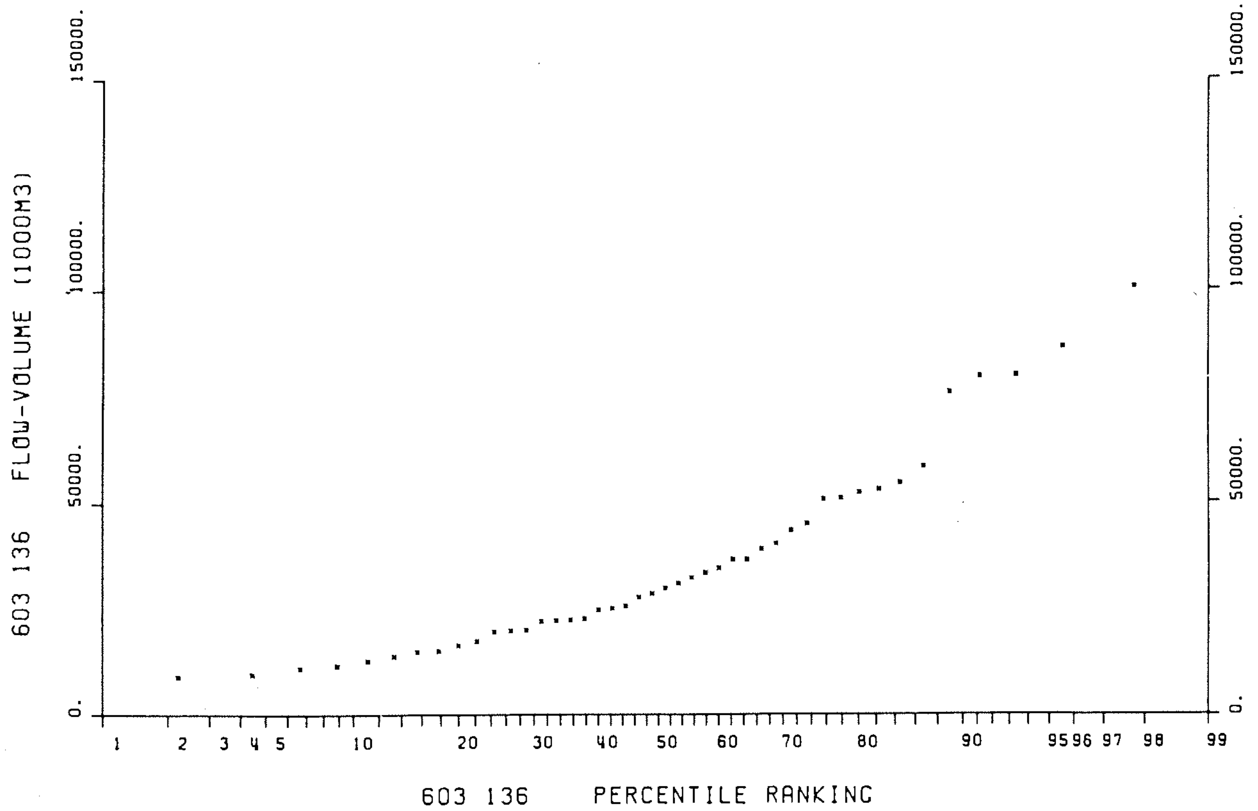

FIGURE 25 PERCENTILE RANKING OF MOUNT LINDESAY FLOW 1940-1983

TABLE 8 RUNOFF AND OUTPUT/INPUT PERCENTAGE STATISTICS FOR THE PERIOD 1975-1983

	YATE FLAT 60% Cleared		KOMPUP 30% Cleared		LINDESAY GORGE - KOMPUP 1.5% Cleared		MT LINDESAY - LINDESAY GORGE 19.7% Cleared	
YEAR	RUNOFF mm	O/I %	RUNOFF mm	O/I %	RUNOFF mm	O/I %	RUNOFF mm	O/I %
1975	75	11.3	31	3.2	28	3.1	117	10.7
1976	63	8.0	28	3.6	27	3.2	114	10.2
1977	123	18.4	59	8.8	56	5.8	220	17.0
1978	235	27.7	136	16.0	144	13.9	244	18.5
1797	91	12.7	49	6.8	37	4.6	242	21.8
1980	79	11.2	39	5.5	25	2.9	124	12.6
1981	115	17.1	66	9.8	56	6.4	202	17.5
1982	12	2.0	6	1.0	11	2.0	85	11.2
1983	54	8.2	28	4.3	10	1.4	64	7.3
MEAN	94	13.0	49	6.6	44	4.8	157	14.1
STD DEV	62	7.4	37	4.5	36	3.8	70	4.7
C of V	.66	.57	.76	.68	.82	.79	.44	.33

The Mt Lindesay - Lindesay Gorge catchment, which is within the 900-1000 rainfall zone, has the largest mean runoff and mean runoff to rainfall ratio and has the lowest coefficient of variation of the catchments (Table 8).

Both the Lindesay Gorge - Kompup and Mt Lindesay - Lindesay Gorge catchments have a significant amount of granite outcrops, including the granite massif, Mt Lindesay. These outcrops are considered to contribute relatively high runoff compared to the forested areas adjacent. Therefore both catchments are expected to have larger streamflow to rainfall ratios than comparable forested catchments in the same rainfall zone.

3.3.4 Cleared Catchment Runoff

The major reasons put forward for the increase in runoff after a land use change from natural forest to cleared land for agriculture is the reduction in evapotranspiration between a mature forest and pasture. Experience from the Collie catchment suggests that much of the increase in flow has been generated from precipitation on, and drainage from, much larger areas of saturated shallow soils extending upslope from the streamline.

An indication of the change in catchment response from a land use change can be seen by comparing the streamflow to rainfall ratio from the Yate Flat catchment to that of the Perillup catchment over the period 1963 to 1973 by a double mass curve (Figure 26). This change in the gradient of the double mass curve indicates that the contribution from the Yate Flat catchment increased 100% relative to the Perillup Brook catchment. Over this period the area cleared for the Perillup

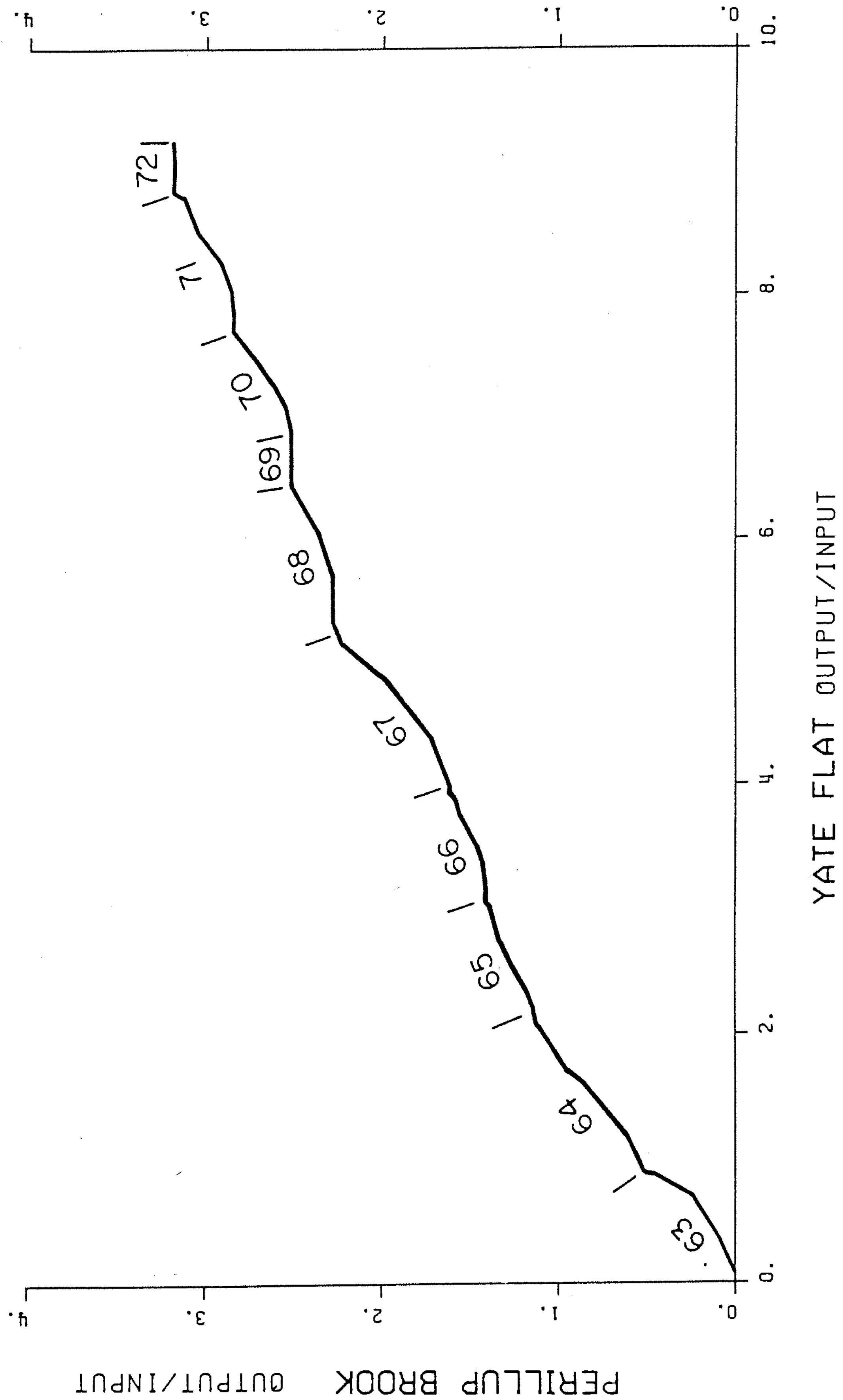

FIGURE 26 DOUBLE MASS CURVE - PERILLUP BROOK VERSUS YATE FLAT OUTPUT/INPUT

Brook catchment remained relatively constant while the Yate Flat clearing increased from 50% to 57% cleared over the same period, an increase of 4 km^2. The location of this clearing is primarily in two areas. The first area is located along the main streamline adjacent to the gauging station, while the second area is located adjacent to a secondary streamline. Both these locations when cleared, would affect the streamflow response considerably.

From Table 8 the mean runoff to rainfall ratio for the Yate Flat catchment is higher than for every other catchment except the Mt Lindesay - Lindesay Gorge catchment. This is considered to be due to the high percentage of land cleared on the Yate Flat catchment as compared to the other catchments.

Figure 23, mentioned previously in section 3.3.2, highlights the differences between the contribution of Yate Flat (60% cleared) and Perillup Brook (14% cleared).

3.3.5 Discussion and Summary

The streamflow records for the Denmark River Basin commenced in 1940, but it is only since 1960 that good quality record commenced with that of the Mt Lindesay gauging station. There are now four gauging stations at; Mt Lindesay, Lindesay Gorge, Kompup and Yate Flat.

The streamflow record of the gauging stations shown on figures 21 and 22, shows no apparent trend with time. This may be due to the decreasing trend in rainfall counteracting any increasing trend due to change in land use. If the record is partitioned and the period 1960 to 1974 analysed, the five year moving average shows a definite trend of reducing stream flow, although the relatively high flows of 1977 to 1979 counteract this apparent trend.

The comparison of the catchments within the Kompup catchment highlights the additional streamflow generated after the change in land use from forest to agriculture. The Yate Flat catchment (60% cleared) produces approximately 130% of the streamflow volume of Perillup Brook (14% cleared) where both catchments have approximately the same area.

The plot of runoff versus rainfall for the Mt Lindesay catchment highlights the variability in annual data and the position of the 1978 runoff as an extreme event for the rainfall recorded. The ranking of the annual streamflows emphasises the approximate log-normal distribution of the runoff and the discontinuity between the extreme events and the data below the 90% probability of non-exceedence.

The effect of land use change is shown in the double mass curve of Perillup Brook versus Yate Flat catchment. Over the period 1963 to 1973, as the percentage of land cleared in Yate Flat increased, whilst that of Perillup remained relatively constant there was a 100% increase in the ratio of Yate Flat to Perillup streamflow volume.

Generally the data detailed in the previous sections on streamflow has identified definite differences between forested and predominantly cleared catchments.

3.4 Stream Salt Yield and Salinity

3.4.1 Aim

The aim of this section is to determine the magnitude and variability of stream salt loads across the catchment and to develop water and salt load relationships for use in the streamflow and salt load simulation described in section 4.

3.4.2 Availability of Data

At each of the gauging stations which operated in the Denmark River Basin water quality analysis were carried out. In addition three sub-catchments had water quality samples taken. These were Upper Denmark (603 1028), West Tributary (603 1026), and East Tributary (603 1027). Prior to 1978 between 10 to 30 water quality samples were taken at each gauging station per year. Since 1979 both Kompup and Mt Lindesay catchments have increased to approximately daily water quality samples. A summary of the water quality data available in the Denmark River basin is shown in Appendix C.

3.4.3 Salt Load Calculation Method

As the water quality at any site varies with the magnitude of the flow and the time in the season, the arithmetic mean of the samples taken at regular intervals during a year would not necessarily represent the average salinity of the total flow for that year. The two main methods to calculate the salt load are the flow weighted salinity and the daily integration method.

The flow weighted salinity concentration is defined as:

$$S_{FW} = \frac{SiQi}{Qi}; \; i = 1,n \qquad 3.1$$

where

S_i is the concentration of an individual sample

Q_i is the instantaneous flow rate at the time of sampling

n is the number of samples

This flow weighted salinity is then multiplied by the total flow volume to arrive at the total salt load. This method only gives an approximate salt load since the salinities are not related to any time scale and all of the samples may have been taken in high flows or at a particular time of the year, thereby giving a biased result.

For streams which have significant variations in salinity, large numbers of samples are necessary to produce accurate estimates of annual flow-weighted salinity (Barrett and Loh, 1982). When the sample frequency is high enough to define water quality changes with changes in discharge it is possible to calculate salt loads by integrating the mass flux of salt through time (as is done with water discharge). This was done for the 1979-1983 Kompup data and the 1978-1983 Mt Lindesay data and compared with the flow-weighted method. The results differed by only a few percent and so either method produced adequate results when the sampling frequency is at least daily for these two sites.

3.4.4 Results

The annual salinity and annual salt load results are shown for the Kompup, Mt Lindesay catchments and the Mt Lindesay-Kompup sub-catchment in Table 9. The results indicate that 72% of the salt load recorded at Mt Lindesay is from the Kompup catchment, even though the catchment area for Kompup is only 45% of the total catchment, and the flow from Kompup contributes 37% of the total streamflow.

Figure 27 shows the relationship between the salt load (T.S.S. tonnes) and the flow volumes for the three catchments. The Kompup catchment has a higher salt load than the Mt Lindesay - Kompup catchment for the same flow - volume. From the gradient lines on the plot the Mt Lindesay - Kompup salinities are within the 250 to 500 mg L^{-1} TSS range while the Kompup salinities range from 900 to 4000 mg L^{-1} TSS.

From the diagram of salinity concentration versus streamflow (Figure 28), the salinities for Mt Lindesay - Kompup show an increase with decreasing streamflow although the variation is not significant. For the Kompup catchment there is a large increase of salinity with decreasing streamflow. The relationship for concentration against streamflow could be approximated by an inverse function or a negative exponential.

Two catchments which are approximately in a forested condition are Perillup Brook and Kompup to Mt Lindesay. The annual salinities for these two catchments were plotted against runoff in Figure 29. Overlaid on this plot are the Collie relationships between concentration and flow derived from Loh and Stokes (1981). The Perillup data is consistently higher than the 700-800 zone from the Collie data primarily due to the Perillup catchment having approximately 14% cleared. The Kompup to Mt Lindesay data is consistently within the 800-900 and 900-1000 rainfall zone relations.

TABLE 9 WATER AND SALT YIELDS

	KOMPUP			MT LINDESAY			MT LINDESAY - KOMPUP		
WATER YEAR	FLOW ($10^6 m^3$)	LOAD (t)	CONC. (mg/L)	FLOW ($10^6 m^3$)	LOAD (t)	CONC. (mg/L)	FLOW ($10^6 m^3$)	LOAD (t)	CONC. (mg/L)
1978/79				79.9	24257	304	47.9		
1979/80	11.4	12350	1081	34.1	19120	560	22.7	6770	298
1980/81	9.16	11186	1221	22.2	14921	674	13.0	3750	288
1981/82	15.9	14825	898	41.3	20189	489	25.4	5904	232
1982/83	1.31	5206	3970	8.37	8097	967	7.06	2891	409
1983/84	6.65	11448	1722	12.7	13570	1069	6.05	2122	351
1984/85	17.40	17197	988	44.4	23266	524	27.00	6069	225

KOMPUP : 235 km^2
MT LINDESAY : 525 km^2
MT LINDESAY - KOMPUP : 290 km^2

Figure 30 shows the annual salinities with respect to runoff for three catchments with the Kompup catchment. These are Perillup, Amuri Creek and Yate Flat. The Perillup figures are consistently lower than either Amuri Creek or Yate Flat which is expected due to the low percentage cleared. Amuri Creek is a sub-catchment of the Yate Flat Catchment.

From the data in Figure 30, the Amuri Creek results are of a higher runoff and salinity for individual years.

The diagrams discussed highlight the higher salinity concentraton and higher salt loads produced from the lower rainfall, cleared catchments. These results from the Denmark River Catchment, confirm the results produced from catchments in the Northern Darling Range and Manjimup Woodchip Licence Area. (Conservation and Environment, 1980).

3.5 Land Use

3.5.1 Aim

To study the hydrological responses associated with a river catchment it is essential to have a knowledge of the environment and the changes that have been made to it by man. The most significant impacts on the study area have been due to timber milling operations and more importantly the clearing of land for farming operations.

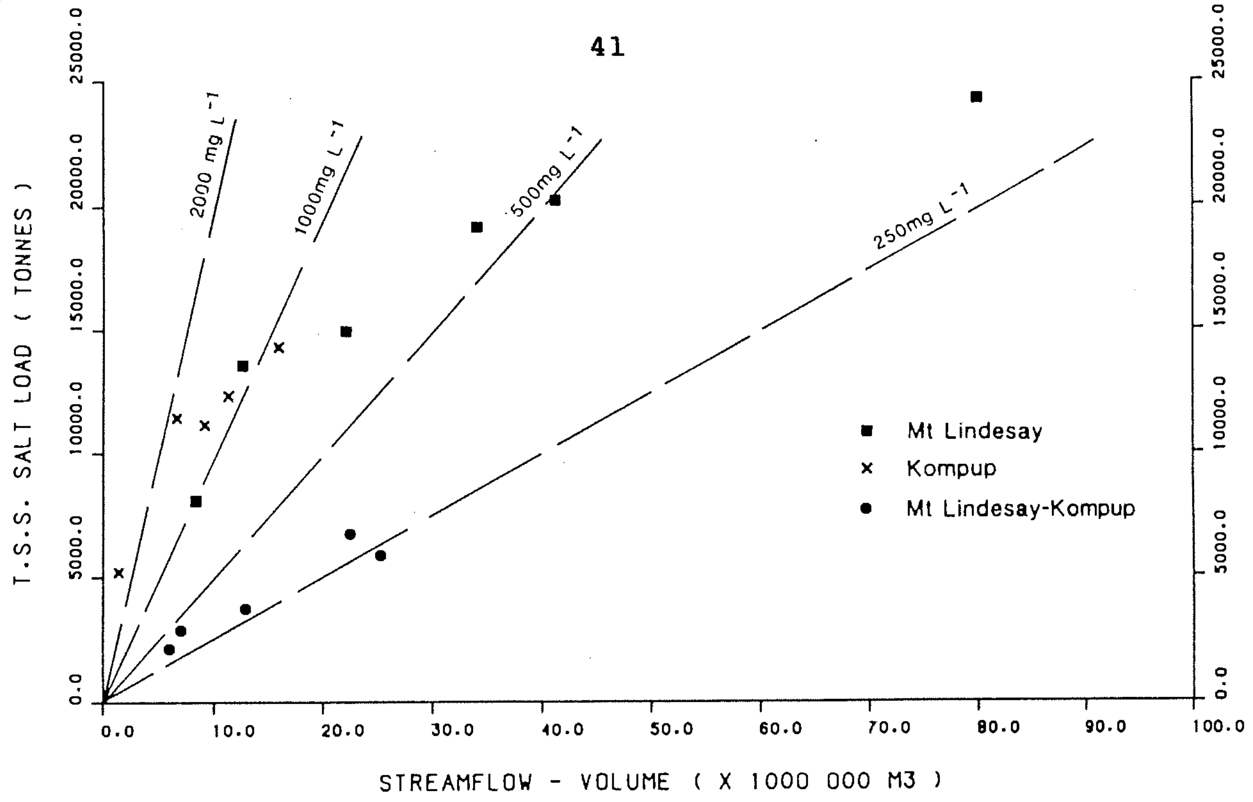

FIGURE 27 SALT LOAD VERSUS STREAMFLOW FOR MOUNT LINDESAY , MOUNT LINDESAY - KOMPUP AND KOMPUP

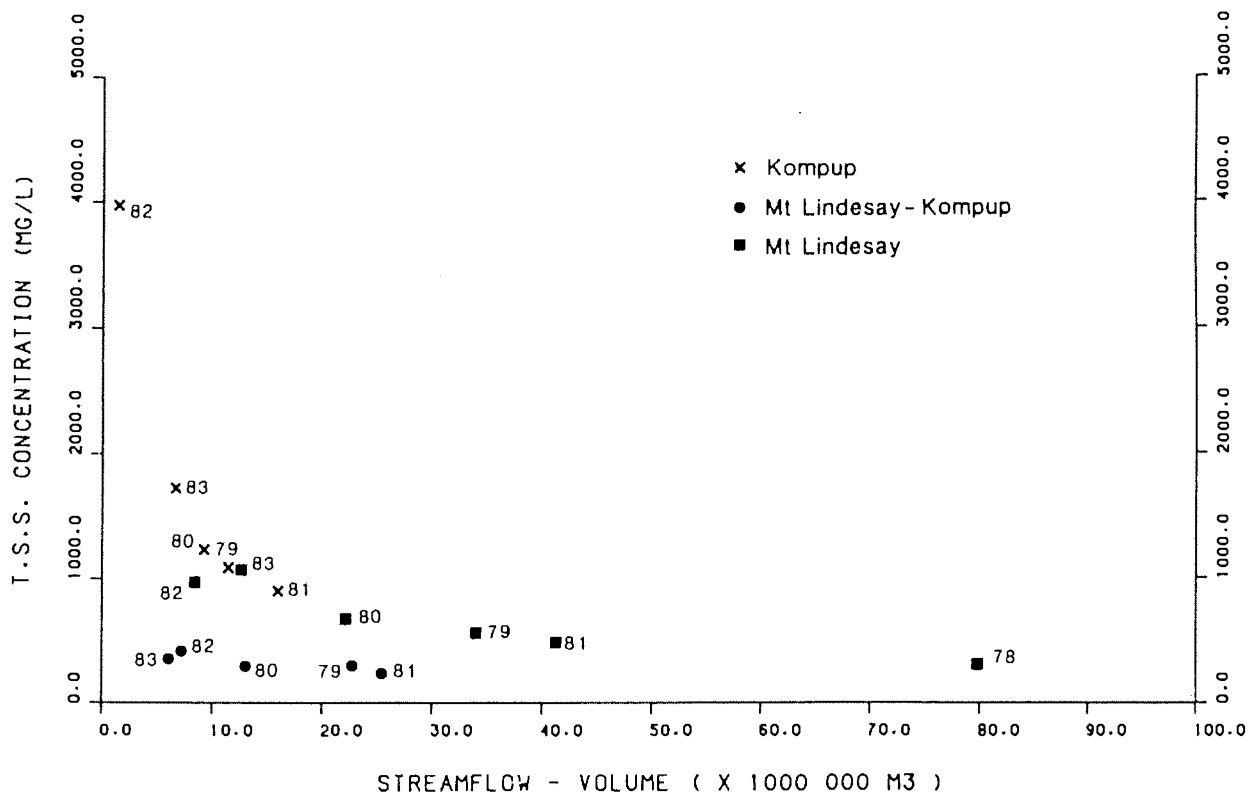

FIGURE 28 TSS CONCENTRATION VERSUS STREAMFLOW FOR MOUNT LINDESAY , KOMPUP AND MOUNT LINDESAY - KOMPUP

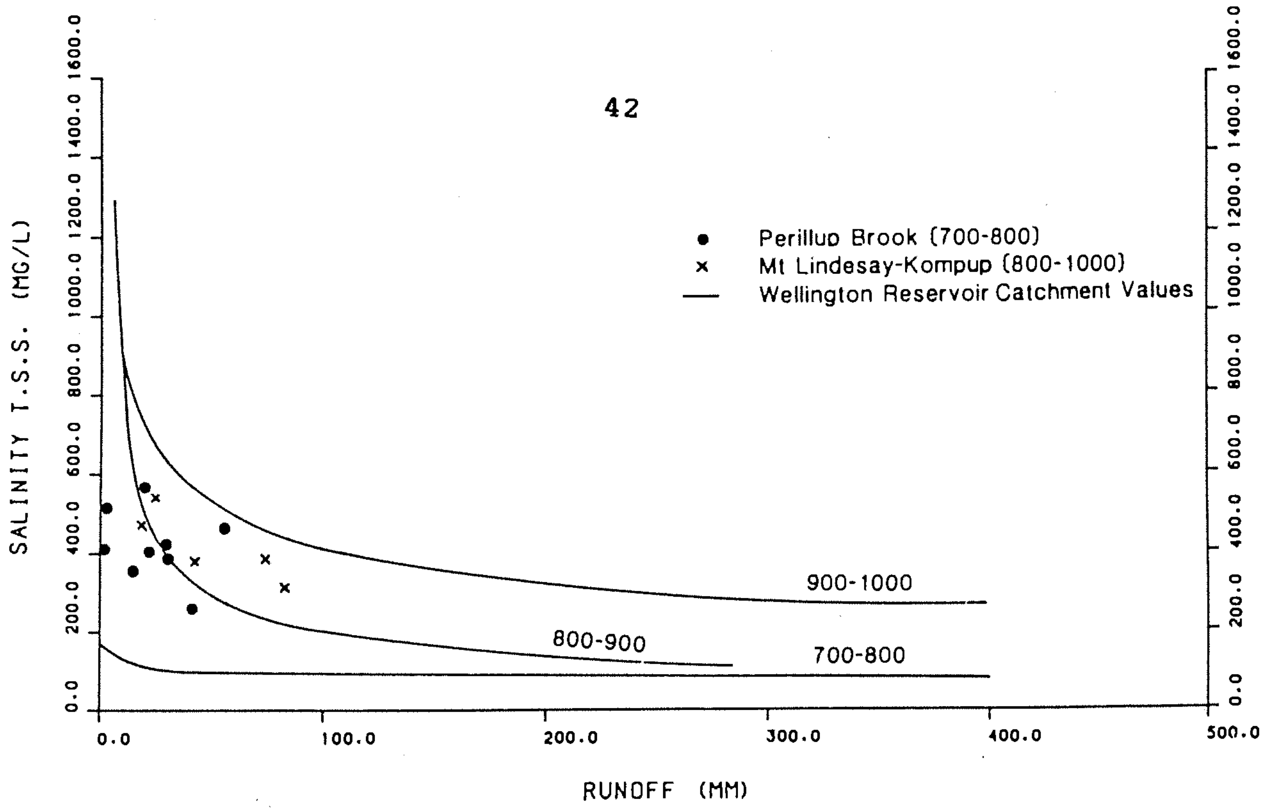

FIGURE 29 CONCENTRATION VERSUS RUNOFF - FOR PERILLUP BROOK AND MOUNT LINDESAY - KOMPUP

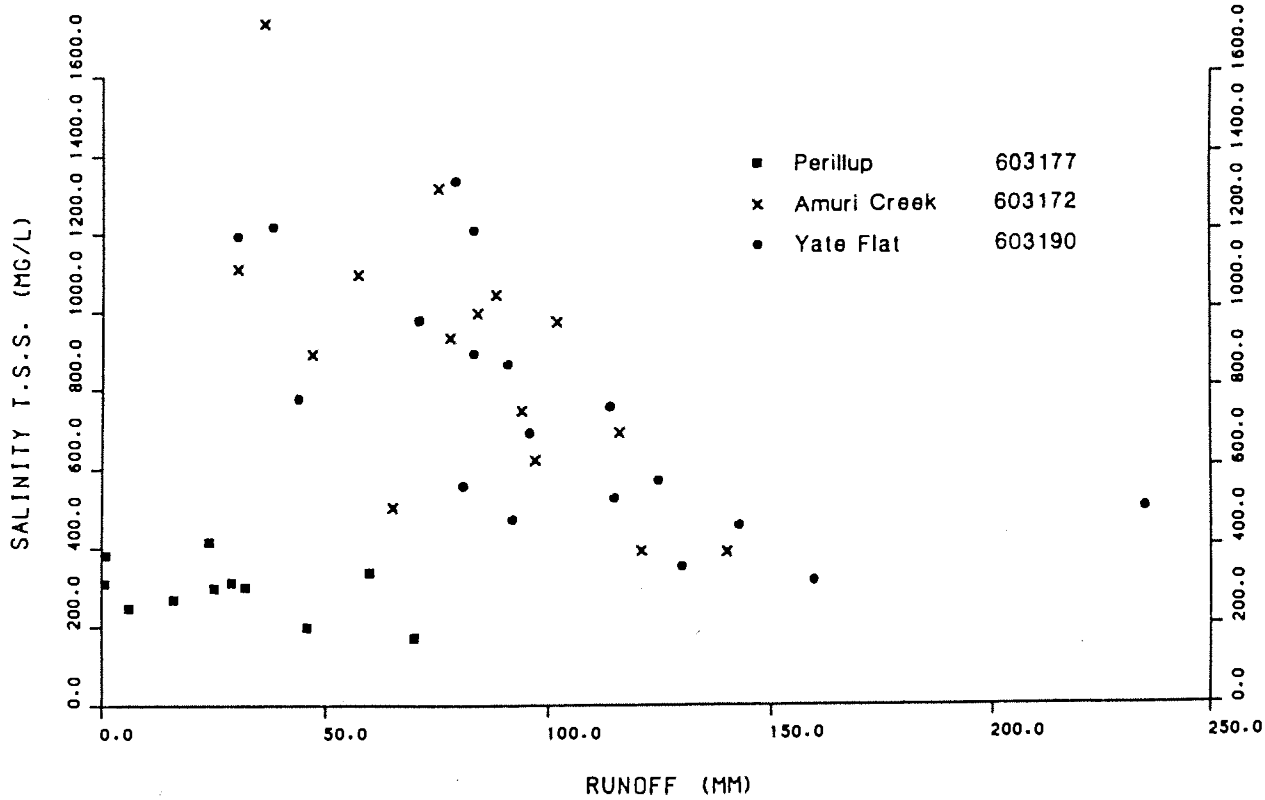

FIGURE 30 CONCENTRATION VERSUS RUNOFF - PERILLUP BROOK , AMURI CREEK , YATE FLAT

3.5.2 History

3.5.2.1 Forestry

The commerical exploitation of the timber resources in the region did not commence until the 1870's when timber mills were established at Amerillup followed by Denmark (Glover, 1979; Collins and Fowlie, 1981). The industry expanded over the next four decades in response to an increased export trade and demands from major works such as the telegraph line, Great Southern Railway and expansions due to the gold rush. Companies operating in the Scotsdale and Karridale areas were required to clear karri trees from areas, under a government timber concession lease to encourage settlement. The number of timber mills operating in and around the catchment peaked at seven in the 1950's (Jarvis, 1979).

The millable timber available in this area has been limited by the fact that 45% of the Mt Lindesay catchment is classified as non-forest (Table 10).

3.5.2.2 Agriculture

Although Albany was first settled in 1826 the exploration of the study area did not take place until 1829 and commercial agricultural development not until the 1860's. Up until the 1890's this development was confined to extensive pastoralism based on sheep (Jarvis, 1979) and was limited to the Kompup catchment area.

At this time small mixed farms were established on the karri loams in the catchment between Mount Lindesay and Lindesay Gorge in areas that had been clear-felled. The introduction of the Government Group Settlement scheme in the early 1920's resulted in a rapid expansion in the amount of cleared and developed land in this area. The area regressed during the 1930's due to the depression and heavy livestock losses from a wasting disease resulting from mineral deficiencies.

Table 10 FOREST TYPES IN THE DENMARK RIVER BASIN

Forest Type	% of Catchment 603014 ($567\ km^2$)	603003 ($235\ km^2$)
Non-forest (Swamps, scrub, rock)	45	39
Karri	0.2	0
Jarrah-Marri	8	7
Jarrah	30	25

Source : Department of Conservation and Land Management. Forest Management and Inventory System (FMIS)

A major expansion of the industry occurred in the early 1950's resulting from a worldwide increase in the demand for beef and the introduction of war service projects in the Rocky Gully-Perillup and Denbarker areas. The abolition of controls on land prices in 1949 encouraged farmers to further develop their properties (Gentilli, 1979).

After a recession in the mid 1960's beef prices again increased until the early 1970's. This caused a wholesale change in the district to beef farming and an expansion in the total area cultivated. Prices peaked in 1972 and in 1973 began to fall and because of this the prosperity of the area has declined.

The implementation of clearing control legislation (Public Works Department, WA, 1979) has resulted in a stabilisation in the area of land cleared.

3.5.3 Data Sources

The watershed catchment boundaries used in this report were defined on 1:50 000 map sheets primarily from the interpretation of contours from topographical maps in conjunction with aerial photography and ground surveying.

The annual average rainfall isohyets (1926-1980) used for this study were obtained from Public Works Department (1980).

A history of clearing was developed from either aerial photography or landsat imagery as documented in Appendix D. The conversion of the aerial photographic interpretation of cleared land for the 1946 and 1979 data sets was done by hand using cadastral boundaries and natural features as the controls.

The information defining the broad cadastral classification of private land was supplied in digital form by the Department of Lands and Surveys.

3.5.4 Data Capture and Analysis

The Land Information System Support Centres (LISSC) Intergraph VAX 11/780 was used to capture data, in a digital form, from maps describing the catchment boundaries, rainfall isohyets, cleared land and generalised cadastral boundaries. This is a general purpose interactive graphics system which includes an extensive suite of data manipulation and analysis programmes. However it was basically only used as a data capture mechanism because it was considered, from past experience (LISAC 1983), that it would not adequately handle the generation of area statements for the production of the required Boolean "AND" type intersections from such a large set of data. This involves the overlaying of the four sets of information, namely catchment boundaries, rainfall isohyets, cadastral boundaries and cleared land.

To carry out this analysis the data was converted from polygon or vector data into grid cell data (or raster data) and transferred by magnetic tape to the Department of Land and Surveys, Remote Sensing Section's I2S Image Processor. A grid cell size of 50 metres by 50 metres was adopted as the standard because it enabled the Landsat imagery, which is inherently raster formated data, to be resampled from its standard format of 70 metre grid cells without significantly degrading its integrity. This format also gave a good coverage of the study area with a moderate amount of data as 1024 by 1024 grid cells.

The classification of the landsat data into a clearing theme was carried out on the I2S image processor by simply making a level slice on band 5 of the imagery. This was validated by comparing the aerial photography for the same period, January 1984, with the resulting cleared classification.

To validate the area statements the data was transfered from the Intergraph system to the Conservation and Land Management's Forestry Management Inventory System (FMIS) for analysis. This raster data base and manipulation system is based on a grid cell size of 140.35 metres.

3.5.5 Clearing Patterns

The areas cleared to 1946, 1957, 1965, 1973, 1979 and 1984 are shown in Figures 31 to 36 and the 'breakdown' by catchment and by isohyetal zones are listed in Table 11. By 1984, 84% of the area cleared, to the probable site of the reservoir at Mt Lindesay gauging station, was upstream of the Kompup gauging station. This represents 15% out of the total of 18% (95 km^2) of cleared land to Mt Lindesay. The majority of the clearing is therefore in the lower rainfall part of the basin where soil salt storages are higher.

As described in the history, major episodes of clearing occurred between 1946 and 1957 and between 1965 and 1973 coincident with improved prices for agricultural products, particularly beef. Little additional clearing occurred in the Woonanup subcatchment (603 190) of Kompup after 1957. By 1979 this area was 60% cleared. In contrast an additional 40 km^2 was cleared elsewhere upstream of Kompup between 1957 and 1979; most of this between 1965 and 1973 (Figures 32 to 36). Less than 5 km^2 of the 82 km^2 increase in area cleared to Mt Lindesay between 1946 and 1979 occurred in the area between Kompup and Mt Lindesay.

A decrease of about 9 km^2 in the area cleared at Mt Lindesay was estimated to have occurred between 1979 and 1984 (Figures 35 and 36). Approximately 2/3 of this occurred as a result of forest regrowth on private land upstream of Kompup. Most of the remaining 1/3 is attributed to differences in interpretation of forest/clearing between the machine processed 1984 Landsat imagery and the manually processed 1979 aerial photographs.

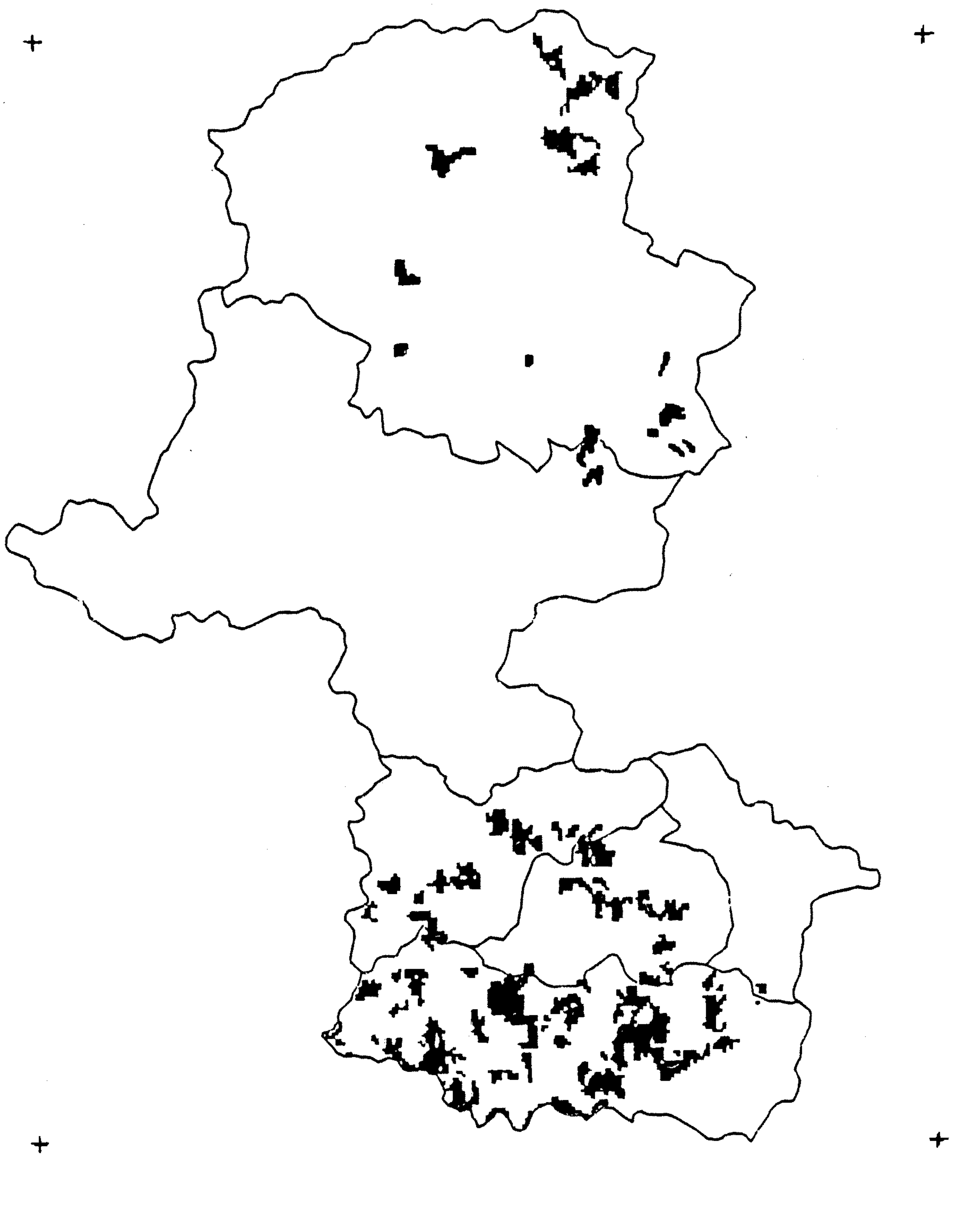

FIGURE 31 CLEARING AT 1946

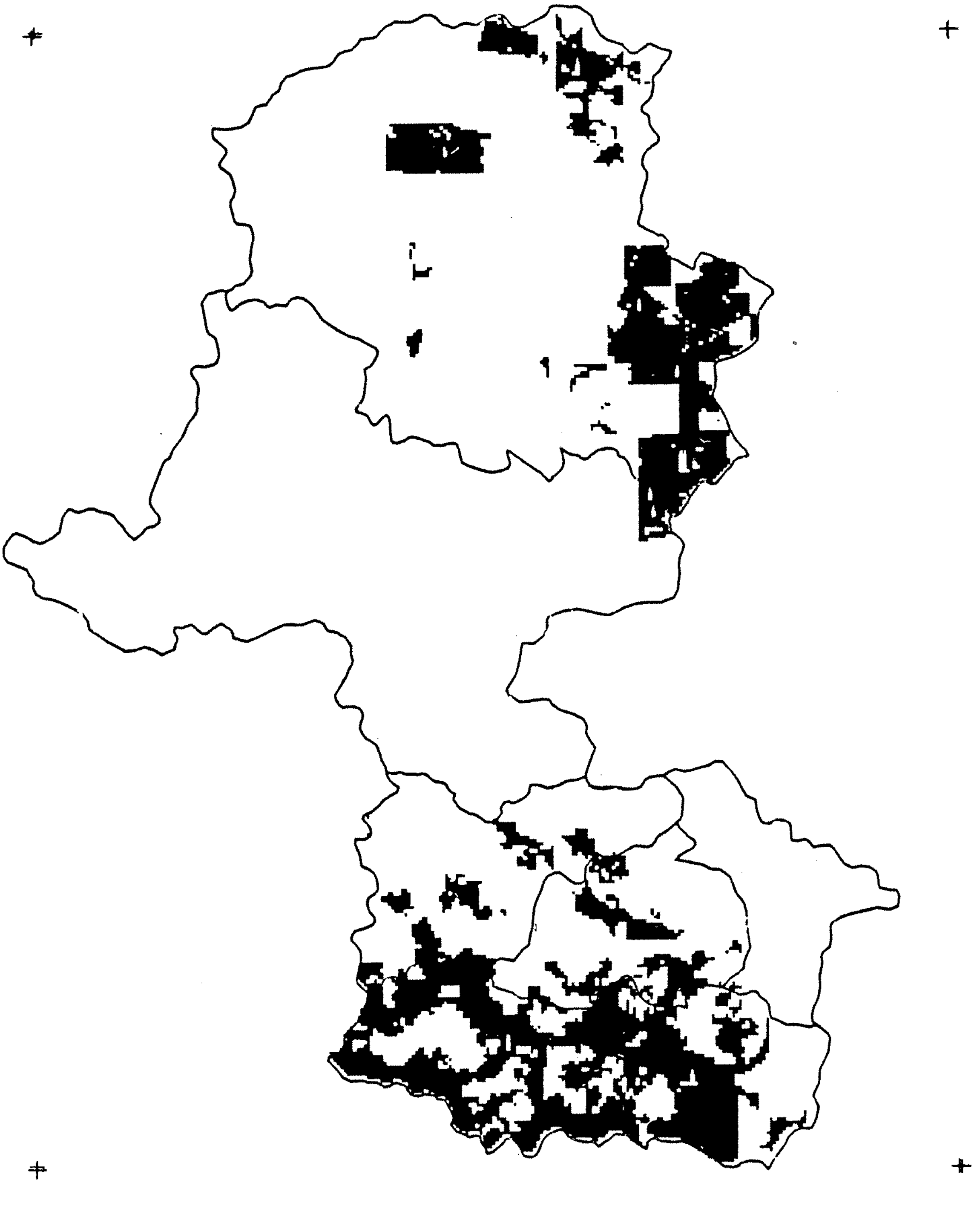

FIGURE 32 CLEARING AT 1957

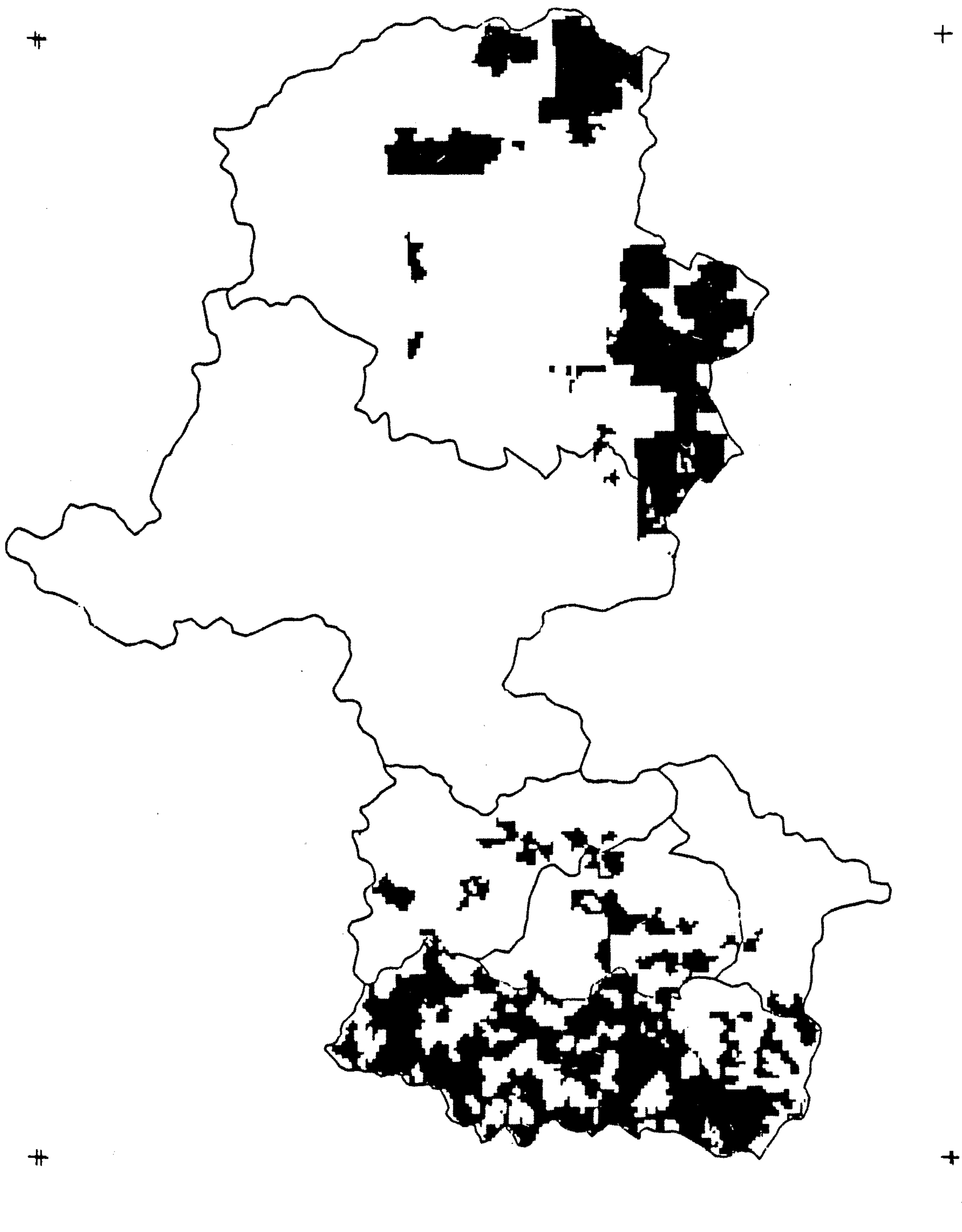

FIGURE 33 CLEARING AT 1965

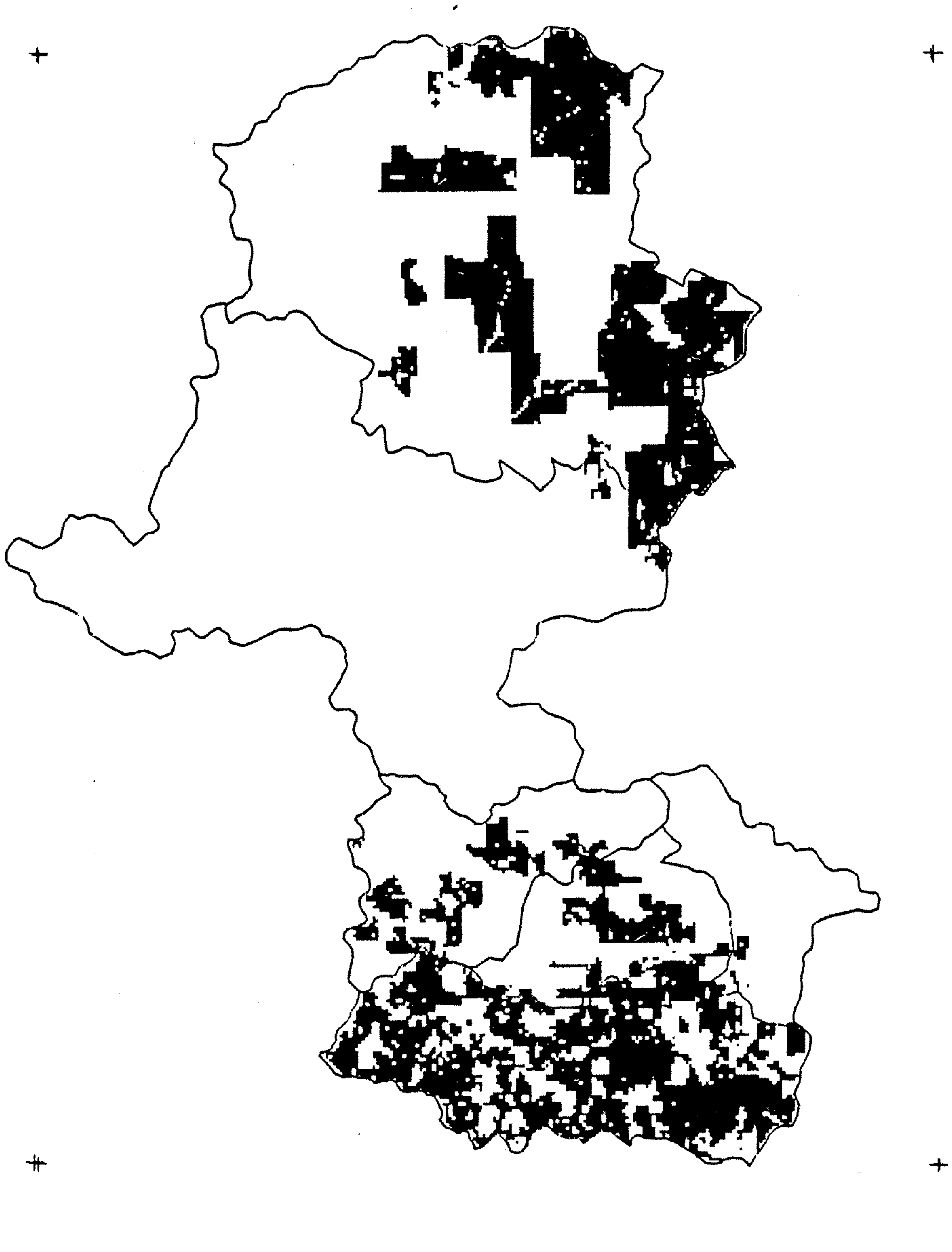

FIGURE 34 CLEARING AT 1973

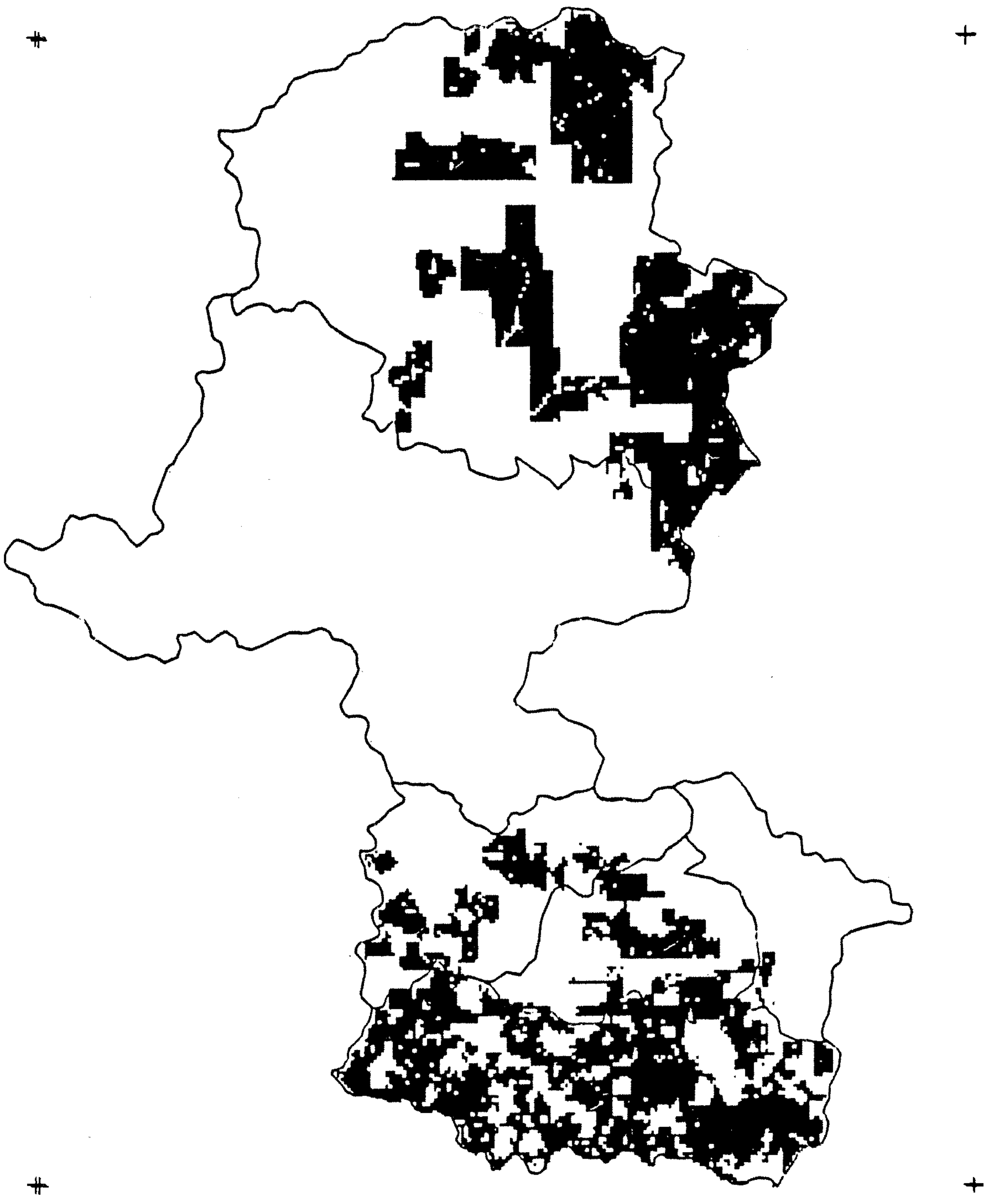

FIGURE 35 CLEARING AT 1979

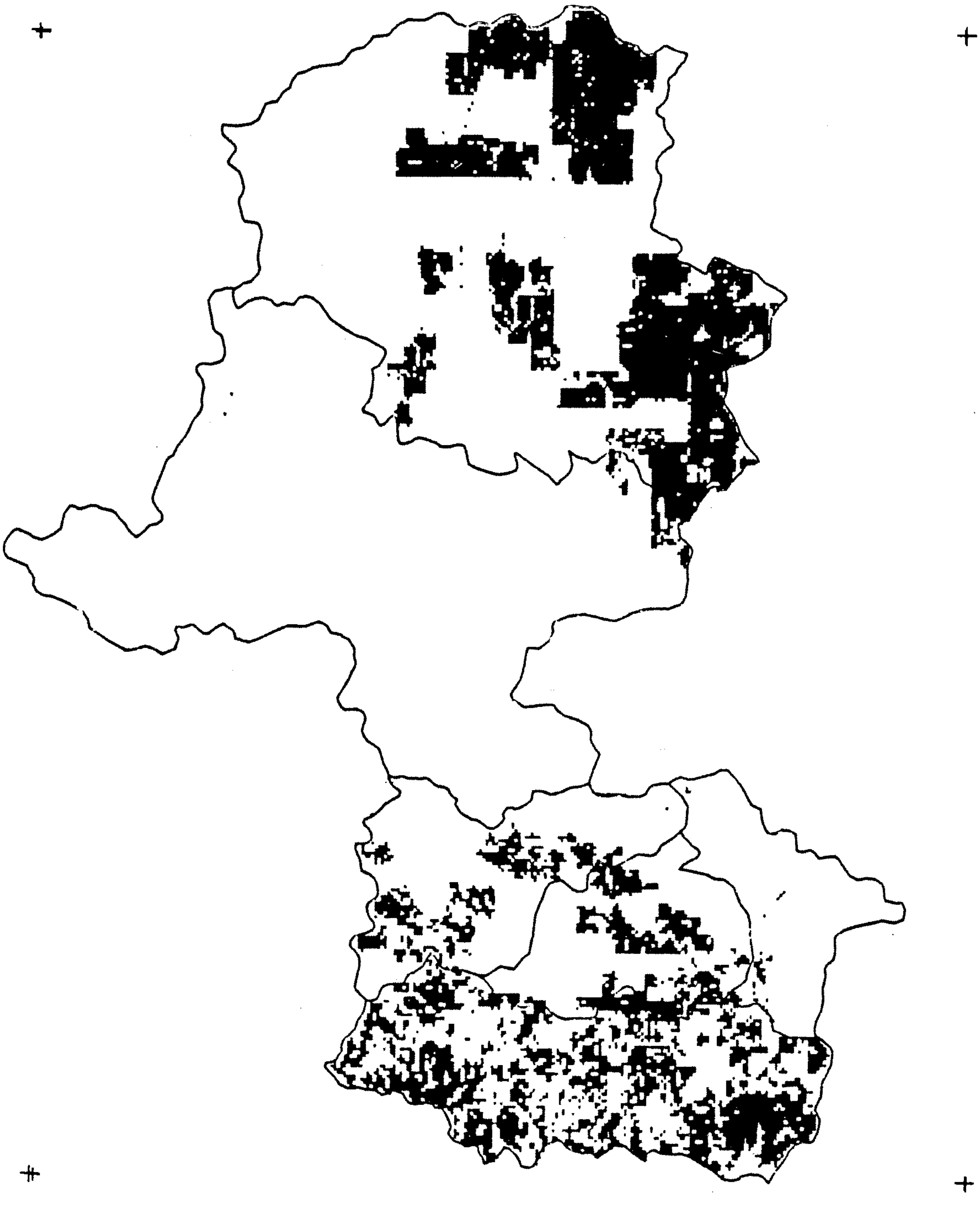

FIGURE 36 CLEARING AT 1984

TABLE 11

CATCHMENT CLEARING IN RAINFALL ZONES

	ISOHYET RANGE				
	700-800	800-900	900-1000	1000-1100	TOTAI
1946					
KOMPUP	7.4				7.
KOMPUP TO LINDESAY GORGE	0.1	0.4			0.
LINDESAY GORGE TO MT LINDESAY		2.1	3.1		5.
MT LINDESAY	7.5	2.5	3.1		13.
1957					
KOMPUP	44.6	0.2			44.
KOMPUP TO LINDESAY GORGE	0.1	2.3			2.
LINDESAY GORGE TO MT LINDESAY		2.3	4.9	0.4	7.
MT LINDESAY	44.6	4.8	4.9	0.4	54.
1965					
KOMPUP	51.2	0.2			51.
KOMPUP TO LINDESAY GORGE	0.2	3.0			3.
LINDESAY GORGE TO MT LINDESAY		2.1	3.1		5.
MT LINDESAY	51.4	5.3	3.1		59.
1973					
KOMPUP	79.8	0.2			80.
KOMPUP TO LINDESAY GORGE	0.4	3.6			4.
LINDESAY GORGE TO MT LINDESAY		3.0	8.0		11.
MT LINDESAY	80.2	6.8	8.0		95.
1979					
KOMPUP	86.9	0.2			87.
KOMPUP TO LINDESAY GORGE	0.4	3.7			4.
LINDESAY GORGE TO MT LINDESAY		3.6	9.4		13.
MT LINDESAY	87.3	7.5	9.4		104.
1984					
KOMPUP	80.3	0.2			80.
KOMPUP TO LINDESAY GORGE	0.4	3.1			3.
LINDESAY GORGE TO MT LINDESAY		3.4	7.7		11.
MT LINDESAY	80.7	6.7	7.7		95.

Note : All values are km^2

4. STREAMFLOW AND SALINITY SIMULATION

4.1 Aim

The aim of this section is to determine the statistics of long term river water yield and salinity due to the fully developed effects of clearing for agriculture.

4.2 Model

4.2.1 Background

The regional prediction model used in the analysis of the Denmark River catchment was originally developed for predicting water yield and salinity variations with time in the south-west of Western Australia (Loh & Stokes, 1981) and in particular the Wellington Reservoir catchment. To produce predictions of the long term salinity with any confidence requires a detailed historical record of the rainfall, streamflow, groundwater levels, forested areas cleared (location and quantity), topography and vegetation (existing and historical). Because this record is very difficult to achieve (and in practice rare), there is an inherent level of uncertainty in the analysis, which is difficult to define other than qualitatively.

4.2.2 Model Structure

The two equations, which are the basis of the model, for streamflow and salt load, (Loh & Stokes, 1981) are:

$$Q_T = QF_i{*}AF_i + QA_i{*}AC_i \quad \text{---------4.1}$$

$$SL_T = QF_i{*}AF_i{*}CF_i+QA_i{*}AC_i{*}CU_i+GR_i{*}F_i{*}AC_i{*}CG_i \quad \text{-------4.2}$$

where Q_T is the total flow in 10^6 m^3
QF_i is the forested flow for zone i in mm
AF_i is the area of zone i in km^2
QA_i is the additional flow for zone i in mm
AC_i is the area cleared in zone i in km^2

SL_T is the Total Soluble Salt (TSS) load in 10^6 kg
CF_i is the forested salinity for zone i in kgm^{-3}
CU_i is the salinity of shallow sub-surface groundwater for zone in kg m^{-3}
F_i is the proportion of the groundwater recharge which is currently being discharged for zone i
GR_i is the groundwater recharge rate for zone i in mm
CG_i is the salinity of discharging groundwater in zone in kgm^{-3}
n is the number of zones

These equations for streamflow and salt load are calculated for separate rainfall zones and summed to provide total streamflow and salinity.

Equation 4.1 expresses the total annual streamflow as a combination of forested flow over the complete catchment and additional flow over the area of the catchment cleared.

Equation 4.2 defines the total annual salt load from the catchment by dividing this salt load into three sections. These three sections are the salt load from the catchment completely forested; additional salt loads due to surface and sub-surface flow in the cleared regions; and additional salt load due to groundwater discharge in the cleared area.

The major assumption made in this flow and salt load prediction are that the location of the land cleared is independent of the flow volume (in that land cleared from a valley, midslope or upland gives the same additional flow).

4.2.2.1 Salt Load from Forested Flow

The salt load from the forested catchment is calculated by the forested flow volume multiplied by the forested flow salinity where the forested flow salinity is defined from historical records for catchments with little or no clearing.

4.2.2.2 Salt load from Additional Flow

The additional salt load due to surface and sub-surface flow in cleared areas is calculated from the additional streamflow from the land use change multiplied by the shallow sub-surface salinity.

4.2.2.3 Salt load from Groundwater Discharge

The additional salt load due to groundwater is a result of the discharging groundwater multiplied by the groundwater salinity. The groundwater recharge is related to the additional groundwater discharge by a time function which delays the discharge relative to recharge (the F factor). This function is governed by the geometric and hydraulic properties of the groundwater aquifer. The model is constructed so that different zones have different time delays between recharge and discharge and different salinities of discharging groundwaters (Loh & Stokes, 1981).

The specific factors in the groundwater salt load are the groundwater salinity, area of land cleared, the groundwater recharge and the F factor. The groundwater salinity is determined from the baseflow salinity and the soil salt storage concentration (see section 3.2).

Groundwater recharge is determined from an analysis of the aquifer, the specific yield and rate of water level rise per year for varying rainfall zones. This analysis calculates the recharge on a regional basis for each rainfall zone and averages any variations within a rainfall zone.

The groundwater salinity is calculated from solute concentration analysis of drilling data and from salinities of the streamflow during the late spring and summer during the hydrograph decay. Stokes et al (1980) summarised the available data on soil salt storage characteristics in the Northern Darling Range. Results from this study have shown that the ratio of soil solute concentration to groundwater salinity in forested areas varies from 1.0 to 10.0, while the ratio for cleared areas approaches 1.0. The soil solute concentrations for the Denmark River Basin were based on the drilling work (detailed in section 3.2) and the data from Johnston et al (1980) on the soil salt storage in the Manjimup Woodchip Licence Area.

The F-factor is a magnitude and response time measure of the ratio of groundwater recharge to discharge. A change in land use, in this case from forested to agriculture increases the groundwater recharge and subsequently results in an increase in groundwater discharge. This discharge will lag behind recharge primarily due to the deeper groundwater rising to intersect the valley floor and commencing discharge to streamflow, (see Figure 37).

The discharge will be delayed depending on the physical separation of recharge and discharge locations and hydraulic characteristics of the aquifer. Depending on the depth of the existing groundwaters the response time (τ_a) varies from zero for shallow depths to initial groundwater level, to 5-10 years and even more for deeper groundwaters.

4.3 <u>Simulation Parameters</u>

4.3.1 Streamflow

In this simulation the catchment was separated into three zones based on annual rainfalls.

Kompup	700 - 800 mm	Zone 1
Lindesay Gorge - Kompup	800 - 900 mm	Zone 2
Mt Lindesay - Lindesay Gorge	900 - 1000 mm	Zone 3

To produce the forested and additional streamflow components, regression analyses were used directly on the catchment rainfalls. This was achieved by assuming the Perillup Brook catchment as a forested catchment with negligible effects due to the clearing and Yate Flat sub-catchment as a cleared catchment, for the 700 to 800 mm rainfall zone.

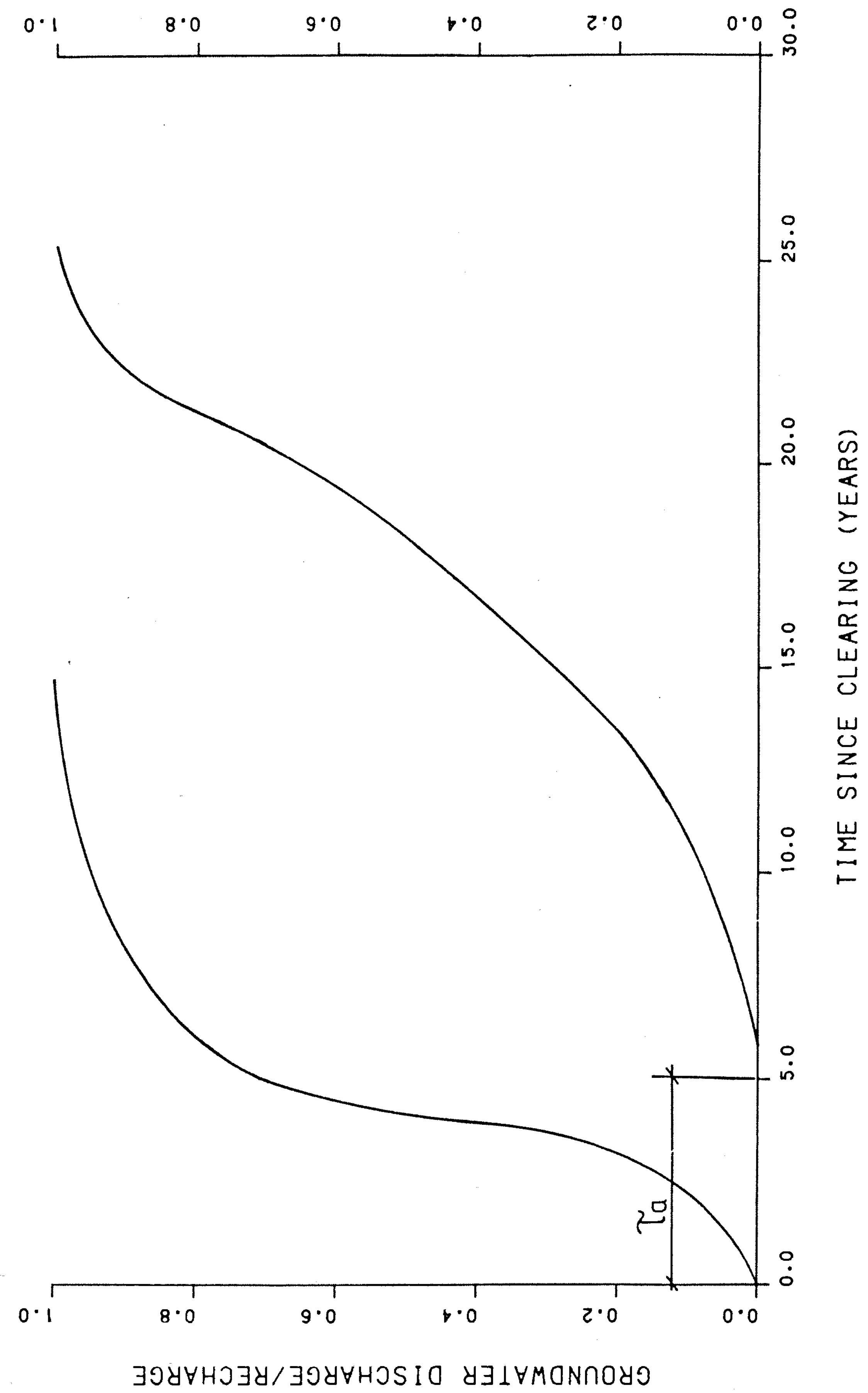

FIGURE 37 GROUNDWATER DISCHARGE/ RECHARGE RELATIONSHIP WITH TIME

Some modifications for the Yate Flat sub-catchment relationship between runoff and rainfall was required to obtain a measure of additional runoff per unit clearing. The Yate Flat runoff was subtracted from the Perillup Brook runoff and divided by the percentage cleared from Yate Flat to produce a runoff-rainfall relationship per unit clearing (see Figure 38). The difficulty in this process is exemplified by comparing the data for 1968 and 1969. In 1968 the flow at Yate Flat was about 3.5 times as large as that for Perillup Brook, however in 1969 this ratio increased to 132.

The Lindesay Gorge - Kompup sub-catchment, with only 1.5% cleared was assumed to be a fully forested catchment for the 800 to 900 mm rainfall zone. The cleared, runoff-rainfall relationship in this rainfall zone was interpolated between the 700 to 800 mm zone and the 900 to 1000 mm zone. The runoff to rainfall relationships developed for the 800 - 900 rainfall zone are detailed in Figure 39.

The Mt Lindesay - Lindesay Gorge sub-catchment was the only catchment within the 900 - 1000mm rainfall zone, and with 20% of the sub-catchment cleared could not be assumed to be a forested catchment. To produce a forested catchment runoff to rainfall relationship the data from the 700 to 800 mm and 800 to 900 mm zones was extrapolated for the forested condition. The unit additional runoff was produced by subtracting Mt Lindesay - Lindesay Gorge values from the simulated forested catchment for the 900 - 1000 rainfall zone and dividing by the percentage cleared. The results of this analysis are shown on Figure 40.

4.3.2 Salinity

The salt load equation is divided into three sections - forested salt load; additional salt load from surface and shallow groundwater flow due to clearing; and groundwater salt load.

4.3.2.1 Forested Salt Load

The forested salinity, for each of the zones under study, was fitted to an exponential equation of the form:

$$C = aQ^b \qquad 4.3$$

where C is the salinity concentration in TSS (mg/L)

Q is the streamflow volume in mm

a, b are constants

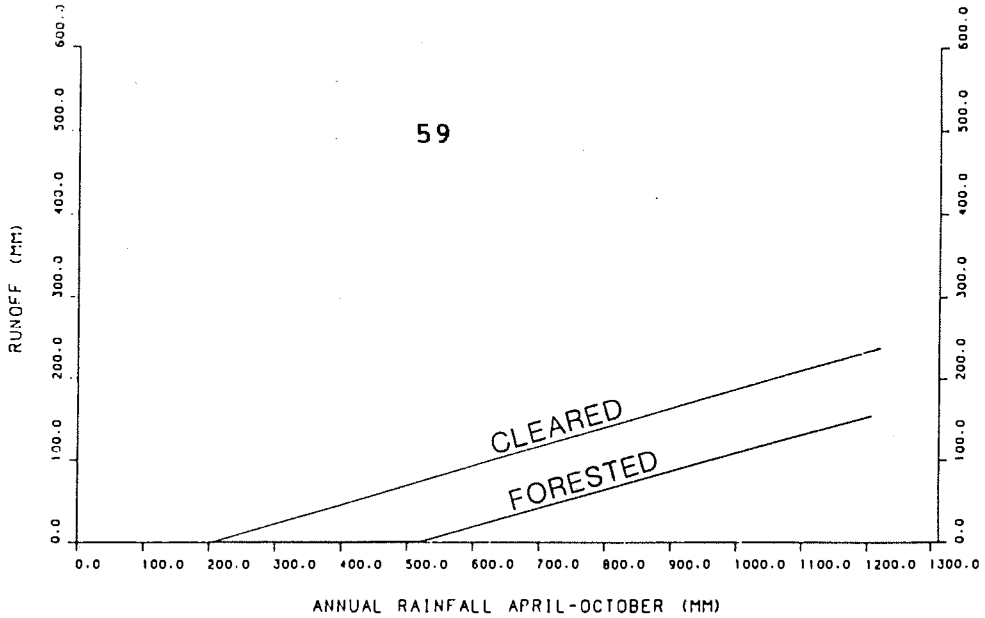

FIGURE 38 700-800 RAINFALL ZONE

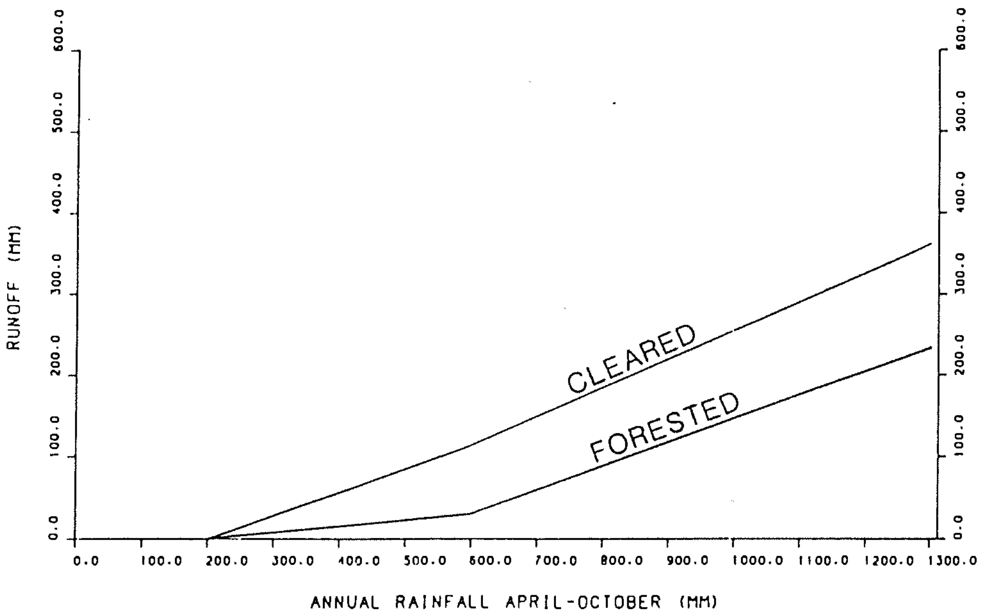

FIGURE 39 800-900 RAINFALL ZONE

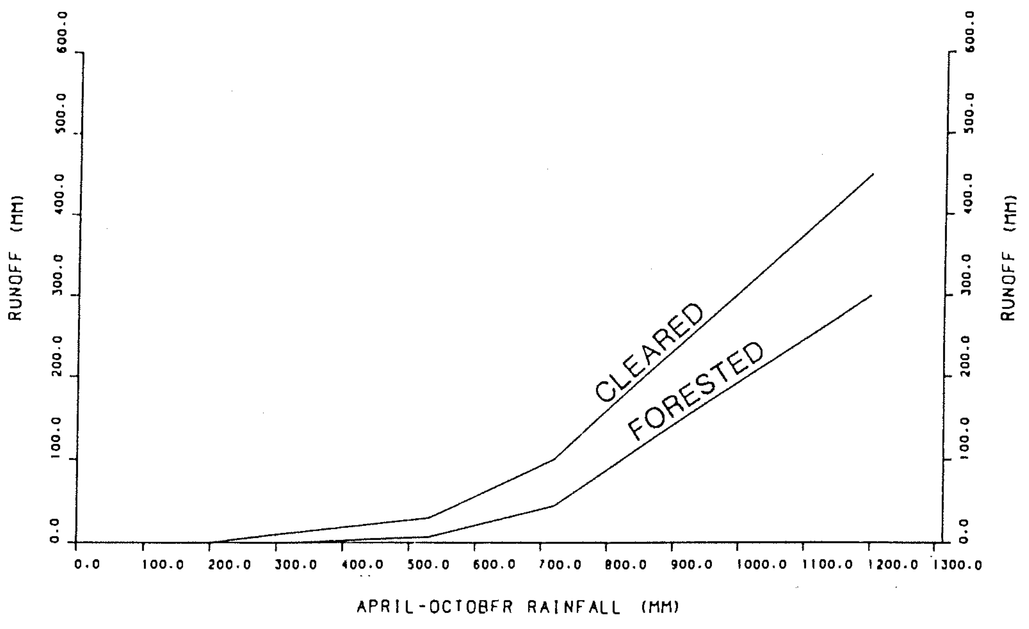

Table 12 shows representative values for equation 4.3 for each of the rainfall zones and constrained minima and maxima. These parameters were derived from the comparison between the recorded data for the Perillup catchment and Mt Lindesay-Kompup sub-catchment and the parameters for the Wellington Reservoir catchment. The Perillup and Mt Lindesay-Kompup sub-catchments were used due to the low percentage cleared and therefore show a relatively stationary relationship between flow and salinity.

The data for the Perillup catchment is consistently above the Wellington Reservoir data for the 700-800 mm zone, particularly in the low-flow region. The curve defined for the Wellington Reservoir in the 700-800mm zone was used in the simulation since the Perillup catchment, with 14% cleared, was considered to give higher salinities than a completely forested catchment in low streamflows.

The data for the Mt Lindesay-Kompup sub-catchment which encompasses the 800-1000 mm range of annual rainfall falls between the 800-900 mm and 900-1000mm zones for the Wellington Reservoir catchment and parameters for forested salinity from this area were used in the Denmark simulation.

4.3.2.2 Surface and Shallow Groundwater

The salinity of the surface and shallow sub-surface flow for each zone has been set at 150 mg/l TSS. This figure was calculated from the mean minimum salinity over the period of record for Perillup Brook, Lindesay Gorge and Mt Lindesay Catchments (Public Works Department, 1984).

4.3.2.3 Deep Groundwater

The deep groundwater salinity was initially based on the drilling data detailed in section 3.2 and the data from the MWLA (Johnston et al, 1980). These values of groundwater salinity are shown in Table 13 for each rainfall zone and the values for the corresponding zones of the Collie catchment are also listed for comparison (Loh & Stokes 1981).

TABLE 12 FORESTED SALINITY EQUATION VALUES

ZONE	a	b	C_{min}	C_{max}
700-800	138	-0.14	60	120
800-900	2354	-0.60	90	350
900-1000	1594	-0.35	200	450

TABLE 13 GROUNDWATER SALINITIES FOR EACH RAINFALL ZONE (C_G)

RAINFALL ZONE	COLLIE/ADOPTED (mg L^{-1})	MWLA/DENMARK (mg L^{-1})
700-800	6000	9000
800-900	3000	6000
900-1000	1500	4000

4.3.3 Groundwater Recharge and Discharge

The groundwater recharge as a function of the annual rainfall is shown in Figure 41 with the values from Loh & Stokes, 1981. The groundwater discharge delay from recharge as a function of the specific zones is shown in Figure 42. These results are empirically derived relationships (Loh & Stokes, 1981) with modifications for the Denmark region conditions.

4.4 Results of Streamflow Simulation

The initial simulations using the Denmark/MWLA groundwater salinities produced very high streamflow salinities in comparison with recorded values. Successively lower groundwater salinities were used until an acceptable correspondence between recorded and simulated streamflow salinities was achieved. The final set of groundwater salinities were close to those used by Loh and Stokes (1981) for the Collie River (Table 13) and so these values were adopted.

Using the parameters defined in the previous section the stream flow, salt loads and salinity were modelled from 1910 to 1984 and then predictions made on the equilibrium values using specific flow-volumes. The period of calibration used was 1962-1983 for the Mt Lindesay data. The longer period of streamflow record from 1940--1983 was not used due to the doubt about the accuracy of the high and medium flow rating (Public Works Department, 1984) prior to 1962.

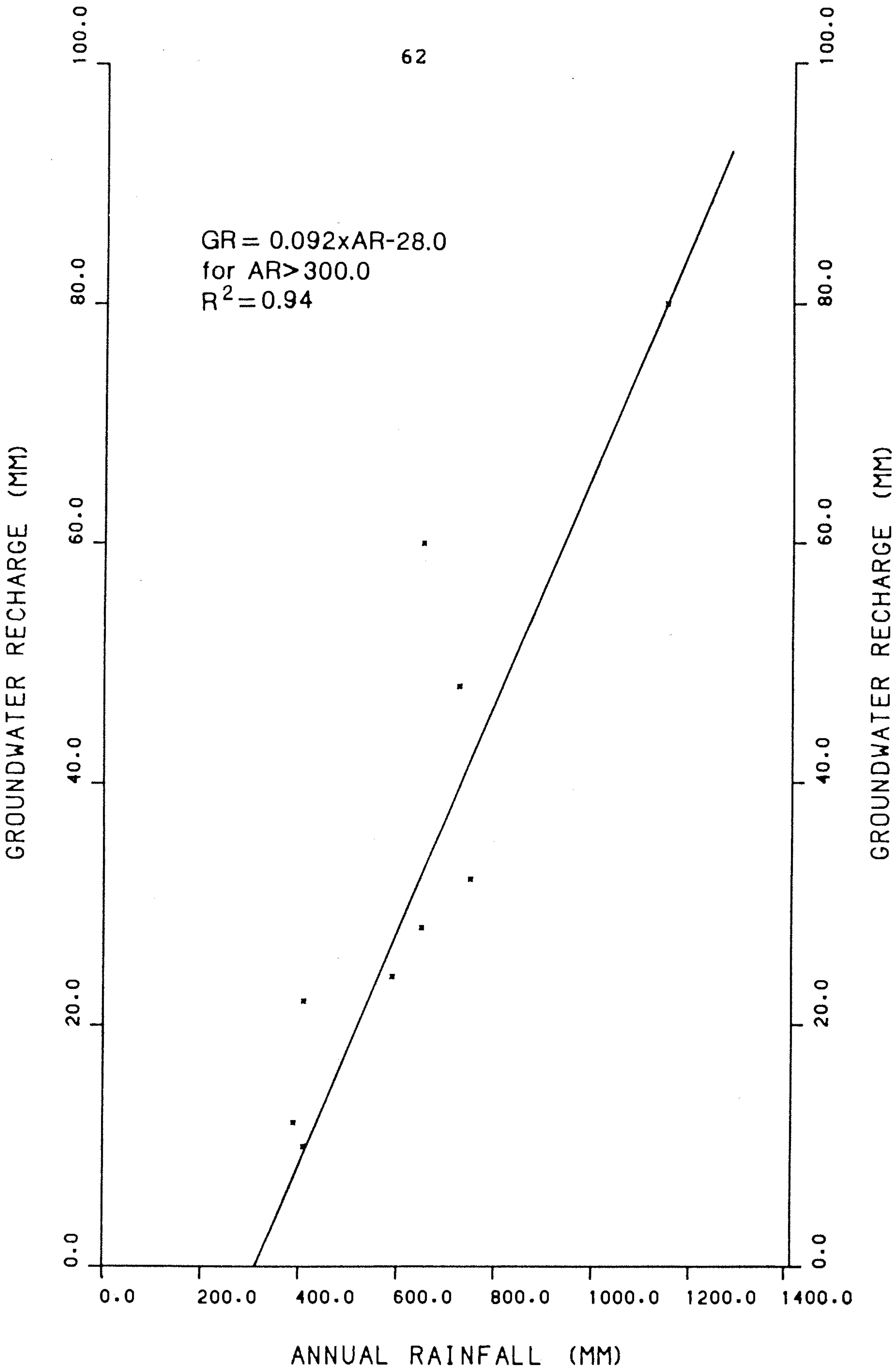

FIGURE 41 GROUNDWATER RECHARGE AS A FUNCTION OF ANNUAL RAINFALL

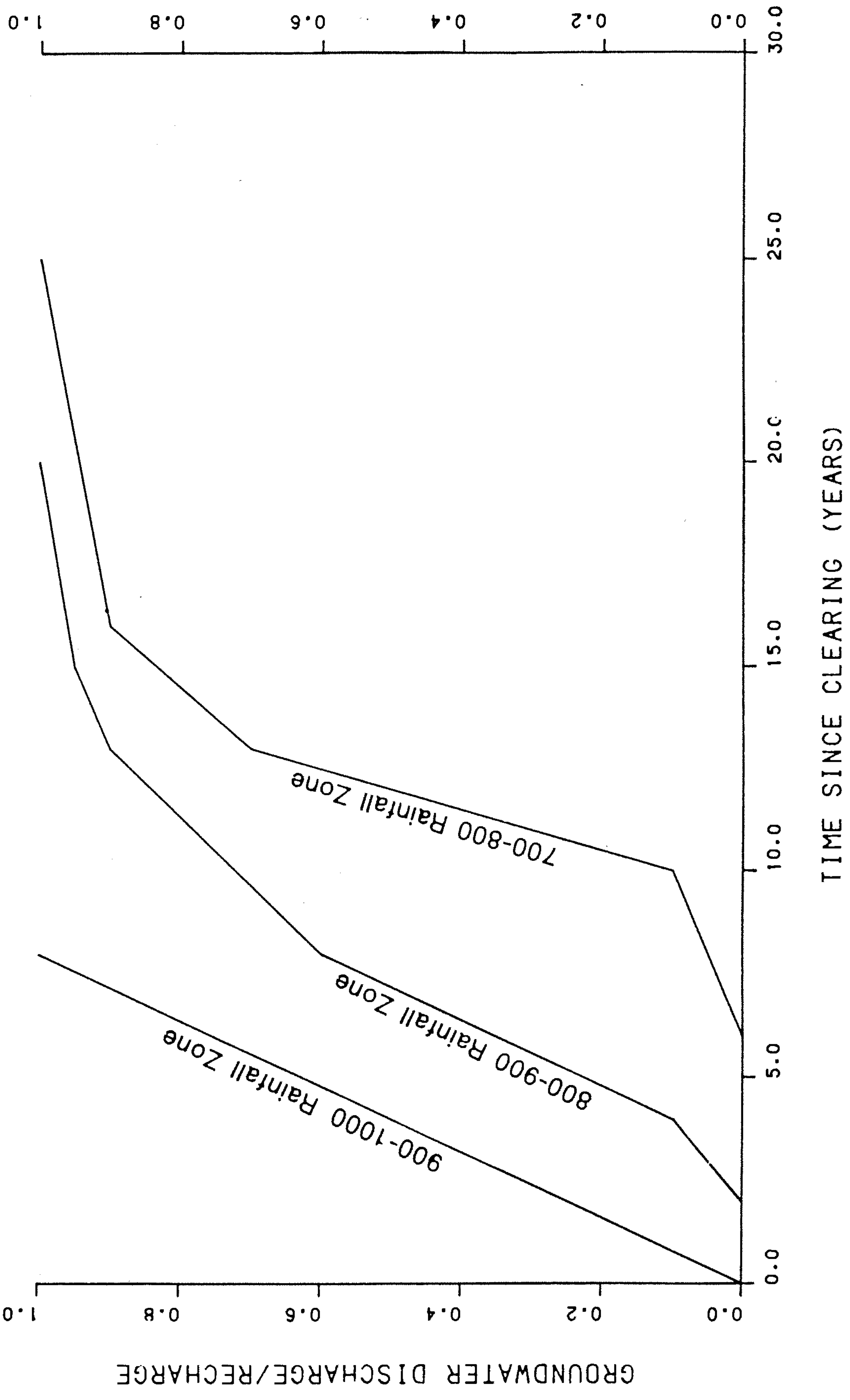

FIGURE 42 DELAY FUNCTION FOR DISCHARGE TO RECHARGE FOR INDIVIDUAL RAINFALL ZONES

4.4.1 Streamflow

The statistical comparison between the recorded data and the simulation are listed in Table 14. The simulation fits the mean very well but the variation in the simulated streamflows does not achieve the same variation as the recorded data, which is emphasised by the greater than 20% difference in the standard deviations. The correlation of the simulated to recorded data gives a low coefficient of determination (r^2) of 0.66.

Figure 43 depicts the comparison between the actual and simulated streamflow. This diagram highlights the inherent difficulty in fitting annual runoff to annual rainfall due to the variation of intensity and duration of rainfall events within each year. The prediction for 1978 emphasises this lack of fit, where two rainfall events produced approximately 40% of the streamflow at Mt Lindesay.

4.4.2 Stream Salinity

The model simulation of annual salinity predicts the mean annual salinity very accurately but the standard deviation, maxima and minima are predicted less well (Table 15). This failure to predict the extremes or the general variability in annual salinity is a product of using annual rainfall to predict annual streamflow. The correlation between the actual and predicted salinity data gives a coefficient of determination of 0.72.

The calculated mean flow weighted annual salinity and the predicted flow weighted salinity with time are shown in Figure 44.

TABLE 14 COMPARISON OF STREAMFLOW - ACTUAL AND SIMULATED 1962 TO 1983

	ANNUAL FLOW ACT. (x $10^6 m^3$)	ANNUAL FLOW SIM (x $10^6 m^3$)	DIFFERENCE %
MEAN	30.14	30.36	-0.7
STD DEV	16.9	13.1	22.4
MAX	79.9	57.9	27.5
MIN	9.1	7.0	23.2

TABLE 15 COMPARISON OF SALINITY - ACTUAL AND SIMULATED 1962 to 1983

	ANNUAL SALINITY ACT. (x $10^6 m^3$)	ANNUAL SALINITY SIM (x $10^6 m^3$)	DIFFERENCE %
MEAN	493.8	494.3	0.2
STD DEV	189.5	128.7	32.0
MAX	987.0	809.0	18.0
MIN	230.0	284.0	-23.4

The salinity was generally under predicted during the 1940-1960 time span, but due to the small number of water quality samples taken the accuracy of the mean annual salinity has some uncertainty. During the 1970's the simulation predicted the actual salinity reasonably well.

4.4.3 Longer-Term Flow and Salinity

The rainfall levels corresponding to the probabilities of non-exceedance of 10%, 50% and 90% for streamflow were introduced into the model as rainfall from 1985 to 2010. These simulations produced long term equilibrium conditions by the year 2005 Figure 45. This analysis gave the median streamflow and salinity, (at equilibrium) of 32 x $10^6 m^3$ and 730 mg L^{-1} TSS respectively while the 10% and 90% probability of non-exceedance values for streamflow and salinity are 11.8 x 10^6, 82 x $10^6 m^3$ and 1081, 458 mg L^{-1} TSS (Table 16).

Figure 46 depicts the long term salinity if the catchment had remained completely forested compared to the predicted salinity from 1910 to 2010. This scenario gives a median salinity of 218 mg L^{-1} TSS. While if the Kompup catchment (700-800 mm rainfall zone) had all privately owned (freehold and leasehold) land cleared the median long term salinity at Mt Lindesay would be 800 mg L^{-1} TSS.

Figure 47 details the long term salinity versus streamflow relationship. Included in this diagram are the historical values from 1978 to 1984. These values follow the general trend of the predicted salinities but at a reduced salinity level. From the plot of equilibrium values, equation 4.4 was fitted:-

$$C = 3286Q^{-.44} \qquad (4.4)$$

where C is the Annual salinity (mg L^{-1} TSS)
Q is the Annual streamflow ($10^6 m^3$)

The exponent in equation 4.4 of -0.44 for a catchment with 18% cleared compares favourably with the Wellington Reservoir Catchment (Loh and Stokes, 1981) where a sub-catchment with 32% land cleared has an exponent of -0.57.

The 1984/85 results of 44.4 x 10^6 m^3 and 530 mgl^{-1} TSS, which are approximately 80% of the long term flow and salinity values, substantiate the continuing trend of increasing salinities with time.

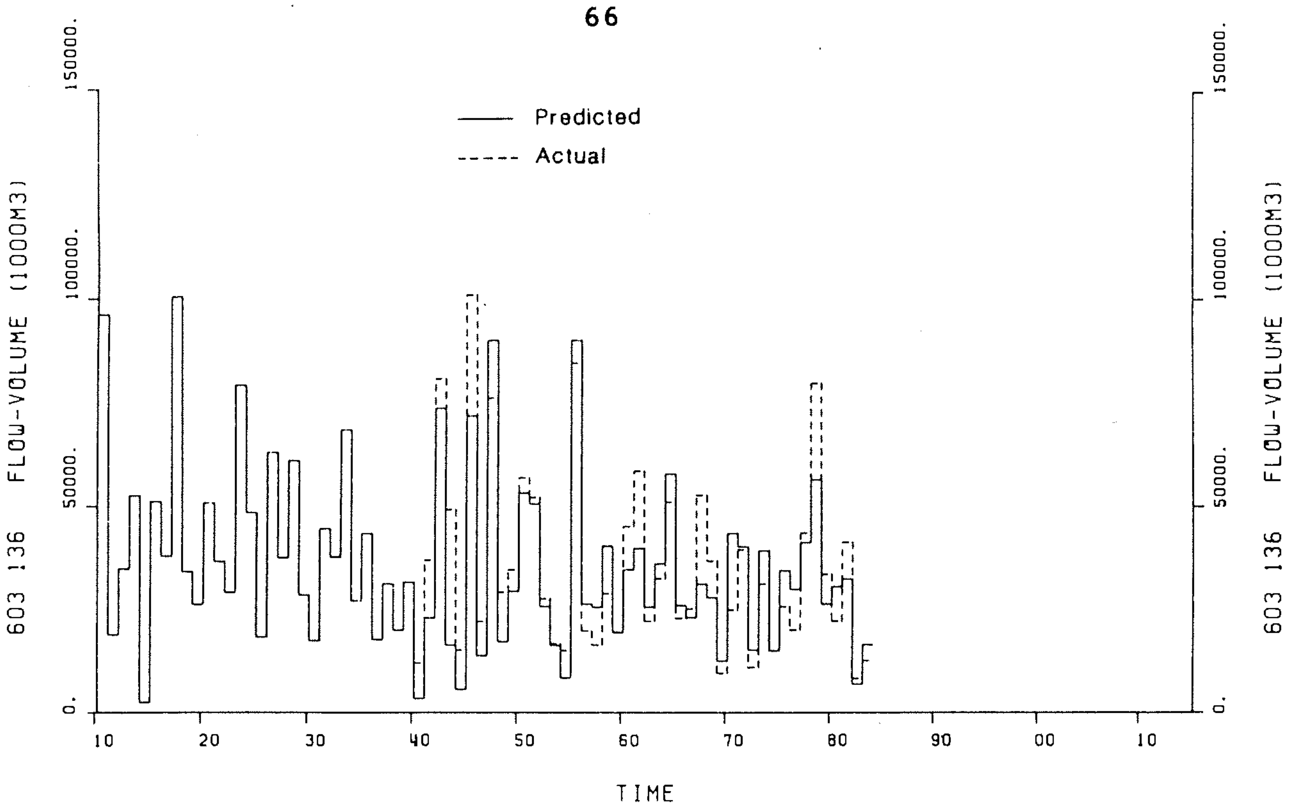

FIGURE 43 COMPARISON BETWEEN ACTUAL STREAMFLOW AND PREDICTED STREAMFLOW

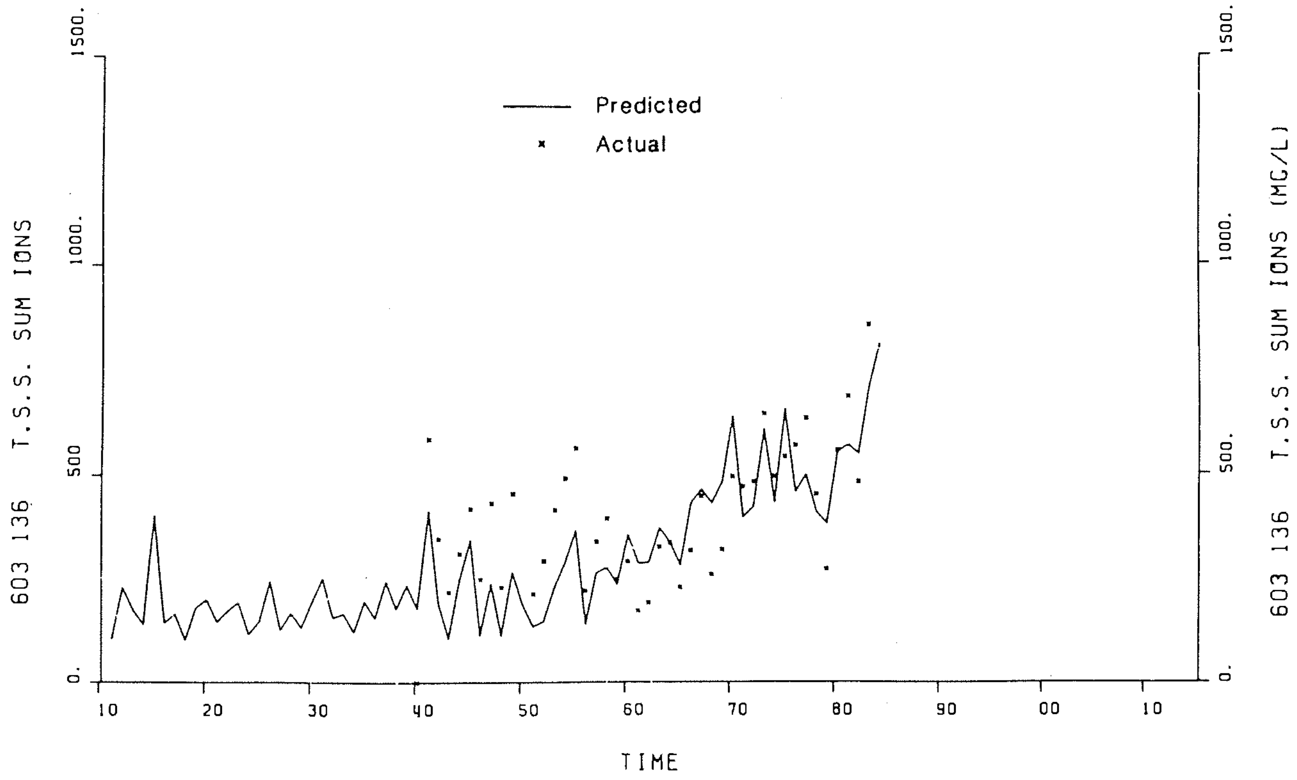

FIGURE 44 COMPARISON BETWEEN ACTUAL FLOW WEIGHTED SALINITIES AND PREDICTED ANNUAL SALINITIES

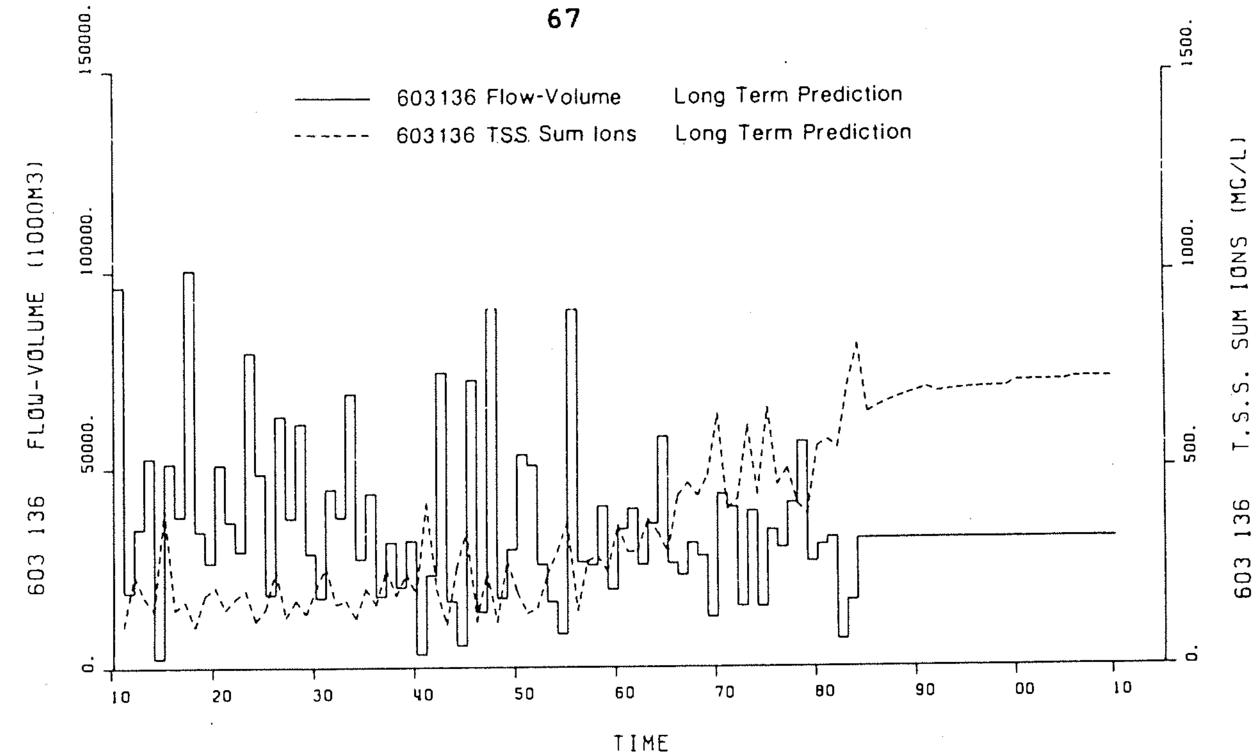

FIGURE 45 LONG TERM PREDICTION FOR STREAMFLOW AND SALINITY TO 2010

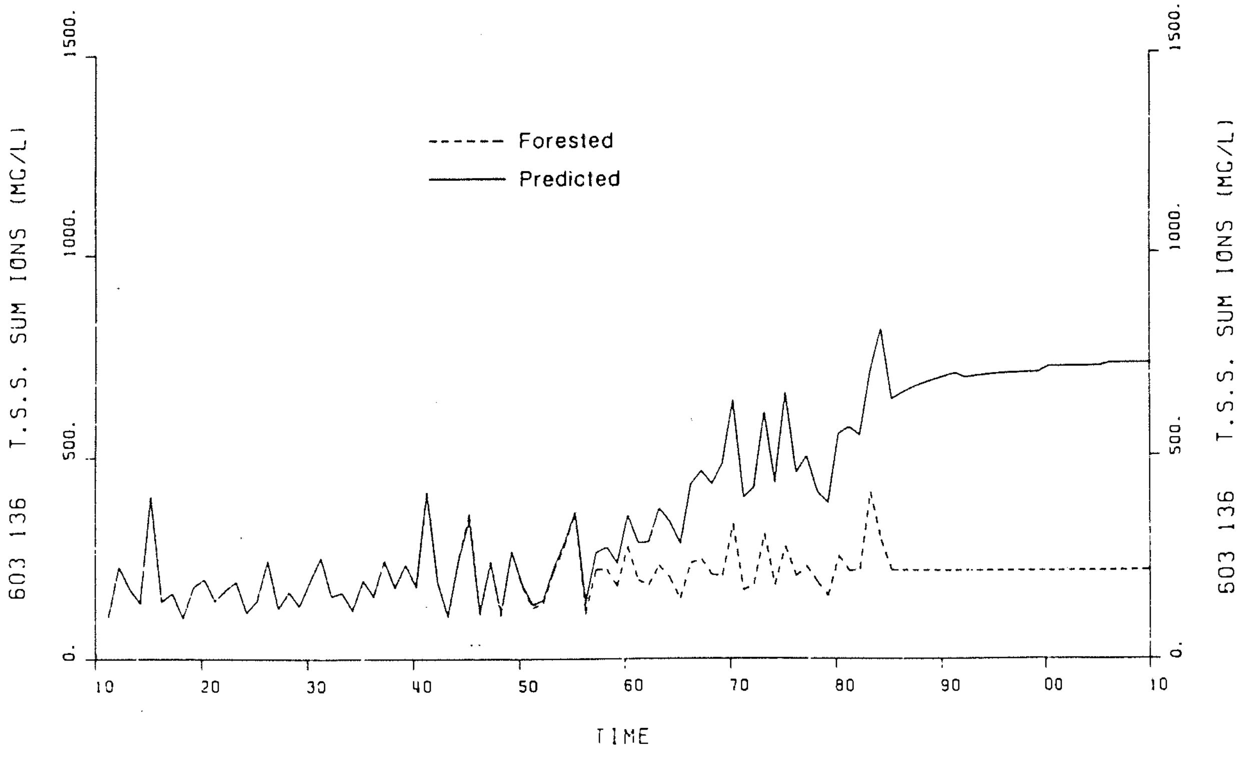

FIGURE 46 COMPARISON BETWEEN PREDICTED AND CONDITIONS FOR SALINITY COMPLETELY FORESTED

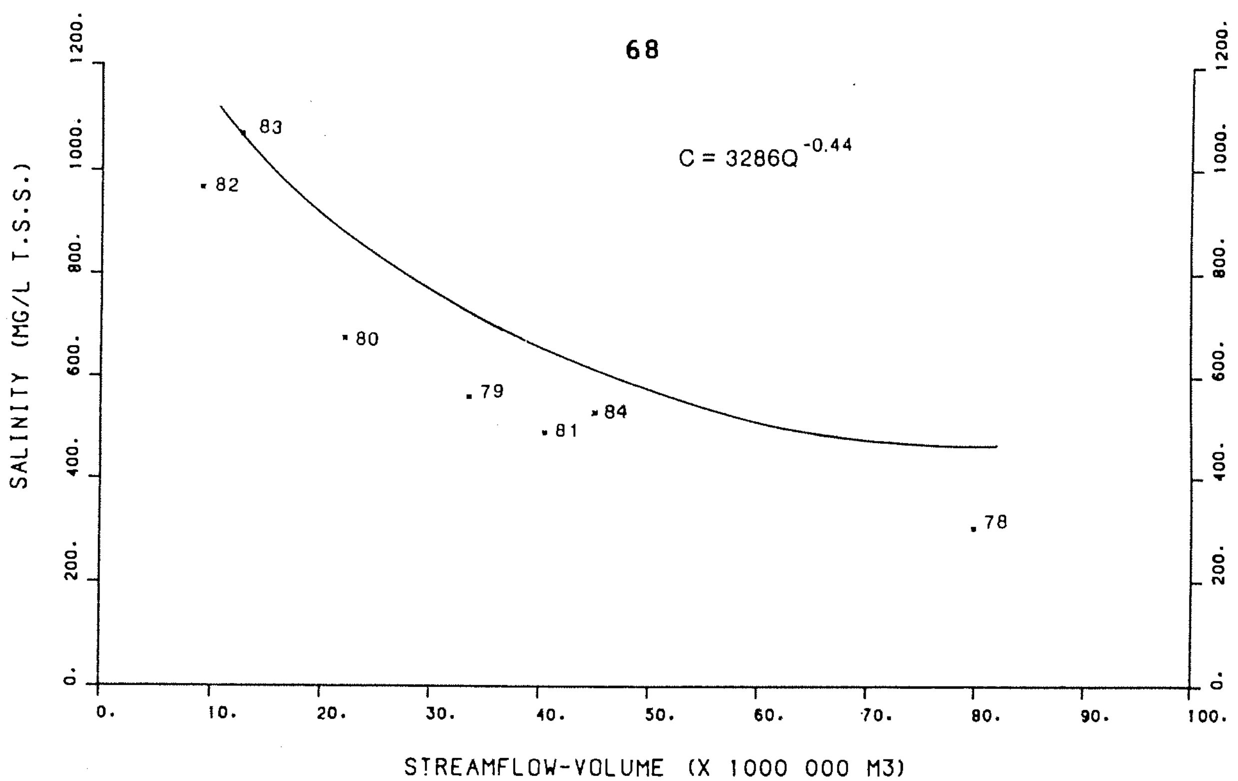

FIGURE 47 ANNUAL SALINITY VERSUS FLOW - EQUILIBRIUM RELATIONSHIP

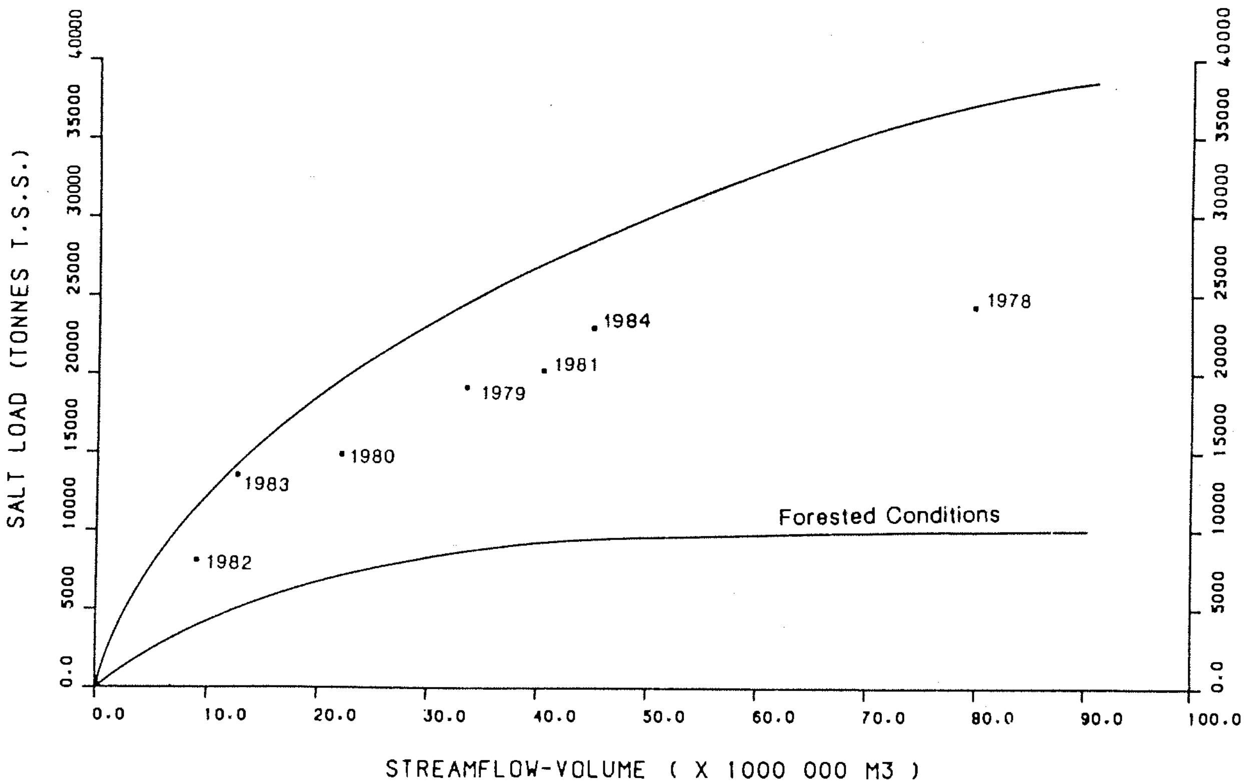

FIGURE 48 ANNUAL SALT LOAD VERSUS FLOW - EQUILIBRIUM RELATIONSHIP

TABLE 16 LONG TERM PREDICTIONS OF STREAMFLOW AND SALINITY

PROBABILITY OF NON-EXCEEDANCE	APR-OCT RAINFALL (mm)	STREAMFLOW PREDICTED ($x10^6m^3$)	SALINITY PREDICTED (mg L^{-1})
10%	538	11.8	1081
50%	674	32.0	726
90%	874	82.1	458

The plot of annual salt load versus annual streamflow is shown in Figure 48. Included in this diagram are the historical salt load values from 1978 to 1984, and the simulation of original conditions prior to the effects of clearing. The salt load data for 1979 to 1984 shows reasonable correlation with the equilibrium data. However the 1978 value is markedly lower than that predicted for that annual flow. One possible reason for the shortfall is because of the very large flows due to two intense rainfall events, with relatively fresh surface runoff and shallow sub-surface flow from the largely uncleared area below Kompup. However as the model is based on annual rainfall totals assumed to be representative on a catchment basis such events would also be expected to generate runoff from the partially cleared northern portion of the catchment. Hence, the total predicted salt load would be significantly higher.

Table 17 lists the flow and salinity statistics for three alternative simulations and the recorded streamflow from 1962-1983. The effect of clearing all private land in the Kompup catchment increases the mean flow by 3.4% however the increase in the mean salinity would be 10.5%.

TABLE 17 FLOW AND SALINITY STATISTICS

STATISTIC	EFFECT OF CURRENT CLEARING 1984	EFFECT OF ALL PRIVATE LAND CLEARED FROM KOMPUP	FULLY FORESTED CONDITION	RECORDED 1962-83
<u>FLOW</u> ($x10^6m^3$)				
Mean	37.7	39.0	27.6	30.1
St. Dev.	23.2	24.0	19.9	16.9
Max	107.4	110.4	86.6	79.9
Min	7.0	7.5	2.7	9.1
<u>SALINITY</u> ($mgL^{-1}TSS$)				
Mean	716	791	224	497
St. Dev.	158	178	74	200
Max	1133	1291	412	987
Min.	436	477	106	261

4.4.4 Generated Streamflow and Salt Loads

To enable a more detailed comparison of results between the recorded and simulated, 500 years of monthly streamflow and salt load were produced.

Annual mean, standard deviation and serial correlation were produced from the 1940 to 1983 rainfall period with the full effects of clearing. Mean monthly streamflows were produced from the recorded data of 1962 to 1983 multiplied by a weighting to take into account the full effects of clearing. This weighting was calculated as the mean annual streamflow from the simulated data from 1940 to 1983 divided by the mean annual streamflow from the recorded data of 1962 to 1983. The monthly standard deviation and serial correlations were produced from the recorded data of 1962 to 1983.

These annual and monthly streamflow statistics were the basis for the 500 years of streamflow record. To generate 500 years of data a Matalas moment transformation algorithm was used to preserve the moments and the lag one serial correlation. This algorithm assumes that the flow is log-normally distributed with two parameters for monthly and annual values. The statistical summary of the synthetic 500 years of streamflow is included as Appendix E.

To compare the generated streamflow with the historical record, an annual streamflow probability curve was produced (Figure 49).

The generated streamflow distribution is higher than the historical streamflow for the entire record. The reasons for this are firstly, that the period of record, 1962 to 1983 is within the land use change period, (the area of catchment cleared increased from 10.7% in 1962 to 18% in 1983), thus altering the catchment runoff characteristics. Secondly the period of record is considered to be one of relatively low rainfall, whereas the generated streamflows were produced from the higher, 1940 to 1983 rainfall sequence.

The monthly salt loads were generated by utilizing the streamflow to salinity relationship produced from the simulations. equation 4.4:-

$$C = 3286\ Q^{-.44} \qquad 4.4$$

This relationship was used to generate annual statistics for a 500 year simulation period, by applying it to the generated annual streamflows. These annual salinities were distributed into monthly salinities based on the mean monthly distributions for the historical record 1979-1983. The generated monthly salinities were then transformed into monthly salt loads with a correcting factor so that the sum of the monthly salt loads equalled the annual salt load. The statistics for the 500 years of generated salt load are listed in Appendix D.

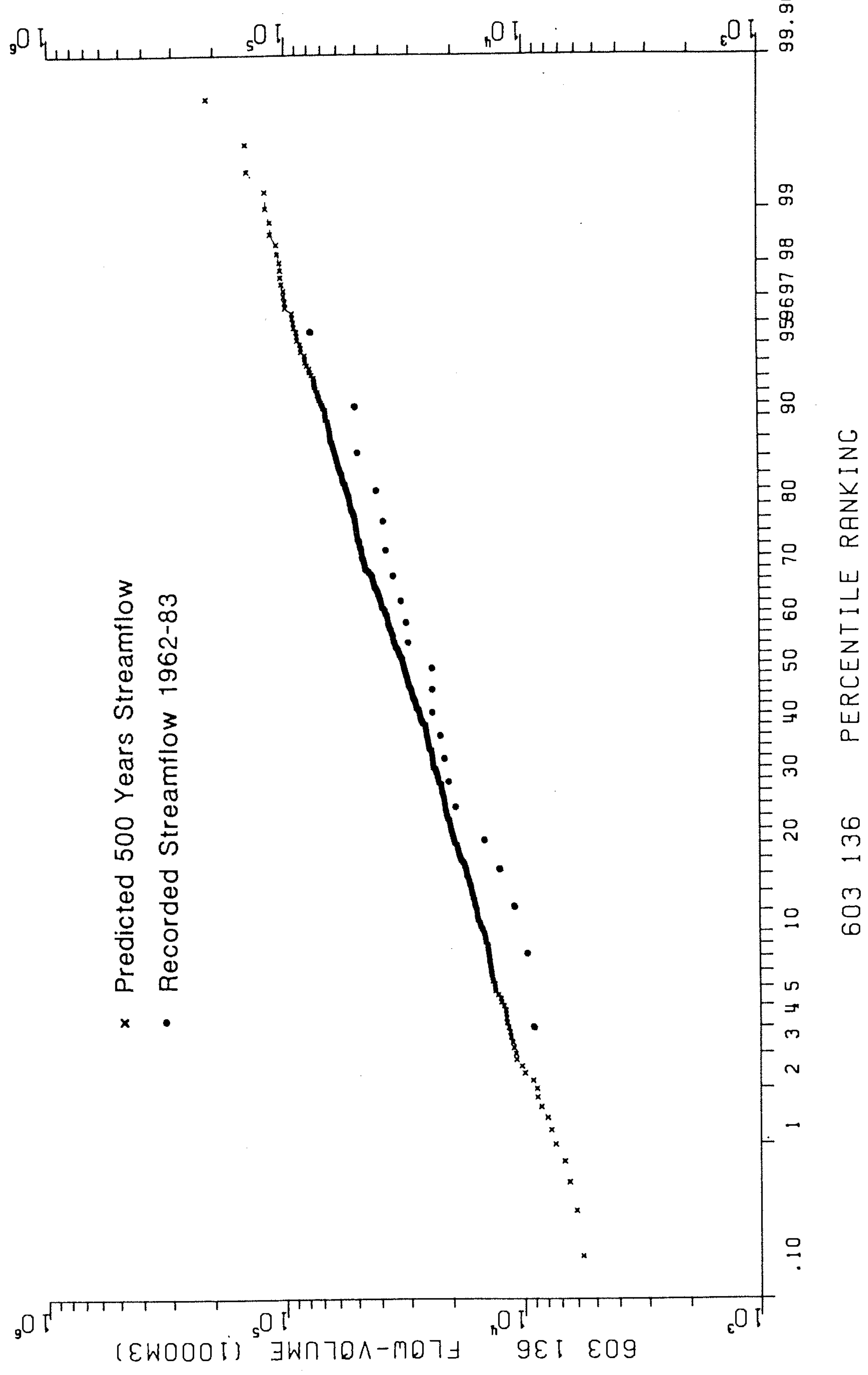

FIGURE 49 STREAMFLOW RANKING - 1962 TO 1983
RECORDED 500 YEARS GENERATED STREAMFLOWS

From these streamflow and salinity simulations the monthly mean salinities were compared to the historical monthly salinities from 1979 to 1983, by means of a cummulative distribution (Figure 50). This diagram shows that the probability of a monthly salinity greater than 800 mg L^{-1} TSS is currently estimated to be 46% and that this will increase to 63% at equilibrium conditions and that the comparison for 1000 mg L^{-1} TSS is 21% for the current data and 38% for equilibrium conditions.

4.5 Discussion and Summary

4.5.1 Assumptions

The major limitation in the streamflow and salinity simulations is the use of an annual time scale. Due to the inherent variability of rainfall events within individual years, the prediction of annual flows from annual rainfall does not simulate the variation in the record (ie. standard deviation). However coefficient of determinations over the period of comparison of .67 and .72 for annual streamflow and annual salinity are reasonable, within the limitations of the model.

In generating streamflow there was some difficulty in separating the initial or pristine conditions of the catchment from the additional flow due to a land use change. This was due primarily to little streamflow record for the initial, forested conditions especially for the 700-800 and 900-1000 zones.

The main assumption in the streamflow model itself is the linear increase in runoff with an increase in catchment area cleared. This does not take into account the location of the clearing and the topography, soil profile and groundwater depths.

The location of the clearing affects the streamflow response by two main characteristics. Clearing in streamline zones generally results in areas of saturation during rainfall events, which give very high runoff. These saturated areas are caused by the generally less permeable soils and the small depth to groundwater levels in the valley invert. In upland areas the soils are generally more permeable and usually more vegetation is retained, therefore the increase in streamflow after clearing is reduced in relation to other areas.

The major assumptions in the salt load model were:

(a) The area cleared is assumed to have a linear effect on the catchment salt load. However this is considered inaccurate because:

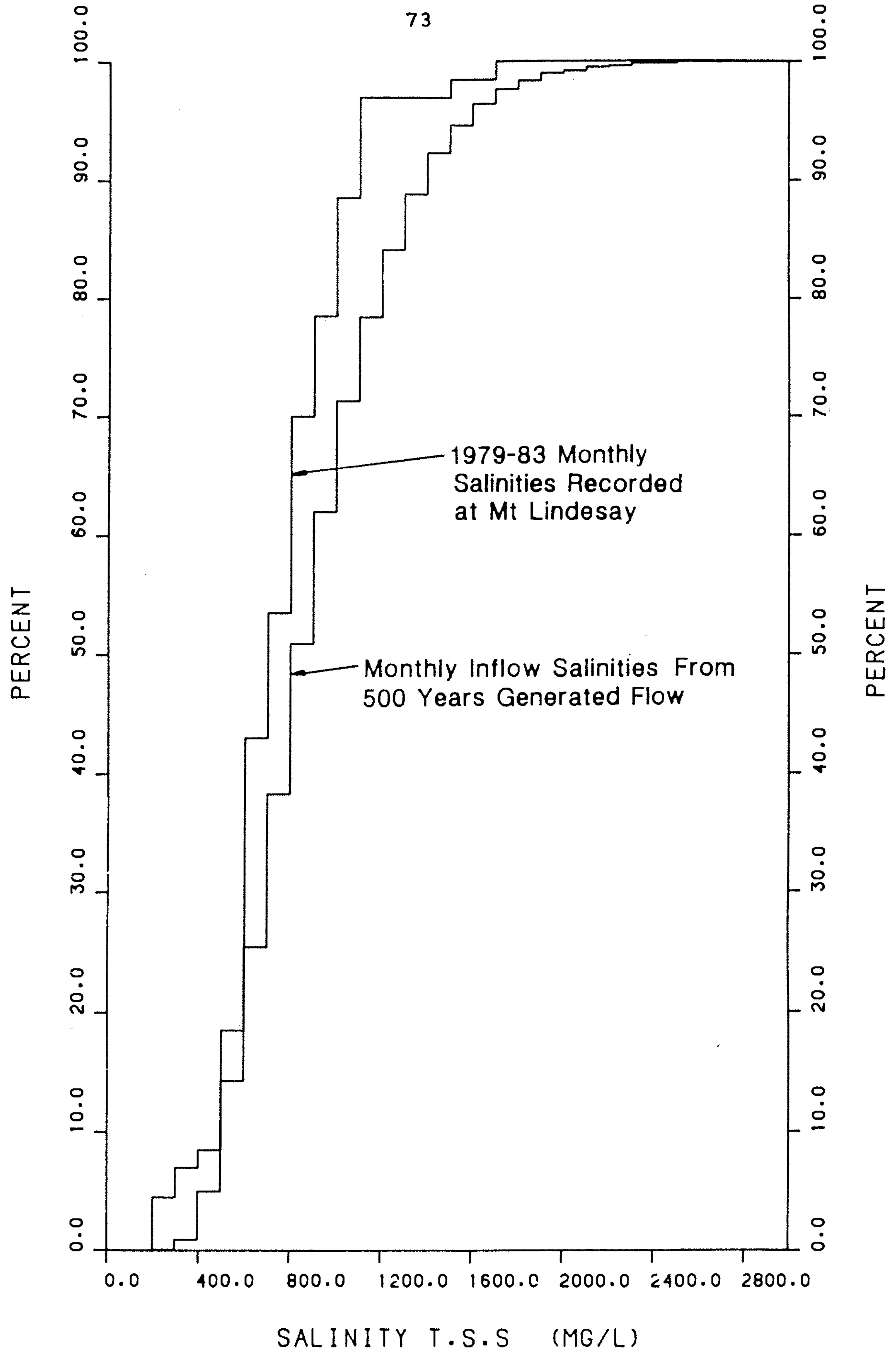

FIGURE 5Ø CUMULATIVE DISTRIBUTION - MONTHLY INLOW SALINITIES - PREDICTED AND RECORDED FROM MOUNT LINDESAY

(i) It does not take into account the spatial distribution of clearing (ie. whether the clearing is within a stream zone, midslope or upland). When the clearing is within a stream zone the depth to groundwater is small and therefore the response time for the input of high salinity groundwaters is less than if the clearing was undertaken in an upland area.

(ii) No account is taken of soil salt profile variability within the catchment. Johnston et al (1980) related the distribution of the profile form and salinity within a small catchment area to topography. In the upper landscape, monotonic salt profiles are common. The bulge type is usually encountered in valleys and lower slopes, but it also occurs in depressions and drainage lines of the upper landscape.

(iii) No account is taken of deep groundwaters completely saturating the pallid clay zone prior to 100% clearing.

(b) The groundwater salinity is assumed to remain constant over the land use change. Because of the prevalence of the bulge type soil salt profile the groundwater salinity will vary as the groundwater level rises. The process of salt diffusion is complicated and the equilibrium groundwater salinity can be less than the average soil solute concentration.

c) The area cleared is assumed to have a linear effect on the salt load contribution from the shallow sub-surface. This again does not take into account variations across the catchment in topography, soil profile and groundwater levels.

d) The recharge to groundwater assumes a linear relationship with rainfall. This again is a simplification of a complicated system.

e) Assumed delay function between groundwater recharge and discharge is empirically derived.

As a check on the validity of the simulation results, the salt load as an output to input ratio was compared between the simulation, the historical record and the results from previous analyses (Stokes and Loh, 1982). For the long term predictions the output over input ratio for chloride varies from 2.3 to 4:1 for the three percentile flows (10, 50, 90) whilst the historical data gives a ratio around 2:1. The data from 100% clearing of Wights catchment (Stokes and Loh, 1982) gave ratios of between 4.8 and 11.1:1. Therefore the data from the long term prediction is not considered to be over producing salt loads, but may be slightly conservative with respect to the data from Wights catchment.

4.5.2 Summary

Overall, the results from the simulation of streamflow and salt load, should be considered with respect to the limitations and assumptions made in the modelling. On a regional scale the results provide valuable insight into the relative magnitude of the effects of past and possible future land management on stream salinity.

The estimates of long-term median annual streamflow and median annual salinity are 32.0 x $10^6 m^3$ and 730 mg L^{-1} TSS.

Analysis of a 500 year sequence of inflow salinity showed that 62% of monthly salinities would be greater than 800 mg L^{-1} TSS and 38% of monthly salinities would be greater than 1000 mg L^{-1} TSS, assuming the full effects of clearing had developed.

5. RESERVOIR YIELD AND SALINITY SIMULATION

5.1 Aim

To determine the water yield and salinity statistics for a major storage development.

5.2 Reservoir Model

The simulation of likely reservoir water yield and salinity responses to future inflows was made using a monthly water and salt balance model. The basic inputs into the model program are reservoir characteristics, rainfall, evaporation, water and salt inflow, demand, and initial conditions. The water balance equation is:-

$$\text{STOR2} = \text{STOR1} + \text{INFLOW} + \text{DIRECT FLOW} - \text{DRAW} - \text{SCOUR} - \text{EVAPORATION LOSS} \qquad 5.1$$

STOR2 = Current months final storage
STOR1 = Previous months final storage
DIRECT FLOW = Direct increase in storage due to rainfall
INFLOW = Monthly streamflow into reservoir
DRAW = Current monthly draw demand
SCOUR = Reduction in storage due to scouring
EVAPORATION LOSS = Direct loss of storage from reservoir due to evaporation from water surface.

The method used in the salt balance is:-

i) The salt load in storage at the start of the period is determined.
ii) Salt inflows are added and total salt load is found.
iii) The average salinity for the period is determined using the total salt load and the volume of storage losses.
iv) All outputs from the reservoir (draw, scour and overflow) are taken at this salinity, which is the salinity at the beginning of the next period.
v) Salt load in storage at the end of the month is calculated.

The salt balance assumes complete mixing of the reservoir with a constant salinity over the entire depth of water in the reservoir. Approximations to the output salinities are inherent due to the assumptions made in the water balance.

5.3 Simulation Parameters

5.3.1 Reservoir Characteristics

The most likely reservoir location is at the Mt Lindesay gauging station (603136). The reservoir storage - elevation and the reservoir surface area - elevation data are shown in Figures 51(a) and (b).

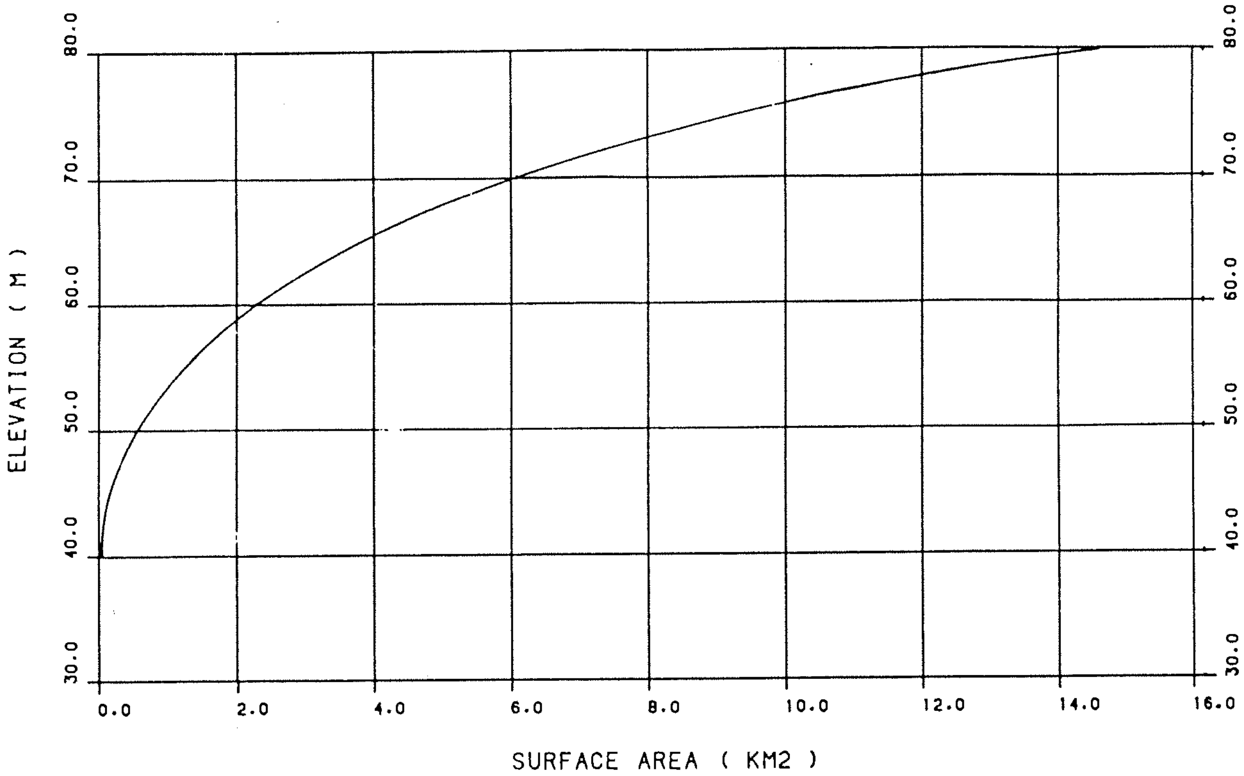

FIGURE 51 a MOUNT LINDESAY RESERVOIR ELEVATION - STORAGE RELATIONSHIP

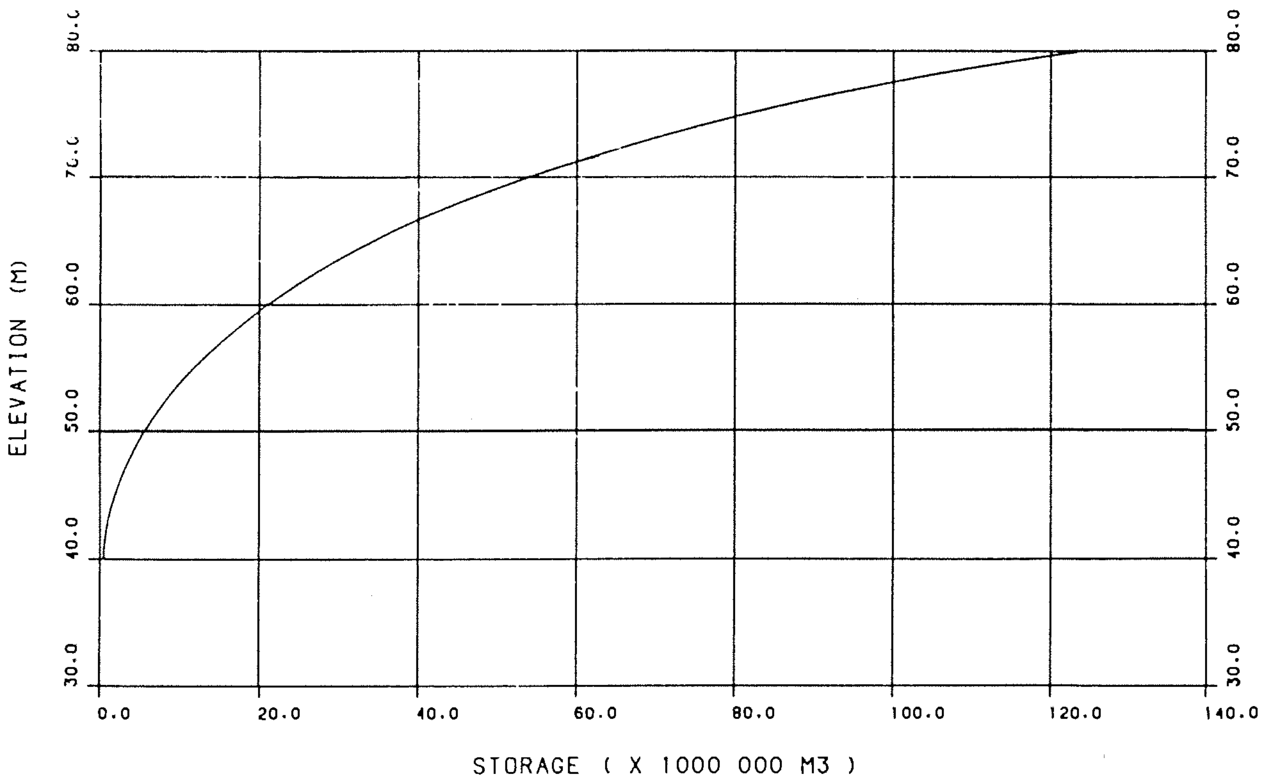

FIGURE 51 b MOUNT LINDESAY RESERVOIR ELEVATION - SURFACE AREA RELATIONSHIP

Some physical properties of the reservoir are:

Lowest drawable level = 48.0 m
Scour rate = 0.0
Catchment Area = 525.4 km^2

The overflow rate is set at instantaneous and infinite while the crest level varies with the storage size of the reservoir.

5.3.2 Rainfall

A 500 year synthetic sequence of monthly rainfall data was produced from the generated streamflow data at Mt Lindesay (603 136). This was achieved by calculating the streamflow to rainfall correlation between streamflow and annual rainfall for Mt Lindesay (see Figure 52). This correlation was used to obtain a corresponding rainfall history from the 500 years generated flow, by using the program RAINGEN. Appendix D details the statistics for the synthetic 500 years monthly rainfall. This correlation is between the Mt Lindesay catchment flow and the catchment rainfall. Therefore to obtain the rainfall record for the Mt Lindesay reservoir the catchment rainfall is factored by a rainfall coefficient.

The salinity of the rainfall has been calculated at 20 mg L^{-1} TSS from Hingston and Gailitis (1976).

5.3.3 Evaporation

The monthly evaporations for the reservoir simulation were calculated from the Albany Airport Class A pan evaporation data. The annual lake to pan coefficient used in this study was 0.8 (Hoy & Stephens, 1979). A monthly distribution of lake to pan coefficients was not used in this preliminary analysis of a proposed reservoir as the accuracy implied was not considered appropriate considering the confidence limits of the other input data.

5.3.4 Water and Salt Inflow

Monthly streamflows and salinities into the reservoir were generated in section 4. These were based on the long term effects of the present level of clearing in the catchment as simulated from the flow and salt model and the recorded streamflow and salinity for the period 1962 to 1983.

5.3.5 Demand

The water supply demand for the reservoir simulations was varied from between 18.9 x $10^6 m^3$ to 34.0 x $10^6 m^3$ (see Table 18).

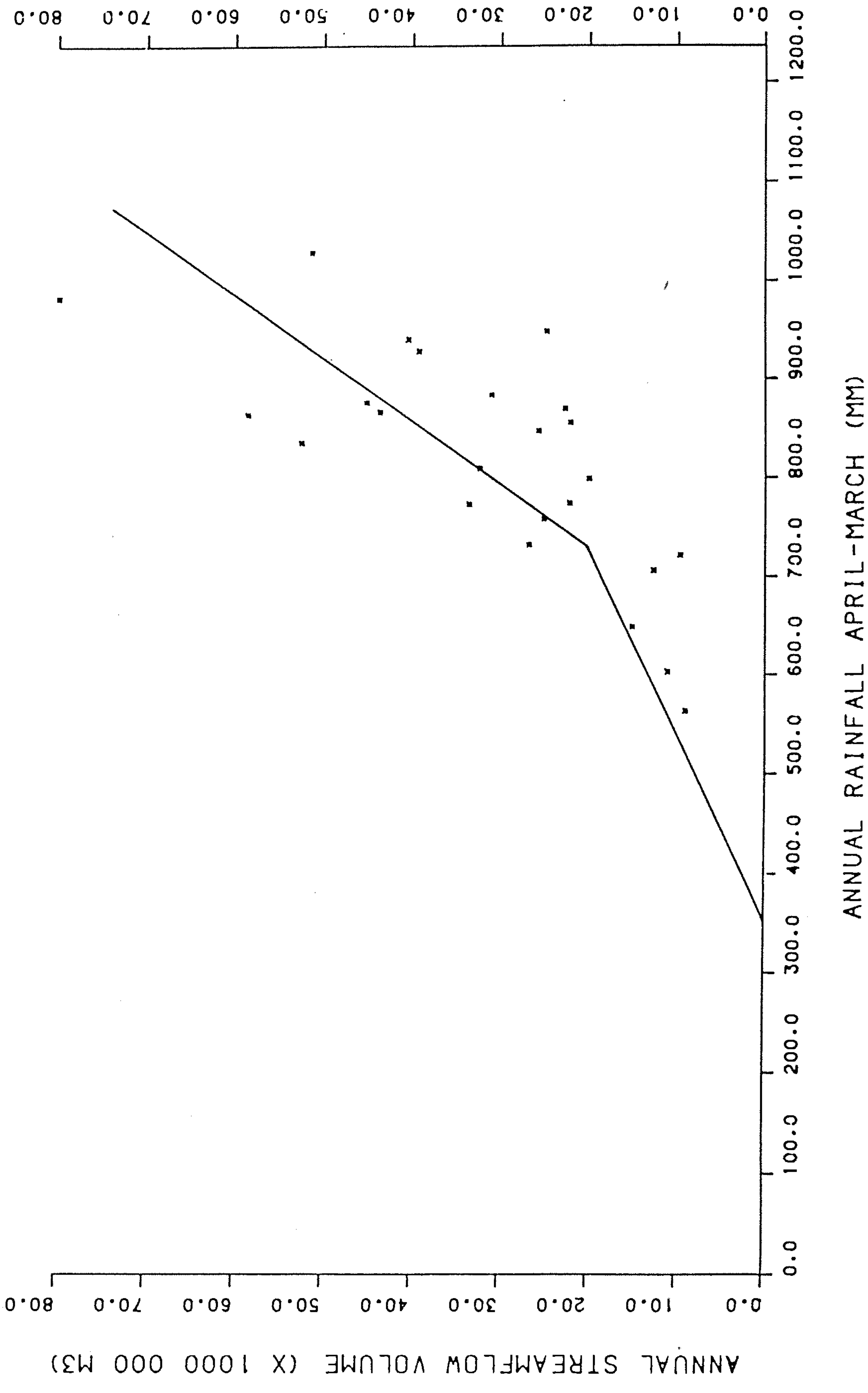

FIGURE 52 MOUNT LINDESAY ANNUAL RAINFALL VERSUS STREAMFLOW

TABLE 18 DEMAND DISTRIBUTION AND DEMAND FLOWS

MONTH	DEMAND DISTRIBUTION	50% MAF (10^3m^3)	60% MAF (10^3m^3)	70% MAF (10^3m^3)	80% MAF (10^3m^3)	90% MAF (10^3m^3)
Jan	0.153	2892	3470	4044	4627	5205
Feb	0.127	2400	2880	3357	3840	4320
Mar	0.093	1758	2110	2458	2812	3164
Apr	0.070	1323	1590	1850	2117	2381
May	0.057	1077	1292	1507	1724	1939
Jun	0.056	1058	1270	1480	1693	1905
Jul	0.052	983	1180	1375	1572	1769
Aug	0.053	1002	1200	1401	1003	1803
Sep	0.061	1153	1383	1613	1845	2075
Oct	0.073	1380	1656	1930	2208	2483
Nov	0.089	1682	2018	2353	2691	3028
Dec	0.115	2174	2609	3040	3478	3912
ANNUAL	1.000	18882	22658	26408	30210	33984

5.3.6 Initial Conditions

For all simulations the reservoir was assumed full for the first month and the initial salinity of the reservoir was set at the median annual salinity of inflow of 730 mg L^{-1} TSS. The starting month of the simulation was January and the number of years of simulation 500.

5.4 <u>Reservoir Simulation Results</u>

5.4.1 Water Yield

From the various simulations a summary of yield is shown in Table 19. This data was also plotted as a set of reliability curves in Figure 53. From the reliability diagram, for a recurrence interval of failure of greater than approximately 30 years, there is a constant gain in annual draw which can be attained from an increase in storage. Also of note is the sensitivity of the annual draw to the recurrence interval of failure for relatively large recurrence intervals. However it is noted that in practice a reservoir would not be run dry, but water restrictions would be implemented.

TABLE 19 SUMMARY OF YIELD

STORAGE		ANNUAL DRAW 2% PROB OF FAILURE		ANNUAL DRAW 5% PROB OF FAILURE	
x $10^6 m^3$	% MAF	x $10^6 m^3$	% MAF	x $10^6 m^3$	% MAF
37.7	100	21.5	57	23.8	63
56.6	150	23.4	62	25.6	68
75.4	200	26.4	70	29.0	77
113.1	300	29.0	77	30.8	81

5.4.2 Water Quality

The salinity of the monthly draw is calculated by a salt balance which takes into account the salinity of the inflow, salinity of the storage and the level of storage, while assuming that complete mixing occurs at the beginning of each month. The comparison of draw salinities for the extreme simulation parameters is shown in Figure 54. For the extreme parameters, the smallest storage and largest demand has been considered as the maximum case, while the largest storage and smallest demand as the minimum case. From Figure 54 the minimum case has zero probability of draw salinities greater than 1000 mg L^{-1} TSS while the maximum case has 4% of its draw salinities above 1000 mg L^{-1} TSS. The maximum case has a greater proportion of salinities less than 600 mg L^{-1} than the minimum case. This is shown more clearly in Figure 55, which defines the difference between the maximum and minimum case and the difference between the maximum case and the inflow salinity. The benefit of a reservoir, even the maximum case, (which is the smallest reservoir) is very clear from Figure 55, especially the reduction in the probability of high salinities.

The probability of exceedance for a specific salinity value for a constant reliability of reservoir size is shown in Figure 56. The lines for specific salinities have been extrapolated to the run of river values for a reservoir size of zero. For a storage greater than 150% mean annual inflow (MAI) the probability of exceeding 900 mgL^{-1} or 1000 mgL^{-1} is relatively constant at 2.5% and 0.5% respectively. However, for 800 mgL^{-1} the probabilities range from 17.5% to 11%. These increase substantially for smaller storage.

Figure 57 details the probability of exceeding 800 mgL^{-1} TSS and 1000 mgL^{-1} TSS respectively for the complete range of storage and draw reservoir simulations. The plot of the probability of exceeding 800 mgL^{-1} TSS shows a greater change in probability for a constant demand and varying storage than the plot for exceeding 1000 mgL^{-1} TSS.

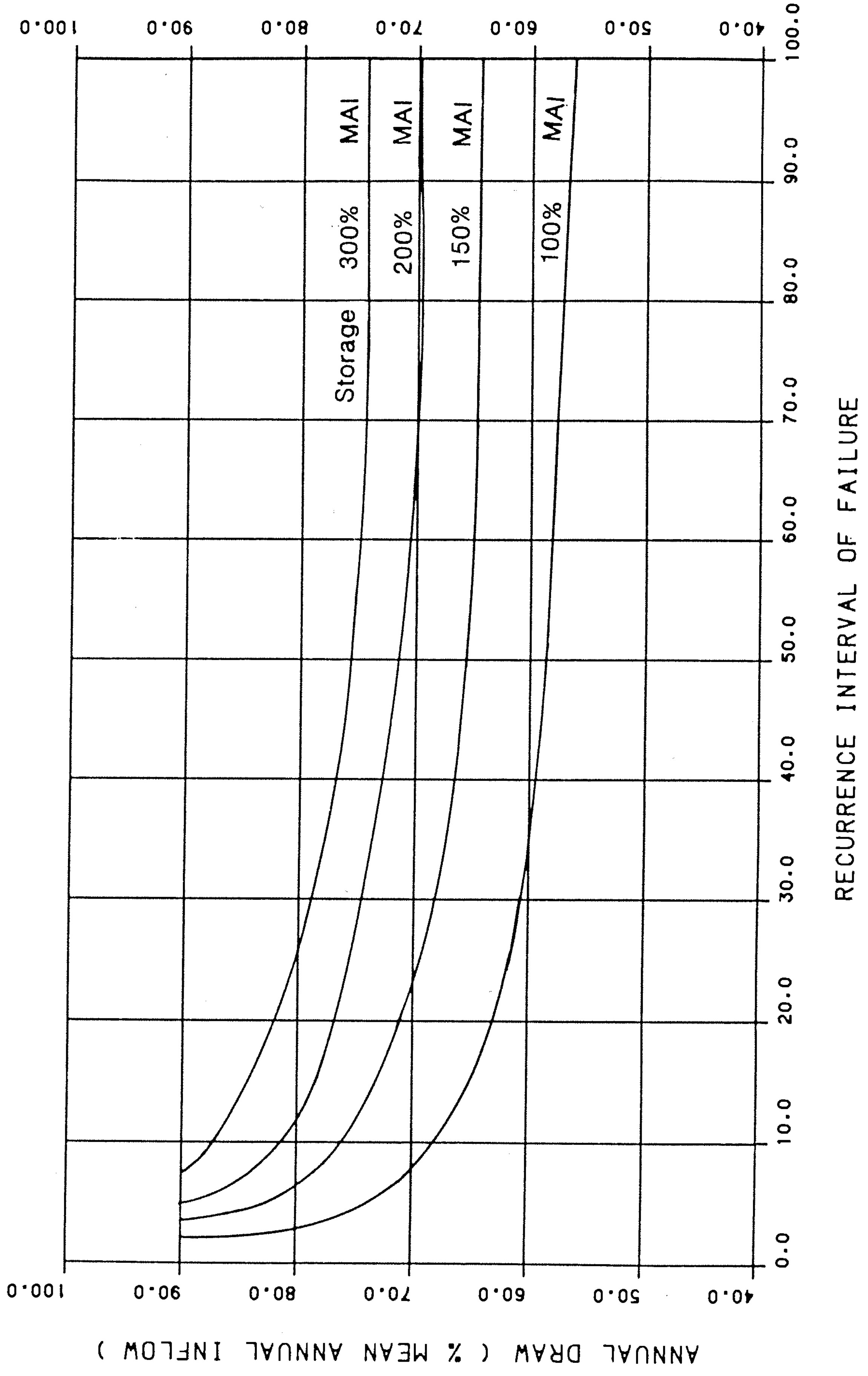

FIGURE 53 MOUNT LINDESAY RESERVOIR RELIABILITY CURVES

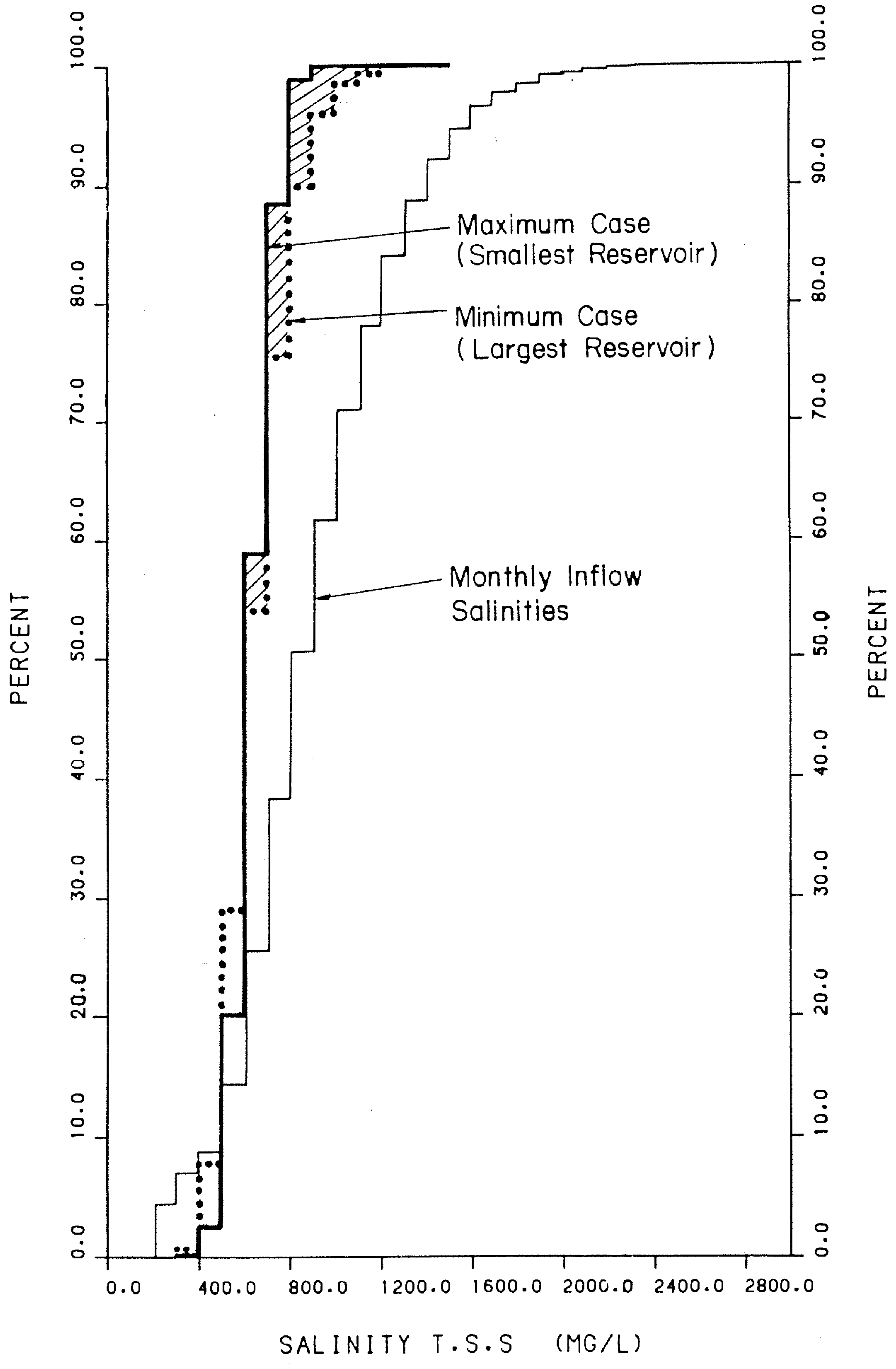

FIGURE 54 CUMULATIVE DISTRIBUTION
-INFLOW SALINITIES ; MAXIMIUM ; MINIMUM

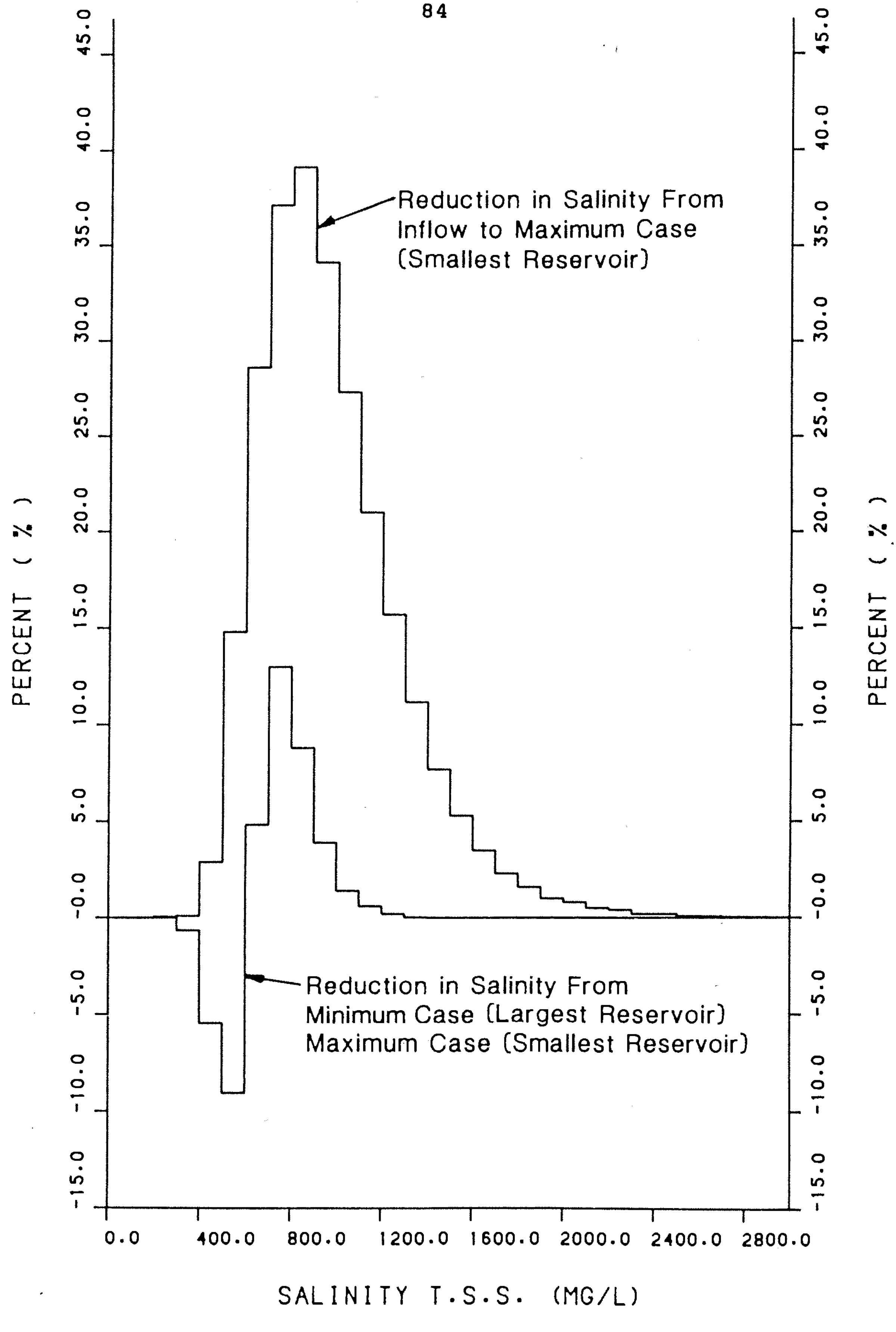

FIGURE 55 COMPARISON OF MAXIMUM TO MINIMUM AND OF INFLOW SALINITY TO MAXIMUM

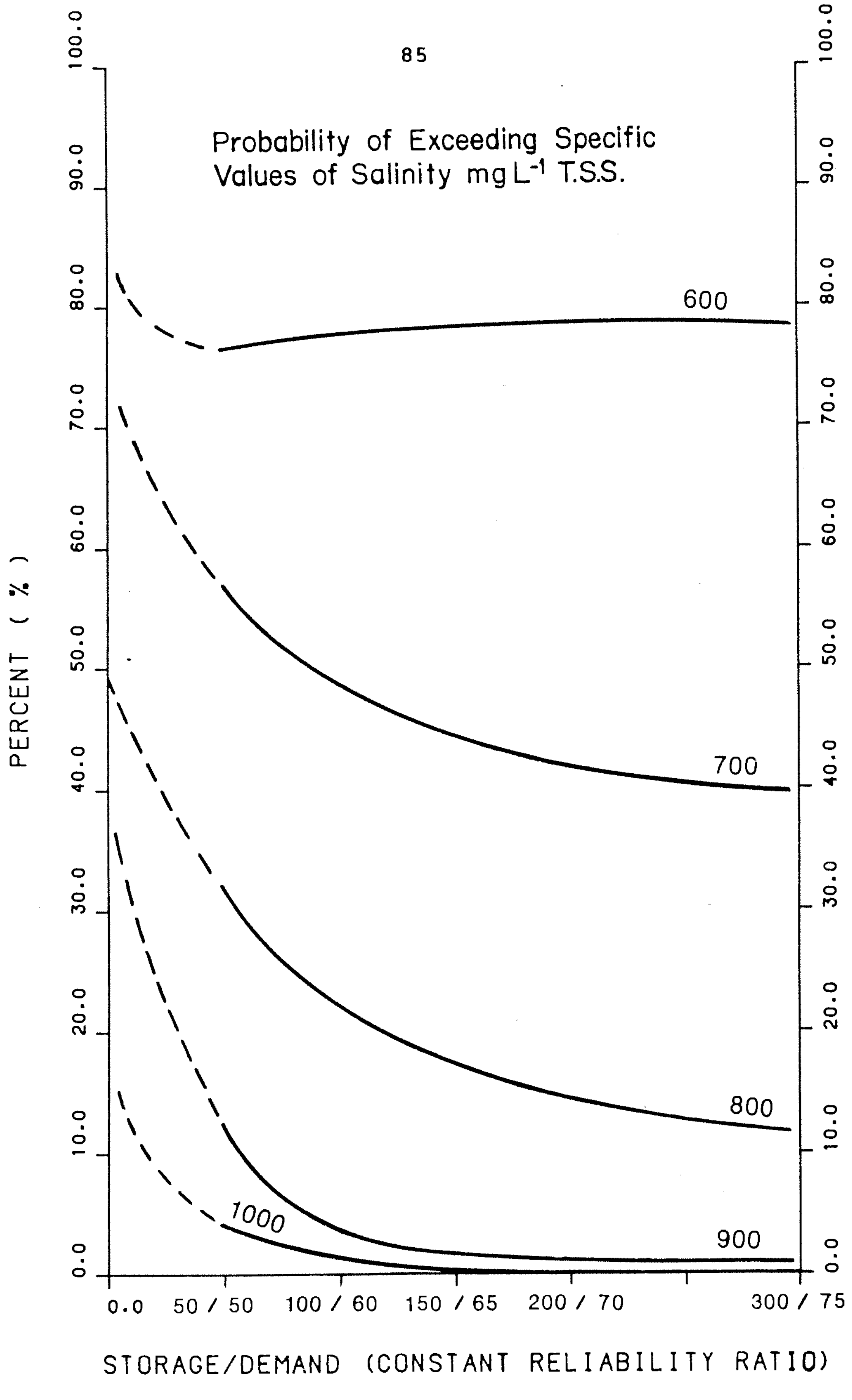

FIGURE 56 PROBABILITY OF EXCEEDANCE FOR CONSTANT RELIABILITY

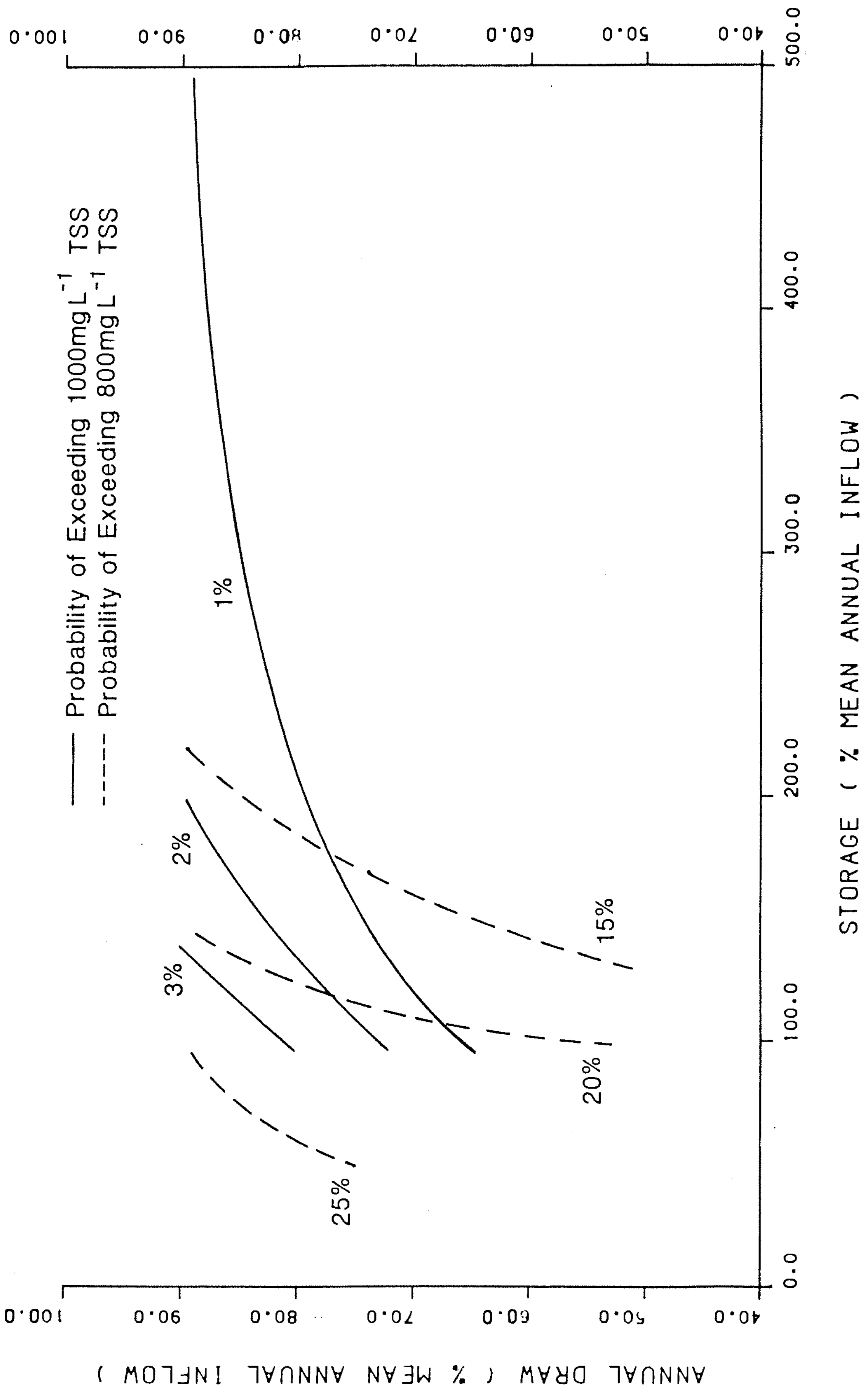

FIGURE 57 PROBABILITY OF EXCEEDANCE OF 800 mg L^{-1} AND 1000 mg L^{-1} TSS FOR DEMAND AND STORAGE COMBINATIONS

5.4.3 Restrictions

To simulate realistic conditions a simulation was included which introduced restrictions on the demand if the storage level was below a specified level. A minimum storage was set which varied depending on the month (a higher minimum was stipulated after winter than just prior). The restriction level was set at 70% of the monthly demand. The effect of this restriction scenario on the 300% MAF storage and a demand of 80% MAF simulation was to alter the probability of exceeding 800 mg L^{-1} TSS and 1000 mg L^{-1} TSS from 11.24% to 11.4% and 0.4% to 0.2% respectively. These differences are very small but the main effect is to reduce the number of monthly salinities exceeding 1100 mg L^{-1} TSS from 7 to 0.

5.5 Discussion and Summary

A monthly water and salt balance reservoir program was utilised to simulate 500 years of reservoir operation. This required the streamflow and salt loads from the results of the yield and salinity simulation, in section 4. From the streamflow record a historical rainfall record was generated. The range of reservoir capacities varied from 38 x $10^6 m^3$ (100% MAI) to 113 x 10^6 (300% MAI), while the range of demand outflows varied from 22.6 x $10^6 m^3$ (60% MAI) to 33.9 x $10^6 m^3$ (90% MAI).

The yield and reliability curves define the reservoir performance for these different reservoir sizes and demands are presented in Table 19 and Figure 53. It was found that for a recurrence interval of failure of greater than 30 years there is a form of steady state condition. However, in these steady conditions, for a specific size of reservoir, a small increase in the demand brings a correspondingly large increase in the probability of failure.

In terms of water quality, the simulations indicate that the reservoir produces an overall reduction in the salinity of the streamflow, particularly for salinities greater than 600 mgL^{-1} TSS, and an eradication of salinities above 1500 mgL^{-1} TSS.

For a constant reliability there is a relatively consistent probability of exceeding 900 mgL^{-1} TSS and 1000% TSS from 150% MAI to 300% MAI storage. However, the 800 mgL^{-1} TSS probability of exceedance varies from 21% to 11% over the storage range of 100% MAI to 300% MAI.

The probability of exceeding 800 mgL^{-1} TSS is relatively constant over the range of demands for a particular storage. For the probability of exceeding 1000 mgL^{-1} TSS there is as much variation in varying storage as there is in varying demand.

All simulations gave a probability of exceeding 800 mg/L in the range 25 to 15%. However, most storages show an ability to reduce the incidence of monthly outflows exceeding 1000 mgL^{-1} to less than 2%. These water qualities are derived without taking into account a stratified reservoir, a scouring policy, or restrictions during low storage. Therefore, a corresponding decrease in the probability of achieving 800 and 1000 mgL^{-1} TSS respectively could be expected under actual operating conditions.

6. DISCUSSION AND SUMMARY

All available data on rainfall, soil salt storage, streamflow, stream salt yield and clearing history was collated for the Denmark River Basin for the simulation of streamflow and salinity.

The results from the simulations indicate that the full effects of clearing will be reached early next century, with a median annual streamflow and median annual salinity at these equilibrium conditions of 32 x 10^6m^3 and 730 mgL^{-1} TSS. The 10% and 90% probabilities of non-exceedance of streamflow are estimated to be 12 x 10^6m^3 and 82 x 10^6m^3 respectively, with associated salinities of 1080 and 460 mgL^{-1} TSS. This will mean that approximately 62% of monthly salinities will be greater than 800 mgL^{-1} TSS and 38% of mean monthly salinities will be greater than 1000 mgL^{-1} TSS. These salinities represent at least a further 20% deterioration in the quality of the resource.

A proposed reservoir located at the Mt Lindesay gauging station was simulated using a monthly water and salt balance, with a reservoir size range between 100% and 300% of mean annual inflow (MAI) and for demands between 60% and 90% MAI. The results from this modelling indicated a significant reduction in the probabilities of monthly draw salinities with the probability of exceeding 800 mgL^{-1} TSS reduced to 20% and that of exceeding 1000 mgL^{-1} TSS reduced to less than 2% for most storage sizes. To achieve more accurate probabilities of water quality a finer time scale and water management policies need to be introduced into the reservoir modelling.

In general, the resource will be of marginal quality even with a large scale reservoir development. Nonetheless it would greatly assist in dampening the short term, seasonal and annual effects of sequences of highly saline flows.

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APPENDIX A

RAINFALL STATISTICS

PUBLIC WORKS DEPARTMENT
WATER RESOURCES SECTION

DENMARK RIVER MT LINDES
N 6141550 E 528650

STATION NO. 603 136
COPY NUMBER (1)

CATCHMENT AREA 525.4 SQ.KM

MONTHLY TOTAL

ACCUMULATED RAINFALL
IN MILLIMETRES

YEAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	ANNUAL
1910	57.*E	149.*E	207.*E	285.*E	150.*E	86.*E	117.*E	65.*E	20.*E	0.	7.*E	44.	1199.*E
1911	35.	57.	30.	171.	84.	94.	92.	11.	34.	10.	6.	33.	739.
1912	20.	91.	115.	233.	70.	165.	48.	43.	20.	27.	11.	53.	902.
1913	215.	53.	30.	126.	167.	104.	91.	25.	83.	2.	92.	52.	1093.
1914	37.	60.	79.	118.	44.	36.	44.	120.	37.	26.	59.	53.	733.
1915	40.	74.	127.	154.	194.	155.	78.	33.	5.	30.	37.	22.	950.
1916	27.	86.	135.	186.	164.	31.	132.	55.	10.*E	29.	37.	140.	1041.*E
1917	130.	231.	229.	148.	142.	163.	90.	14.	52.	100.	91.	47.	1408.
1918	45.	148.	179.	44.	129.	77.	85.	37.	15.	8.	34.	17.	859.
1919	109.	59.	52.	151.	132.	79.	83.	47.	15.	8.	62.	52.	890.
1920	34.	110.*E	220.	130.	196.	80.	45.	20.	14.	38.	52.	11.	967.*E
1921	41.	150.	55.	130.	105.	106.	93.	44.	55.	19.	26.	33.	948.
1922	90.	164.	102.	187.	131.*E	72.*E	53.*E	57.	57.	14.	6.	39.	992.*E
1923	35.	220.	249.	139.	102.	172.	60.	13.	15.	12.	19.	12.	1058.
1924	17.	150.	97.	95.	153.	116.	174.	70.	11.	35.	21.	44.	1001.
1925	76.	92.	75.	115.	45.	84.	127.	20.	49.	[illegible]	41.	69.	928.
1926	143.	53.	51.	239.	113.	114.	114.	70.	25.	41.	14.	100.	1143.
1927	35.	99.	140.	110.	111.	154.	102.	17.	19.	56.	6.	28.	860.
1928	113.	99.	134.	165.	156.	133.	77.	15.	24.	9.	30.	26.	988.
1929	59.	137.	135.	105.	100.	67.	51.	102.	30.	1.	11.	33.	894.
1930	43.	114.	104.	151.	70.	107.	38.	43.	52.	10.	14.	23.	751.
1931	71.	109.	113.	149.	144.	139.	53.	20.	32.	12.	13.	21.	876.
1932	59.	101.	137.	148.	155.	82.	79.	33.	15.	41.	6.	54.	913.
1933	59.	137.	231.	125.	117.	110.	135.	45.	23.*E	19.	6.	94.	1109.*E
1934	41.	55.	129.	142.	109.	135.*E	102.	57.	45.	37.	35.	14.	909.*E
1935	54.	49.	130.	199.	120.	120.	59.	17.	34.	39.	6.	4.	894.
1936	32.	113.	130.	110.	138.	55.	56.	17.	20.	16.	7.	52.	754.
1937	57.	170.	75.	111.	143.*E	92.	77.	33.	17.	9.	7.	35.*E	831.*E
1938	49.*E	120.	125.*E	124.*E	106.*E	60.	51.	37.	25.	159.	30.	16.*E	921.*E
1939	36.*E	105.	136.	113.*E	193.*E	27.	132.*E	53.	5.	16.	6.	5.	829.*E
1940	58.	34.	55.*E	95.*E	53.	70.	43.	52.	41.	11.*E	12.	131.	668.*E
1941	73.	68.	105.	125.	104.	126.*E	59.	41.	5.	21.	6.	67.	824.*E
1942	149.	150.	149.	111.	159.	124.	95.	25.	15.	37.	41.	171.	1294.
1943	111.	[illegible]	7.	161.	92.	59.	22.	19.	35.	11.	17.	21.	723.
1944	37.	117.	[illegible]	151.*E	61.	68.	22.	27.	75.	8.*E	11.	57.	705.*E
1945	29.	139.	205.*E	155.	201.	149.	36.	33.	55.	10.	8.	15.	1029.*E
1946	21.	110.	145.	147.	83.	48.	39.	74.	45.	10.*E	22.*E	21.*E	785.*E
1947	155.*E	116.*E	225.*E	135.*E	61.*E	102.*E	197.*E	52.*E	34.*E	5.	3.	20.	1135.*E
1948	55.	45.	95.	132.*E	119.	117.	60.	70.	30.	21.	3.	46.	791.*E
1949	50.	51.	71.	155.	115.	51.	160.	55.	5.	23.	4.	5.	790.

KEY

NA RECORD NOT AVAILABLE
NR NOT RECORDED
* FAULTY - VERY CONFIDENT IN CORRECTED TRACE
** FAULTY - SOME DOUBT IN CORRECTED TRACE
*E ESTIMATED TRACE
\# DERIVED FROM INCOMPLETE RECORD

PROGRAM PULIST
PROCESSED ON 11.47 07 NOV 1985

COLLECTING AUTHORITY WATER RES(03)

YEARS 1910 - 1949
STATION NO. 603 136

PUBLIC WORKS DEPARTMENT — WATER RESOURCES SECTION
DENMARK RIVER — N 6141550 E 528650
MT LINDES
STATION NO. 603 136
COPY NUMBER (1)

CATCHMENT AREA 525.4 SQ.KM — MONTHLY TOTAL — ACCUMULATED RAINFALL IN MILLIMETRES

YEAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	ANNUAL
1950	4.	234.	120.	160.	84.	123.	85.	63.	34.	37.	55.	17.	1017.
1951	125.	100.	154.	97.	138.	107.	75.	44.	77.	58.	12.	58.	1051.
1952	43.	114.	150.	103.	85.	97.	103.	64.	39.	7.	49.	13.	848.
1953	57.	79.	120.*E	102.	73.	83.	99.	80.	27.	16.	7.	23.	759.*E
1954	54.	34.	79.	107.*E	79.	56.	52.	54.	21.	24.	187.	25.	834.*E
1955	147.	95.	137.	140.	221.	104.	149.	33.	45.	2.	8.	79.	1160.
1956	45.	130.	139.	156.*E	56.	58.	84.	40.*E	43.*E	17.*E	15.*E	59.*E	847.*E
1957	75.*E	95.*E	137.*E	70.*E	121.*E	56.*E	53.*E	5.*E	24.*E	38.*E	37.*E	15.*E	782.*E
1958	74.*E	123.*E	55.*E	201.*E	87.*E	122.*E	73.*E	42.*E	35.*E	9.	30.	18.	879.*E
1959	48.	52.	119.	73.	101.	136.	95.	87.	37.	33.	10.	134.	908.
1960	38.	131.	90.	229.	68.	81.	35.	15.	25.	42.	25.	46.	876.
1961	207.	29.	127.	165.	116.	58.	49.	14.	55.	1.	13.	26.	864.
1962	15.	100.	123.	114.	135.	61.	106.	40.	51.	41.	23.*E	45.	856.*E
1963	44.	215.	59.*E	154.*E	127.	59.*E	49.	31.*E	5.	16.	12.	12.	810.*E
1964	61.*E	47.*E	179.*E	227.*E	105.*E	71.*E	145.*E	34.	35.*E	25.*E	23.*E	75.	1029.*E
1965	47.	92.	110.	75.	123.	80.	127.	85.	94.	10.	12.	14.*E	870.*E
1966	55.	82.	155.*E	93.*E	73.*E	105.*E	87.*E	22.*E	30.*E	5.*E	15.*E	49.*E	759.*E
1967	40.*E	120.*E	130.*E	137.*E	124.*E	33.*E	55.*E	21.*E	27.*E	35.*E	7.*E	50.*E	836.*E
1968	63.*E	50.*E	135.*E	100.*E	110.*E	122.*E	71.*E	18.*E	10.*E	6.*E	2.*E	25.*E	733.*E
1969	50.*E	55.*E	129.*E	114.*E	69.*E	55.*E	37.*E	60.*E	20.*E	1.*E	53.*E	9.*E	722.*E
1970	95.*E	100.*E	104.*E	111.*E	33.*E	126.*E	52.*E	32.*E	32.*E	42.*E	39.*E	54.*E	949.*E
1971	55.*E	175.*E	55.*E	59.*E	113.*E	145.*E	100.*E	131.*E	24.	17.*E	8.	16.	929.*E
1972	55.*E	45.*E	80.*E	149.	111.*E	51.*E	58.*E	9.	4.*E	8.	10.*E	12.*E	603.*E
1973	57.*E	54.*E	100.*E	139.*E	121.*E	117.*E	105.*E	71.	22.*	35.*E	17.	16.*E	884.*E
1974	55.*E	100.*E	70.*E	152.*E	72.*E	37.*E	50.*E	59.*E	5.*E	5.	9.*E	10.*E	649.*E
1975	107.*E	127.*E	50.*E	150.*E	87.*E	69.*E	79.*E	36.*E	4.	56.*E	52.*E	4.*E	849.*E
1976	113.*E	120.*E	55.*E	55.*E	84.*E	64.*E	112.*E	91.*E	14.*E	11.*E	9.*E	13.*	800.*E
1977	39.*E	105.*E	93.*E	54.*E	132.*E	58.*E	143.*E	37.*E	25.	15.	55.*E	16.*E	857.*E
1978	40.*E	112.*E	232.*E	155.*E	55.*E	131.*E	45.*E	39.*E	45.*E	21.*E	40.*E	39.*E	963.*E
1979	27.*E	110.*E	152.*E	134.*E	89.*E	95.*E	75.*E	95.*E	7.*E	5.*E	24.*E	7.*E	774.*E
1980	55.*E	47.*E	105.*E	143.*E	110.*E	90.*E	111.*E	52.*E	17.*E	5.*E	8.	25.*E	775.*E
1981	55.*E	121.*E	133.*E	135.*E	131.*E	52.*E	47.*E	49.*E	14.*E	125.*E	25.*E	49.*E	941.*E
1982	15.*E	54.*E	95.*E	72.*E	65.*E	60.*E	36.*E	54.*E	17.*E	5.*E	46.*E	8.	563.*E
1983	75.*E	51.*E	117.*E	104.*E	95.*E	135.*E	53.*E	55.*E	37.*E	6.*E	24.*E	23.*E	766.*E

KEY

NA	RECORD NOT AVAILABLE
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x	DERIVED FROM INCOMPLETE RECORD

PROGRAM MDLIST
PROCESSED ON 11.47 07 NOV 1985

COLLECTING AUTHORITY WATER RES(03)

YEARS 1950 - 1983
STATION NO. 603 136

*********** EXIT000 //// END OF LIST ////
*********** EXIT000 //// END OF LIST ////

STATISTICS OF MONTHLY DATA FOR STATION 603 136 PARAMETER S01000 TRANS 5 END TIME 09 COPY 1 YEARS 74

	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	ANNUAL
MEAN	65.705	107.201	124.021	137.686	112.807	92.481	81.655	45.690	31.095	24.086	26.063	38.727	887.218
MEDIAN	65.076	102.815	121.715	135.010	110.340	87.425	77.653	41.337	27.239	16.530	15.576	25.748	872.600
STD. DEV.	41.411	45.790	46.998	42.591	38.008	35.168	36.830	26.620	20.272	26.631	28.056	33.452	151.537
SKEW	1.555	.817	.882	.873	.599	.265	.794	.989	1.093	2.998	3.119	1.901	.830
MAXIMUM	215.130	233.570	246.890	234.840	221.450	171.670	196.650	130.890	94.306	159.490	186.780	171.470	1407.700
MINIMUM	3.872	29.134	50.056	43.760	43.560	26.955	22.023	5.331	3.978	0.000	2.279	3.977	562.680
S. CORR.	.155	-.172	.259	.004	.029	.122	.076	.195	-.025	-.035	.129	-.048	-.033
C. VAR.	.630	.427	.379	.309	.337	.330	.451	.583	.652	1.106	1.076	.864	.171

STATISTICS OF MONTHLY DATA (EXPRESSED AS PERCENT OF ANNUAL TOTAL)

	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
MEAN (%)	7.334	12.048	13.909	15.752	12.715	10.408	9.157	5.310	3.498	2.631	2.958	4.230
S.E.E.	.431	.527	.501	.552	.428	.412	.435	.388	.256	.317	.377	.437

PUBLIC WORKS DEPARTMENT
WATER RESOURCES SECTION

DENMARK RIVER LINDESAY ROE
N 6143650 E 524700

STATION NO. 603 002
COPY NUMBER (1)

CATCHMENT AREA 466.5 SQ.KM MONTHLY TOTAL ACCUMULATED RAINFALL IN MILLIMETRES

YEAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	ANNUAL
1910	67.*E	147.*E	[illegible]	279.*E	152.*E	60.*E	115.*E	65.*E	17.*E	0.	7.*E	46.	1174.*E
1911	34.	57.	71.	167.	82.	95.	94.	11.	32.	9.	5.	32.	721.
1912	25.	55.	108.	255.	62.	158.	44.	42.	19.	27.	11.	51.	871.
1913	218.	52.	75.	122.	163.	100.	91.	25.	60.	1.	91.	50.	1063.
1914	35.	76.	75.	118.	42.	35.	41.	119.	57.	25.	58.	49.	715.
1915	45.	72.	120.	146.	188.	150.	75.	31.	5.	29.	36.	23.	915.
1916	25.	79.	125.	136.	158.	28.	132.	63.	10.*E	28.	36.	117.	996.*E
1917	104.	230.	227.	141.	143.	160.	57.	14.	49.	103.	66.	43.	1385.
1918	77.	143.	159.	42.	126.	74.	80.	35.	14.	7.	31.	17.	819.
1919	110.	55.	77.	149.	126.	75.	82.	47.	15.	6.	63.	45.	863.
1920	34.	109.*E	217.	128.	192.	76.	42.	20.	13.	36.	52.	10.	929.*E
1921	40.	150.	54.	121.	100.	103.	96.	44.	57.	18.	26.	31.	915.
1922	55.	101.	99.	156.	131.*E	59.*E	50.*E	55.	52.	14.	5.	39.	659.*E
1923	34.	220.	237.	135.	98.	165.	57.	12.	15.	11.	19.	10.	1015.
1924	15.	100.	95.	95.	143.	114.	171.	65.	11.	34.	20.	42.	966.
1925	72.	56.	72.	111.	42.	81.	126.	22.	45.	6.	35.	65.	794.
1926	141.	61.	[illegible]	234.	114.	111.	112.	57.	23.	38.	12.	101.	1115.
1927	37.	95.	135.	103.	105.	151.	97.	17.	13.	53.	6.	23.	843.
1928	109.	92.	120.	164.	153.	129.	75.	17.	22.	9.	27.	24.	941.
1929	52.	130.	151.	104.	95.	65.	59.	95.	37.	1.	9.	29.	855.
1930	44.	109.	134.	145.	82.	102.	34.	40.	25.	9.	12.	22.	717.
1931	50.	105.	109.	135.	137.	131.	51.	20.	29.	11.	11.	17.	822.
1932	58.	150.	134.	144.	149.	77.	77.	33.	15.	39.	5.	52.	683.
1933	52.	131.	227.	121.	118.	111.	130.	41.	25.*E	18.	5.	93.	1079.*E
1934	35.	53.	125.	142.	103.	132.*E	100.	57.	45.	38.	30.	13.	879.*E
1935	54.	55.	127.	151.	117.	113.	37.	15.	31.	38.	8.	3.	658.
1936	31.	109.	120.	107.	131.	57.	52.	17.	25.	17.	6.	53.	732.
1937	59.	174.	64.	105.	149.*E	92.	78.	31.	15.	7.	5.	35.*E	613.*E
1938	40.*E	124.	114.*E	113.*E	165.*E	53.	56.	55.	25.	157.	32.	16.*E	890.*E
1939	34.*E	102.	129.	112.*E	165.*E	27.	132.*E	57.	4.	16.	5.	5.	809.*E
1940	34.	77.	55.*E	92.*E	50.	45.	39.	30.	40.	9.*E	10.	141.	647.*E
1941	71.	55.	105.	123.	100.	130.*E	62.	42.	7.	19.	5.	67.	625.*E
1942	151.	155.	143.	110.	100.	127.	73.	25.	88.	57.	44.	174.	1318.
1943	113.	45.	75.	177.	90.	59.	22.	13.	55.	9.	14.	20.	704.
1944	33.	115.	55.	150.*E	83.	65.	19.	26.	76.	7.*E	10.	57.	698.*E
1945	29.	142.	200.*E	154.	205.	147.	34.	35.	47.	8.	8.	14.	1033.*E
1946	26.	112.	147.	151.	85.	49.	39.	99.	45.	7.*E	20.*E	19.*E	793.*E
1947	158.*E	144.*E	215.*E	99.*E	76.*E	101.*E	146.*E	49.*E	31.*E	5.	3.	16.	1103.*E
1948	45.	37.	59.	120.*E	122.	115.	56.	71.	34.	21.	2.	46.	769.*E
1949	55.	[illegible]	59.	159.	114.	79.	159.	54.	5.	22.	3.	3.	763.

KEY

NA	RECORD NOT AVAILABLE
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PROGRAM MOLIST
PROCESSED ON 11.15 07 NOV 1985

COLLECTING AUTHORITY WATER RES(03)

YEARS 1910 - 1949
STATION NO. 603 002

PUBLIC WORKS DEPARTMENT
WATER RESOURCES SECTION

DENMARK RIVER
N 6143650 E 524700

LINDESAY [illegible]E

STATION NO. 603 002
COPY NUMBER (1)

CATCHMENT AREA 480.5 SQ.KM

MONTHLY TOTAL

ACCUMULATED RAINFALL
IN MILLIMETRES

YEAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	ANNUAL
1950	3.	245.	120.	150.	82.	122.	85.	64.	33.	39.	52.	16.	1025.
1951	124.	165.	158.	95.	135.	93.	77.	42.	74.	62.	12.	53.	1042.
1952	41.	137.	127.	99.	81.	90.	106.	62.	35.	0.	49.	13.	818.
1953	52.	77.	122.*E	100.	68.	81.	100.	68.	27.	16.	6.	22.	740.*E
1954	55.	77.	76.	102.*E	76.	52.	51.	55.	19.	22.	188.	27.	803.*E
1955	143.	87.	133.	136.	210.	101.	144.	30.	44.	2.	7.	78.	1120.
1956	39.	123.	135.	152.*E	52.	57.	80.	45.*E	40.*E	16.*E	14.*E	57.*E	813.*E
1957	72.*E	93.*E	135.*E	62.*E	122.*E	54.*E	47.*E	4.*E	24.*E	39.*E	39.*E	11.*E	757.*E
1958	71.*E	119.*E	53.*E	135.*E	64.*E	118.*E	59.*E	39.*E	33.*E	8.	27.	16.	828.*E
1959	43.	47.	115.	70.	96.	125.	91.	67.	35.	29.	9.	130.	857.
1960	75.	123.	39.	222.	63.	81.	33.	14.	23.	42.	23.	44.	832.
1961	191.	23.	136.	159.	112.	54.	45.	13.	55.	0.	14.	23.	820.
1962	12.	95.	117.	113.	134.	54.	105.	35.	49.	39.	19.*E	47.	813.*E
1963	35.	145.	74.*E	130.*E	126.	57.*E	45.	30.*E	5.	15.	9.	9.	741.*E
1964	50.*E	41.*E	177.*E	223.*E	100.*E	65.*E	135.*E	33.	34.*E	23.*E	21.*E	74.	973.*E
1965	45.	35.	101.	67.	112.	73.	125.	73.	65.	7.	12.	13.*E	806.*E
1966	54.	57.	155.*E	90.*E	64.*E	100.*E	50.*E	22.*E	25.*E	8.*E	15.*E	43.*E	714.*E
1967	59.*E	123.*E	123.*E	173.*E	116.*E	29.*E	55.*E	19.*E	25.*E	34.*E	5.*E	47.*E	796.*E
1968	78.*E	43.*E	145.*E	103.*E	104.*E	120.*E	72.*E	15.*E	9.*E	4.*E	1.*E	24.*E	719.*E
1969	55.*E	56.*E	125.*E	112.*E	31.*E	99.*E	34.*E	59.*E	25.*E	1.*E	65.*E	5.*E	693.*E
1970	99.*E	107.*E	154.*E	105.*E	83.*E	127.*E	50.*E	29.*E	32.*E	44.*E	41.*E	54.*E	931.*E
1971	51.*E	155.*E	57.*E	65.*E	107.*E	141.*E	100.*E	125.*E	25.	16.*E	7.	12.	893.*E
1972	62.*E	43.*E	75.*E	133.	107.*E	50.*E	55.*E	7.	1.*E	0.	9.*E	10.*E	570.*E
1973	55.*E	54.*E	95.*E	135.*E	119.*E	117.*E	105.*E	73.	21.*	36.*E	16.	14.*E	870.*E
1974	55.*E	101.*E	74.*E	155.*E	71.*E	36.*E	55.*E	55.*E	4.*E	4.	7.*E	10.*E	636.*E
1975	101.*E	122.*E	55.*E	155.*E	64.*E	67.*E	77.*E	34.*E	4.	52.*E	53.*E	4.*E	819.*E
1976	114.*E	123.*E	55.*E	94.*E	41.*E	52.*E	105.*E	67.*E	14.*E	11.*E	8.*E	13.*	767.*E
1977	33.*E	124.*E	33.*E	75.*E	123.*E	55.*E	137.*E	35.*E	23.	15.	55.*E	15.*E	624.*E
1978	43.*E	135.*E	221.*E	162.*E	53.*E	127.*E	45.*E	57.*E	44.*E	20.*E	44.*E	35.*E	940.*E
1979	26.*E	110.*E	97.*E	125.*E	53.*E	92.*E	55.*E	99.*E	5.*E	5.*E	24.*E	7.*E	736.*E
1980	62.*E	45.*E	104.*E	143.*E	107.*E	65.*E	107.*E	55.*E	15.*E	7.*E	3.	23.*E	755.*E
1981	57.*E	114.*E	127.*E	127.*E	124.*E	58.*E	45.*E	48.*E	14.*E	127.*E	24.*E	44.*E	902.*E
1982	14.*E	55.*E	95.*E	97.*E	62.*E	56.*E	37.*E	52.*E	13.*E	5.*E	44.*E	3.	535.*E
1983	25.*E	51.*E	115.*E	101.*E	92.*E	101.*E	51.*E	43.*E	40.*E	5.*E	23.*E	21.*E	655.*E

KEY
- NA RECORD NOT AVAILABLE
- NR NOT RECORDED
- * FAULTY - VERY CONFIDENT IN CORRECTED TRACE
- ** FAULTY - SOME DOUBT IN CORRECTED TRACE
- *E ESTIMATED TRACE
- \# DERIVED FROM INCOMPLETE RECORD

PROGRAM [illegible]
PROCESSED ON 11.45 07 NOV 1985

COLLECTING AUTHORITY WATER RES(03)

YEARS 1950 - 1983
STATION NO. 603 002

********** EWR1030 //// END OF LIST ////
********** EWR1030 //// END OF LIST ////

STATISTICS OF MONTHLY DATA FOR STATION 503 002 PARAMETER S01000 TRANS 5 END TIME 09 COPY 1 YEARS 74

	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	ANNUAL
MEAN	63.165	103.656	120.004	133.093	109.126	89.483	79.523	44.489	29.801	23.380	25.154	37.080	857.951
MEDIAN	53.257	101.215	116.195	127.405	106.465	84.919	76.946	39.675	25.891	16.071	14.235	23.876	824.575
STD. DEV.	40.897	45.963	46.515	42.478	37.795	35.021	36.706	26.578	19.948	26.627	28.271	33.233	152.471
SKEW	1.513	.865	.352	.863	.573	.252	.784	.980	1.131	2.951	3.166	1.952	.996
MAXIMUM	239.770	246.310	238.780	279.300	210.250	165.470	196.250	128.010	88.314	156.810	188.440	174.320	1385.400
MINIMUM	3.078	23.090	50.115	41.654	41.642	26.628	19.195	3.955	3.574	0.000	1.443	3.133	535.470
S. CORR.	.155	-.153	.248	.006	.035	.131	.079	.180	-.038	-.019	.140	-.049	-.035
C. VAR.	.647	.443	.389	.319	.346	.391	.462	.597	.669	1.139	1.124	.896	.178

STATISTICS OF MONTHLY DATA (EXPRESSED AS PERCENT OF ANNUAL TOTAL)

	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
MEAN (%)	7.279	12.040	13.923	15.755	12.723	10.410	9.232	5.347	3.468	2.633	2.956	4.235
S.E.E.	.485	.545	.517	.569	.440	.423	.451	.378	.261	.325	.396	.424

*********** LWX1002 //// END OF LIST ////
*********** LWX1002 //// END OF LIST ////

PUBLIC WORKS DEPARTMENT
WATER RESOURCES SECTION

DENMARK RIVER
N 6160150 E 519550

KOMPUP

STATION NO. 603 003
COPY NUMBER (1)

CATCHMENT AREA 234.6 SQ.KM

MONTHLY TOTAL

ACCUMULATED RAINFALL
IN MILLIMETRES

YEAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	ANNUAL
1910	64.*E	140.*E	132.*E	264.*E	147.*E	71.*E	103.*E	63.*E	14.*E	0.	7.*E	47.	1107.*E
1911	32.	32.	50.	157.	77.	92.	94.	11.	29.	6.	5.	29.	675.
1912	23.	81.	85.	265.	40.	143.	30.	34.	17.	29.	14.	51.	815.
1913	170.	45.	74.	103.	158.	86.	95.	25.	80.	1.	92.	51.	1009.
1914	30.	74.	64.	125.	39.	27.	36.	115.	37.	39.	57.	41.	693.
1915	35.	68.	95.	124.	175.	146.	69.	25.	5.	24.	36.	28.	829.
1916	21.	55.	109.	180.	153.	18.	134.	82.	11.*E	21.	33.	85.	911.*E
1917	125.	237.	215.	121.	148.	157.	83.	12.	38.	120.	68.	38.	1360.
1918	74.	134.	152.	37.	127.	75.	70.	33.	12.	6.	22.	16.	763.
1919	117.	50.	70.	151.	117.	69.	79.	51.	15.	8.	76.	33.	847.
1920	30.	98.*E	199.	113.	193.	74.	36.	21.	9.	34.	41.	9.	858.*E
1921	30.	157.	82.	100.	89.	103.	95.	44.	72.	13.	28.	34.	865.
1922	83.	99.	98.	135.	131.*E	56.*E	45.*E	54.	41.	13.	5.	39.	798.*E
1923	30.	200.	241.	130.	88.	157.	57.	9.	13.	7.	20.	6.	964.
1924	11.	157.	77.	83.	138.	109.	172.	52.	10.	33.	18.	36.	908.
1925	55.	80.	65.	151.	33.	30.	129.	14.	57.	9.	32.	53.	737.
1926	135.	59.	77.	222.	100.	105.	107.	52.	19.	26.	10.	102.	1036.
1927	29.	30.	135.	90.	93.	132.	98.	17.	15.	50.	4.	14.	759.
1928	105.	75.	87.	154.	148.	129.	74.	13.	19.	7.	19.	17.	850.
1929	44.	128.	156.	95.	82.	58.	51.	94.	35.	1.	7.	24.	778.
1930	37.	100.	111.	123.	57.	90.	29.	35.	23.	5.	9.	25.	654.
1931	51.	52.	107.	93.	126.	113.	40.	22.	23.	9.	8.	10.	689.
1932	62.	37.	121.	136.	146.	63.	55.	32.	15.	37.	3.	48.	827.
1933	50.	165.	223.	110.	114.	116.	129.	35.	25.*E	17.	1.	101.	1028.*E
1934	33.	40.	119.	149.	94.	127.*E	131.	65.	40.	44.	23.	11.	854.*E
1935	55.	55.	126.	172.	114.	102.	73.	10.	27.	37.	6.	2.	789.
1936	27.	104.	120.	100.	120.	56.	45.	17.	28.	16.	5.	57.	694.
1937	51.	171.	57.	95.	134.*E	83.	73.	32.	15.	0.	5.	35.*E	773.*E
1938	47.*E	115.	135.*E	114.*E	97.*E	56.	53.	31.	27.	143.	34.	16.*E	836.*E
1939	33.*E	95.	129.	107.*E	169.*E	25.	136.*E	53.	3.	15.	5.	3.	778.*E
1940	31.	58.	93.*E	65.*E	46.	59.	37.	29.	37.	6.*E	8.	141.	601.*E
1941	51.	79.	105.	113.	99.	121.*E	61.	39.	8.	16.	4.	70.	777.*E
1942	131.	154.	131.	105.	151.	118.	34.	23.	34.	38.	42.	169.	1231.
1943	107.	41.	70.	164.	84.	81.	20.	17.	31.	5.	12.	19.	654.
1944	30.	100.	47.	142.*E	80.	55.	15.	23.	73.	6.*E	9.	54.	543.*E
1945	26.	126.	192.*E	140.	185.	133.	30.	31.	44.	6.	6.	12.	934.*E
1946	16.	104.	135.	140.	77.	45.	33.	98.	42.	6.*E	19.*E	17.*E	733.*E
1947	157.*E	155.*E	207.*E	85.*E	68.*E	96.*E	187.*E	45.*E	26.*E	5.	7.	15.	1035.*E
1948	43.	26.	76.	115.*E	113.	103.	48.	64.	32.	19.	2.	39.	682.*E
1949	49.	51.	63.	144.	102.	71.	144.	49.	4.	17.	3.	2.	709.

KEY

NA	RECORD NOT AVAILABLE
NR	NOT RECORDED
*	FAULTY - VERY CONFIDENT IN CORRECTED TRACE
**	FAULTY - SOME DOUBT IN CORRECTED TRACE
*E	ESTIMATED TRACE
#	DERIVED FROM INCOMPLETE RECORD

PROGRAM MOLIST
PROCESSED ON 13.20 22 OCT 1985

COLLECTING AUTHORITY WATER RES(03)

PUBLIC WORKS DEPARTMENT
WATER RESOURCES SECTION

DENMARK RIVER KOMPUP
N 6160150 E 519550

STATION NO. 603 003
COPY NUMBER (1)

CATCHMENT AREA 234.6 SQ.KM

MONTHLY TOTAL

ACCUMULATED RAINFALL
IN MILLIMETRES

YEAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	ANNUAL
1950	2.	230.	110.	144.	73.	113.	77.	57.	28.	39.	52.	13.	938.
1951	128.	95.	148.	90.	118.	84.	73.	40.	70.	56.	11.	48.	962.
1952	40.	99.	116.	92.	72.	79.	96.	56.	32.	5.	43.	13.	754.
1953	29.	75.	113.*E	90.	63.	74.	96.	81.	24.	15.	6.	20.	684.*E
1954	53.	73.	69.	93.*E	70.	48.	47.	45.	17.	27.	173.	24.	741.*E
1955	135.	32.	124.	128.	204.	94.	133.	26.	41.	2.	5.	75.	1050.
1956	36.	125.	127.	144.*E	47.	58.	76.	41.*E	39.*E	13.*E	12.*E	43.*E	761.*E
1957	66.*E	97.*E	135.*E	53.*E	114.*E	46.*E	45.*E	3.*E	22.*E	44.*E	44.*E	8.*E	729.*E
1958	63.*E	109.*E	54.*E	170.*E	76.*E	106.*E	51.*E	37.*E	33.*E	9.	25.	15.	757.*E
1959	41.	26.	105.	66.	92.	115.	80.	85.	32.	27.	9.	120.	800.
1960	57.	115.	33.	212.	57.	30.	27.	13.	22.	39.	22.	45.	783.
1961	175.	23.	128.	154.	107.	54.	44.	13.	53.	0.	14.	20.	787.
1962	11.	65.	113.	107.	138.	49.	94.	35.	42.	33.	18.*E	52.	777.*E
1963	37.	175.	70.*E	130.*E	116.	58.*E	43.	29.*E	5.	16.	8.	8.	695.*E
1964	48.*E	55.*E	174.*E	215.*E	99.*E	63.*E	125.*E	31.	34.*E	21.*E	20.*E	71.	934.*E
1965	43.	33.	97.	63.	105.	56.	122.	63.	82.	8.	13.	13.*E	765.*E
1966	47.	52.	149.*E	86.*E	59.*E	95.*E	85.*E	24.*E	25.*E	8.*E	12.*E	39.*E	681.*E
1967	37.*E	119.*E	120.*E	165.*E	114.*E	30.*E	51.*E	19.*E	25.*E	33.*E	5.*E	47.*E	764.*E
1968	71.*E	48.*E	140.*E	100.*E	104.*E	113.*E	63.*E	17.*E	11.*E	6.*E	2.*E	25.*E	710.*E
1969	50.*E	53.*E	114.*E	106.*E	74.*E	45.*E	31.*E	55.*E	18.*E	2.*E	82.*E	8.*E	648.*E
1970	37.*E	100.*E	145.*E	102.*E	75.*E	120.*E	57.*E	28.*E	29.*E	41.*E	36.*E	54.*E	875.*E
1971	49.*E	151.*E	57.*E	83.*E	97.*E	133.*E	95.*E	122.*E	21.	17.*E	8.	12.	845.*E
1972	58.*E	42.*E	59.*E	125.	102.*E	46.*E	58.*E	5.	4.*E	7.	12.*E	8.*E	537.*E
1973	52.*E	62.*E	35.*E	122.*E	111.*E	114.*E	105.*E	75.	23.*	33.*E	16.	15.*E	841.*E
1974	49.*E	99.*E	72.*E	152.*E	67.*E	36.*E	59.*E	58.*E	3.*E	5.	9.*E	12.*E	620.*E
1975	91.*E	115.*E	49.*E	153.*E	70.*E	62.*E	74.*E	30.*E	5.	56.*E	43.*E	3.*E	758.*E
1976	112.*E	107.*E	52.*E	77.*E	76.*E	59.*E	98.*E	84.*E	13.*E	9.*E	6.*E	11.*	715.*E
1977	34.*E	136.*E	75.*E	66.*E	105.*E	60.*E	116.*E	37.*E	21.	13.	51.*E	14.*E	729.*E
1978	53.*E	85.*E	198.*E	154.*E	48.*E	118.*E	40.*E	32.*E	39.*E	20.*E	37.*E	31.*E	854.*E
1979	23.*E	99.*E	91.*E	109.*E	74.*E	94.*E	59.*E	79.*E	5.*E	4.*E	24.*E	6.*E	667.*E
1980	76.*E	36.*E	97.*E	140.*E	102.*E	56.*E	100.*E	41.*E	15.*E	8.*E	6.	20.*E	711.*E
1981	55.*E	98.*E	117.*E	120.*E	112.*E	48.*E	44.*E	49.*E	12.*E	128.*E	19.*E	34.*E	835.*E
1982	11.*E	53.*E	84.*E	62.*E	61.*E	44.*E	38.*E	50.*E	17.*E	4.*E	42.*E	8.	494.*E
1983	26.*E	60.*E	112.*E	100.*E	63.*E	94.*E	46.*E	44.*E	42.*E	4.*E	22.*E	19.*E	654.*E

KEY

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#	DERIVED FROM INCOMPLETE RECORD

DATE. ..SOU: SECT... PROGRAM ....2 RUN ON 03/10/22 AT 13.20

STATISTICS OF MONTHLY DATA FOR STATION 603 003 PARAMETER S01000 TRANS 5 END TIME 09 COPY 1 YEARS 74

	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	ANNUAL
MEAN	59.229	95.756	112.208	124.195	101.807	83.453	74.871	42.120	27.938	22.521	23.248	34.521	801.868
MEDIAN	48.901	95.245	108.165	117.735	99.605	79.942	71.745	36.173	24.301	14.051	13.480	24.285	776.950
STD. DEV.	39.685	44.188	45.399	42.751	37.655	33.355	36.326	25.858	19.229	26.730	26.811	32.032	146.312
SKEW	1.492	.986	.897	1.100	.543	.249	.765	.965	1.241	2.817	3.016	2.016	1.181
MAXIMUM	195.050	236.570	241.240	265.040	203.790	157.000	186.950	121.830	84.468	142.800	173.350	168.810	1360.400
MINIMUM	1.843	23.052	46.814	36.798	32.899	17.963	15.542	2.662	3.043	0.000	1.355	1.664	494.380
S. CORR.	.150	-.117	.245	-.032	-.027	.102	.093	.184	-.055	-.035	.165	-.069	-.052
C. VAR.	.670	.461	.405	.344	.370	.400	.485	.614	.688	1.187	1.153	.929	.182

STATISTICS OF MONTHLY DATA (EXPRESSED AS PERCENT OF ANNUAL TOTAL)

	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
MEAN (%)	7.264	11.911	13.933	15.748	12.697	10.402	9.288	5.420	3.488	2.704	2.933	4.211
S.E.E.	.499	.555	.546	.611	.474	.434	.479	.408	.270	.345	.406	.441

*********** EXX1042 //// END OF LIST ////
*********** EXX1042 //// END OF LIST ////

APPENDIX B

STREAMFLOW STATISTICS

ANNUAL STREAMFLOW VOLUMES FROM 1962 TO 1984

OBS	YEAR	ANNUAL STREAMFLOW
1	1962	22088
2	1963	32380
3	1964	50969
4	1965	22728
5	1966	25134
6	1967	52532
7	1968	36776
8	1969	9660
9	1970	24820
10	1971	39293
11	1972	11139
12	1973	31077
13	1974	15073
14	1975	25686
15	1976	19996
16	1977	43669
17	1978	79904
18	1979	33589
19	1980	22218
20	1981	40540
21	1982	9135
22	1983	12748
23	1984	44400

UNIVARIATE

VARIABLE=ANFLOW

MOMENTS

N	23	SUM WGTS	23
MEAN	30676.3	SUM	705554
STD DEV	16726.5	VARIANCE	279774694
SKEWNESS	1.11677	KURTOSIS	1.96163
USS	2.780E+10	CSS	6155043274
CV	54.5255	STD MEAN	3487.71
T:MEAN=0	8.79553	PROB>|T|	0.0001
SGN RANK	138	PROB>|S|	0.0001
NUM ~= 0	23		

QUANTILES(DEF=4)

100% MAX	79904	99%	79904
75% Q3	40540	95%	74429.3
50% MED	25686	90%	51906.8
25% Q1	19996	10%	10251.6
0% MIN	9135	5%	9240
		1%	9135
RANGE	70769		
Q3-Q1	20544		
MODE	9135		

EXTREMES

LOWEST	HIGHEST
9135	43669
9660	44400
11139	50969
12748	52532
15073	79904

APPENDIX C

WATER QUALITY SUMMARY

DENMARK RIVER BASIN
WATER QUALITY SUMMARY

TABLE C1

YEAR	603014 NO SAMPLES	FLOW WEIGHTED AVERAGE TSS (mg/L)
1940	27	582
1941	40	345
1942	32	218
1943	23	310
1944	8	416
1945	30	249
1946	41	429
1947	25	230
1948	25	452
1949	-	
1950	3	213
1951	13	292
1952	22	413
1953	23	488
1954	19	560
1955	46	221
1956	45	338
1957	6	393
1958	5	248
1959	5	292

DENMARK RIVER BASIN
WATER QUALITY SUMMARY
TABLE C2

YEAR	603136 NO SAMPLES	FLOW WEIGHTED AVERAGE TSS (mg/L)	603002 NO SAMPLES	FLOW WEIGHTED AVERAGE TSS (mg/L)	603003 NO SAMPLES	FLOW WEIGHTED AVERAGE TSS (mg/L)	603173 NO SAMPLES	FLOW WEIGHTED AVERAGE TSS (mg/L)	603177 NO SAMPLES	FLOW WEIGHTED AVERAGE TSS (mg/L)	603190 NO SAMPLES	FLOW WEIGHTED AVERAGE TSS (mg/L)
1960	4	173										
1961	8	192										
1962	5	326					13	520	12	249		
1963	6	336					0	-	21	197	21	470
1964	10	230					28	243	23	170	25	317
1965	23	318					12	982	12	417	13	1206
1966	24	446					11	612	7	268	10	557
1967	17	261					7	368	6	337	7	451
1968	13	320					12	619	11	299	18	569
1969	18	493					8	1314	1	309	10	1196
1970	20	469					16	868	11	312	18	890
1971	18	481					14	471	8	300	16	351
1972	15	642					6	1800	3	382	15	1220
1973	10	494	7	598			5	721			10	691
1974	19	541	22	629	14	1007	9	1324			16	778
1975	8	568	10	728	7	903	3	729			16	978
1976	11	632	12	901	8	1189	6	799			-	-
1977	13	452	12	519	10	580	12	1245			8	753
1978	198	274	20	272	22	547					25	499
1979	422	557	33	717	181	974					35	864
1980	415	684	12	942	224	1200					10	1333
1981	392	482	11	418	216	1462					11	523
1982	367	855	30	1887	336	3777					8	3273

TABLE C3

	6031026 NO SAMPLES	AVERAGE TSS (mg/L)	6031027 NO SAMPLES	AVERAGE TSS (mg/L)	6031028 NO SAMPLES	AVERAGE TSS (mg/L)
1978	3	439	12	266	15	1969
1979			12	383	16	3171
1983			1	771	5	2711
1984					1	4626

APPENDIX D

DEVELOPMENT OF TEMPORAL DATA SET OF CLEARING

APPENDIX D

CLEARING DATA SOURCES

DATE :	16 to 24/3/1946
SOURCE :	Aerial photography
DETAILS :	Survey 84//I50/11/471
	Forest Hill - runs 1, 2, 3, 4, 5, 6A, 6
	Denmark - runs 1, 2, 3, 4, 5, 6, 7
COMPILATION :	interpreted onto 1:50,000 topographic maps
AVAILABILITY :	aerial photography - Department of Land and Surveys, Cathedral Ave, Perth
	digital data - Water Authority of Western Australia

DATE :	1957
SOURCE :	Department of Conservation and Land Management's Forest API type maps at 1:25,000
	Maps 2 to 15 and 90 to 96
DETAILS :	generated from the amalgamation of the following classifications
	"PT Cl" (part cleared) "Cl" (cleared) "Rb" (ringbarked) "Orch" (orchard) "Cul" (cultivated) "P" (pasture) "S.T." (shade trees)
AVAILABILITY :	maps - Department of Conservation and Land Management, Hayman, Como
	digital data - Water Authority of Western Australia

DATE :	1965
SOURCE :	topographic compilation maps at 1:50,000 maps 2328 I, II, III and IV

DETAILS :	captured directly off the compilation maps
COMPILATION :	carried out by the Department of Land and Surveys from aerial phtography
AVAILABILITY :	Compilation maps - Department of Lands and Surveys, Wembley aerial photography - Department of Lands and Surveys, Cathedral Ave, Perth - Water Authority of Western Australia
DATE :	1979
SOURCE :	aerial photography
DETAILS :	Department of Lands and Surveys job number 780100, Kent River and Denmark ruin catchments, scale 1:20,000, runs 5 to 17
COMPILATION :	interpreted onto 1:50,000 topographic maps
AVAILABILITY :	aerial photography - Department of Lands and Surveys, Cathedral Ave, Perth - Water Authority of Western Australia digital data - Water Authority of Western Australia.
DATE :	13/3/84
SOURCE :	Landsat remote sensed data
DETAILS :	classification by Level 5 scale of Department of Lands and Surveys, Remote Sensing Sections I25 image processor.
AVAILABILITY :	digital data - Department of Lands and Surveys, Remote Sensing Section.

APPENDIX E

GENERATED RAINFALL, STREAMFLOW AND SALT LOAD STATISTICS

*AMR*AMR*AMR*AMR*AMR*AMR*AMR*AMR*AMR*AMR*AMR*AMR*AMR*A-85/11/07-EQUIP.LR07-15.38.30-AMR*AMR*AMR*AMR*AMR*AMR*AMR*AMR*AMR*AMR*AMR*AMR*AMR*AMR*A<

WATER RESOURCES SECTION **Rainfall** PROGRAM AUSTAT2 RUN ON 85/11/07 AT 13.39

STATISTICS OF MONTHLY DATA FOR STATION 503 135 PARAMETER 501000 TRANS 5 END TIME 24 COPY 4 YEARS 500

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
MEAN	22.232	24.052	35.569	60.620	98.825	114.368	126.967	103.979	85.326	75.346	42.131	28.715	818.085
MEDIAN	21.255	22.985	34.087	57.933	94.443	109.295	121.340	99.368	81.544	72.005	40.264	27.442	781.615
STD. DEV.	4.109	4.441	6.556	11.193	18.243	21.118	23.444	19.199	15.755	13.912	7.779	5.302	151.057
SKEW	1.698	1.698	1.698	1.698	1.698	1.698	1.698	1.698	1.698	1.698	1.698	1.698	1.698
MAXIMUM	51.073	55.205	81.869	139.140	226.330	262.510	291.430	233.660	195.350	172.940	96.704	65.909	1877.700
MINIMUM	13.257	14.340	21.265	36.142	58.920	68.187	75.698	61.992	50.872	44.921	25.119	17.120	487.740
S. CORR.	.104	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.103
C. VAR.	.185	.185	.185	.185	.185	.185	.185	.185	.185	.185	.185	.185	.185

STATISTICS OF MONTHLY DATA (EXPRESSED AS PERCENT OF ANNUAL TOTAL)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MEAN (%)	2.720	2.940	4.350	7.410	12.080	13.930	15.520	12.710	10.430	9.210	5.150	3.510
S.E.E.	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000

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WATER RESOURCES SECTION **Streamflow** PROGRAM HDSTAT2 RUN ON 85/11/07 AT 13.33

STATISTICS OF MONTHLY DATA FOR STATION 503 136 PARAMETER 521000 TRANS 5 END TIME 24 COPY 4 YEARS 500

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
MEAN	.054	.025	.035	.079	.526	1.681	7.690	10.564	7.476	6.293	2.859	.340	37.664
MEDIAN	.039	.017	.017	.059	.412	1.340	5.763	8.266	5.598	4.716	1.568	.207	31.248
STD. DEV.	.139	.032	.053	.081	.391	1.745	7.065	9.574	6.199	5.394	3.052	.422	24.237
SKEW	4.246	2.500	3.311	2.536	1.617	2.144	2.440	2.559	2.249	2.384	2.714	3.803	1.978
MAXIMUM	1.252	.232	.402	.565	2.339	10.846	59.974	76.652	41.014	43.064	24.092	4.415	213.340
MINIMUM	.002	.001	.000	.002	.047	.143	.420	.769	.392	.447	.033	.006	5.722
S. CORR.	.105	.527	.945	.702	.630	.503	.794	.527	.525	.597	.646	.801	.101
C. VAR.	1.547	1.141	1.432	1.019	.725	.929	.918	.812	.829	.857	1.068	1.241	.640

STATISTICS OF MONTHLY DATA (EXPRESSED AS PERCENT OF ANNUAL TOTAL)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MEAN (%)	.224	.076	.100	.217	1.400	4.893	20.230	27.655	19.571	16.775	7.643	.914
S.E.E.	.014	.003	.005	.005	.023.	.130	.502	.445	.419	.377	.268	.041

VALUES HAVE BEEN SCALED BY THE FACTOR 10.0**-6

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WATER RESOURCES SECTION **Salt Load** PROGRAM MOSTAT2 RUN ON 85/11/07 AT 12.05

STATISTICS OF MONTHLY DATA FOR STATION 603 136 PARAMETER 034100 TRANS 5 END TIME 24 COPY 4 YEARS 500

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
MEAN	.084	.034	.035	.087	.427	1.536	4.186	6.433	4.769	3.863	2.008	.275	23.736
MEDIAN	.045	.023	.019	.065	.351	1.253	3.454	5.713	4.137	3.317	1.567	.187	22.274
STD. DEV.	.123	.033	.048	.073	.212	1.092	2.968	3.421	2.772	2.395	1.685	.289	8.023
SKEW	4.012	2.566	5.126	2.336	1.042	1.540	1.736	1.415	1.294	1.572	1.605	3.367	.970
MAXIMUM	1.174	.225	.332	.529	1.294	6.368	22.894	22.470	17.597	15.591	5.799	2.635	64.808
MINIMUM	.002	.001	.001	.005	.095	.200	.344	.706	.417	.339	.023	.007	8.667
SER. CORR.	.147	.006	.946	.559	.480	.208	.713	.323	.166	.346	.459	.767	.120
COEF. VAR.	1.459	.971	1.355	.845	.496	.711	.709	.532	.581	.620	.840	1.050	.338

STATISTICS OF MONTHLY DATA (EXPRESSED AS PERCENT OF ANNUAL TOTAL)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MEAN (%)	.594	.145	.154	.373	1.604	6.409	17.573	27.015	20.155	16.340	8.510	1.157
S.E.E.	.021	.008	.009	.014	.030	.170	.451	.441	.419	.362	.292	.051

VALUES HAVE BEEN SCALED BY THE FACTOR 10.0**-6

EOF ENCOUNTERED ON FIRST READ

ERROR - ABANDON HAS BEEN CALLED

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