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SOUTH AUSTRALIA
Technical Report No. 122
November 1987

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REPORT TO SOUTH EASTERN DRAINAGE BOARD

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Technical Report No. 122 ISSN-0727-601X

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Abstract

The main benefit of the South East Drainage System is that 381,000 ha of flood prone land is now used for mainly grazing of sheep and beef cattle. The agriculture production of this land is valued at $68 million per year. The total annual cost (in 1987 values) of the 1,450 km long drainage system is estimated to be equivalent to $8 million per year. An indirect benefit of the drains is the removal of at least three times more salt than deposited as cyclic salt; this results in a better environment for plant growth on the interdunal flats.

The 140,000 ml of low salinity drain flow during winter can not be economically stored in drains. About 3,000 ha is flood irrigated with drainage water when flows are available in spring. There is probably scope for some more on-farm storage along Bakers Range Drain. The need for drainflow conservation is questionable because groundwater supplies are abundantly available in the South East for irrigation. An alternative use for the drainage flows is diversion into the (scattered) wetlands and recreation areas, where practical and appropriate for the existing water habitat.

Previous field studies indicate that over drainage is likely to occur along the main drains. It is estimated that 20,200 ha (i.e. less than one percent of the 'benefitted' area) along 159 km of main drains is affected by over drainage. The value of this farm production loss is estimated to be $311,000 per year. About 100 of the 137 holdings affected by over drainage have a land area between 100 ha and 1,000 ha. This category of farmers bear about 70 percent of the estimated financial loss. Those properties that are

assumed to have suffered during dry periods generally receive the greatest benefit from drainage during wet periods as they are on the lowest flood prone land. There are many variable factors involved and thus the degree of over drainage will fluctuate widely along the drains.

The return on the investment of Mount Bruce weir is nil. In contrast to this, the net return for the Magarey Lane weirs and the McCourt's centre pivot irrigator is estimated to be 12 percent as a combined result of restored pasture production on the (peat) flats and water harvesting for 240 ha of centre pivot irrigation.

The considerable benefits from the Magarey Lane investments should not be used for the justification of investments into weirs at other sites. The construction of a series of weirs in main drains would be expensive and only partly remedy the over drainage losses on the adjacent land. Proposals made by farmers to rectify over drainage should be considered on their merits. Whether or not the South Australian Government provides funds, if farmers want to construct weirs, then they should be allowed to proceed at their own expense. The structures should meet the standards set by the South Eastern Drainage Board which has the overall responsibility for the drain flow management.

1. INTRODUCTION

A total of 1450 km of surface drains and associated structures have been constructed progressively over the past 100 years to remove surplus water from the interdunal flats in the South East of South Australia.

While drainage is recognized as a prerequisite for land development and establishment of agricultural land use there has been a continuing ground swell of public opinion, that the drains remove too much water (farmers call it 'over drainage') and adversely affect agricultural production, particularly in years with below average rainfall.

In this report 'over drainage' is defined as the accelerated lowering of the watertable in land along the drains after the winter drain flows have ceased. This relatively faster lowering of the watertable is less at greater distance from the drain; its effect on plant growth commences normally by about mid spring when the water level in the drains has fallen below the rootzone in adjacent pasture (or cropped land). This over drainage is almost unavoidable along the main drains; the vegetation dries off earlier and thus pasture production or crop yield near the drain is relatively lower than its potential in absence of over drainage.

The construction of weirs in drains to maintain the water level close to the surface later into spring is seen by land holders and others as attractive means for reducing the over drainage effects and for utilisation of surplus water, which - in their opinion - is now 'wasted' into the sea.

The disenchantment of the land holders with the drainage system and the emerging efforts of environmentalists to protect the remaining shrub land,

and wetlands in particular, culminated in a request by Cabinet in 1976 for an Environmental Impact Study (EIS) on the effect of drainage in the South East - ironically - after the works had been completed.

In relation to over drainage, the EIS report by the South Eastern Drainage Board (1980) recommends that a high priority be given to the on-going investigations into the effects of weirs in the drainage scheme on ground water levels and pasture production, and falling groundwater levels in some areas (e.g. in Counties Cardwell and Buckingham). The responsibility for these actions was assigned to the South Eastern Drainage Board in conjunction with the Departments of Engineering and Water Supply, Mines and Energy and Agriculture.

In 1979 Cabinet approved funding for the construction of two major 'experimental'weirs in Drain M between Beachport and Furner. From 1979 to 1984 the Mines and Energy Department collected large amounts of data on watertable fluctuations around the newly constructed 'Mount Bruce' weir and 'Magarey Lane' weir and also at other weir sites. The staff of the Department of Agriculture determined the 1980 and 1981 pasture production at Mount Bruce. The field results varied greatly because of the spatial variability of pasture growth at this site, similar to that experienced during the earlier Conmurra weir investigations (1970-1974). It was then decided to estimate the dry matter production by using the relationship between 'actual' pasture water use and depth to water table. This relationship was determined by Schrale (1983) at the Konetta lysimeter station.

Whilst assessing the benefits of weirs it became clear that this should be addressed within the wider perspective of the overall benefits of the South East Drainage System.

This report deals firstly with hydrological aspects of the surface drainage system in the South East. The available data on drain flows were further analysed to demonstrate the function of the drains, their impact on the soil water regime on the interdunal flats, and the potential of weirs to overcome over drainage. In addition, the benefit of salt removal from the flats has been quantified. The benefits of the drainage/land development are related to the production statistics of the South East. All the weir investigations are briefly summarized.

Thereafter an attempt is made to assess the associated agro-economic variables:

* the cost benefit of the South East Drainage System;
* the loss of agricultural production due to over drainage;
* the return on investment of weirs in drains, in particular of those constructed since 1980.

This review study may assist the South Eastern Drainage Board to develop a more definite policy on future weir proposals.

2. BRIEF DESCRIPTION OF THE SOUTH EAST DRAINAGE SYSTEM

2.1 Physiography of South East Region

The South East Region is often considered to be the wedge-shaped portion of South Australia below 36 S latitude (See Figure 1). It comprises the Counties of Cardwell, Buckingham, Mac Donnell, Robe and Grey. The total area of this relatively high rainfall area is about 1.9 million hectares, i.e. 1 percent of the entire State. The hydrological boundaries of the South East are not as clearly defined as this. The considerable surface run-off and groundwater entering from Western Victoria are important parts of the water resources of this region.

The climate in the South East is Mediterranean. The relatively high and reliable (predominantly winter) rainfall varies from about 800 mm near Millicent to 450 mm in the north east near Bordertown. The annual isohytes for this area are shown in Figure 1.

The South East is relatively flat because of its marine origin. The area comprises parts of two sedimentary basins: the Otway Basin in the south and the Murray Basin in the north east. These basins are separated by an area of shallow basement rocks, the Padthaway Ridge. Sedimentation in the two basins commenced about 150 million years ago. The land emerged after a number of sea level fluctuations which resulted in a number of dune ranges and flats of varying widths and which are almost parallel to the present coast (See Figure 2 and 3). The dune ranges are only about 10 metres above the flats. The outstanding topographic features are the Mount Burr Range, Mount Gambier and Mount Schank which are up to 270 m above sea level. The uplift of the Mount Burr area gave a gentle north western tilt of the seaward gradient plain. The overall slope towards the coast is typically 1:1600 and the north westerly gradient is generally less than 1:5000.

Due to the low gradients in the topography, no major water courses exist in the South East. The only well defined water courses are the few creeks rising in Western Victoria but after crossing the border these flows are dispersed in the swamps and lakes, e.g. the Marcollat water course.

The deep sandy soils on the ranges have a limited waterholding capacity. The ranges are used for winter grazing, the annual pastures dry off soon after the spring rains cease. The soils on the flats are shallow to medium depth of red and black clays over calcrete and limestone rubble.

There are two main aquifers in the South East. The water table aquifer occurs in the cavernous Gambier Limestone and the (lower) confined aquifer is in the Dilwyn Formation, a sequence of calcareous sand and gravel layers.

It is estimated that about 10 percent of the annual recharge of the upper aquifer occurs as lateral inflow from Victoria (See Figure 4). The confined (deep) aquifer is mainly recharged by downward leakage from the water table aquifer and by rainfall in areas where the strata of the confined aquifer are exposed at the surface. Lateral inflow of confined groundwater from Victoria represents about 25 percent of the annual recharge (See Figure 5). On the other hand, upward leakage into the water table aquifer is known to occur in the coastal areas where the confined aquifer is artesian.

Prior to artificial drainage, surplus winter rainfall inundated large portions of the interdunal flats for up to 6 months. The water drained west initially with the next range forcing slow water movement towards the north west; swamps were filled and spilled into the next (See Figure 6). The surplus water is now collected by the drains. The watertable on the flats is near or above the surface for only a short period in wet winters; it gradually falls to a depth of 1m or 2m by the end of the summer.

2.2 History of Land Development

The drainage works commenced in 1863 with cuttings in the Woakwine Ranges to release water to Lake Frome and Lake Bonney. In the following two decades some 40,000 ha of land was drained in the Millicent-Tantanoola area. This drainage area is now administered by the Millicent District Council. Drainage facilitated the establishment of profitable agriculture on the highly fertile land with soils of peat and organic (black) clay over limestone.

The success of the Millicent-Tantanoola system gave the incentive to construct four main drains and their tributaries in the middle South East. The construction and administration was initially carried out by a number of government agencies but in 1931 responsibilities were transferred to the South Eastern Drainage Board (SEDB). The total area administered under the South Eastern Drainage Act, 1931-1985 is about 1,250,000 ha (See Figure 7). The network provides drainage for 697,000 ha of which 381,000 ha was flood prone land. A further 24,000 ha of the latter could potentially be drained for agricultural use.

Over the past 100 years a total of 1450 km of open drains were constructed with the overall objective of realizing the full production potential of the agricultural land in the SEDB administered area by discharging the winter flows, and by controlling and utilizing the spring and summer flows in the drainage system.

There are still areas of uncleared land remaining in the South East. In the northwest are large areas of infertile high land with a high erosion potential after clearing. Furthermore, small portions of undeveloped land are scattered throughout the middle and lower South East. These latter comprise mainly the depressions which are often uneconomical to drain. All uncleared areas with seasonal or permanent surface water were assessed for their conservation value by the South Eastern Wetlands Committee (1983). The location of the wetland sites in relation to the drainage system is shown in Figure 8. It was found that most sites have potential as wetland habitat and should be retained as wetlands under the existing regulations of the Planning Act.

Since 1972 only a few minor drainage construction works have been undertaken because the agricultural development potential of the South East has been largely attained. The results of the EIS (1980) and the Wetlands Study completed in 1983 show that the development phase has ended. It can be expected that in future the regional agricultural production will be increased by better farm management and intensification of land use rather than by development of the remaining uncleared land.

Due to the growing emphasis of the community on conservation and recreation it is expected that in future the South Eastern Drainage Board will manage the drainage system in a manner whereby both the interests of farmers with diverse forms of land use and those of conservationists are optimally met.

2.3 Drainage and Agricultural Productivity

The construction of the South East drainage scheme was closely interwoven with clearing and other aspects of land development for agriculture. This can be seen in Figure 9 where progress of the drainage works (shown as length of drain constructed) is plotted against time, and similarly the annual production of the three main agricultural commodities for the South East Region. Figure 9 shows also the diversification from solely grazing to a mixture of grazing and cropping which has resulted from declining farm returns and new market opportunities and overall intensification of land use, e.g. by subdivision and introduction of irrigation.

The value of the Region's primary production for 1985/86 is detailed in Table 1. Agricultural earnings in the South East Region are dominated by livestock sales and produce. The total value is $316 million which represents a considerable portion (20 percent) of the State's agricultural production.

TABLE 1: SIGNIFICANCE OF PRIMARY PRODUCTION IN THE SOUTH EAST (1985/86 ABS DATA)

Activity	Commodities	Value ($ million)		Proportion (%)
		South East	State	from South East
Cereals	Wheat, Barley	23.0	550.3	4
Other crops	Legume, Oilseed	22.2	50.9	44
Pasture	Hay, Seed	17.4	35.4	49
Vegetables	Potatoes, Onions, Peas	10.9	100.9	11
Viticulture	Wine, Grape	7.4	76.8	10
Livestock Sales	Beef, Sheep, Pigs	67.1	251.6	27
Livestock Prod	Wool, Milk, Eggs	112.9	429.9	26
Forestry	Cut logs	54.7	60.8	90
TOTAL		315.6	1556.6	20

Other data available from the Australian Bureau of Statistics show that the South East with a 1% land area of the State has 50% of the cattle, 30% of sheep and 6% of crops grown in South Australia. In addition the South East has now 92 000 ha of pine forests, 4 000 ha of vines and an expanding vegetable industry.

3. DRAIN CATCHMENT HYDROLOGY:

3.1 Layout and Functions.

The composite drainage scheme managed by the SEDB consists of three categories of man made channels. There are four main drains running in an east-west direction; secondly, a series of sub drains on the lower (western) edge of the interdunal flats; and finally, numerous laterals crossing the flats and connecting the swampy areas.

On average the main drains are about 2 m deep and up to 40 m wide.

The overall function of the drains is to remove surplus (rain) water from the interdunal flats. This surplus water has originated from one or more of the following sources:

* Swamps or natural watercourses (e.g. Mosquito Creek)
* Groundwater interception from:
  - inter-flow in duplex soils
  - watertable aquifer
  - confined aquifer
* Seepage and overland flow from the highlands
* North westerly overland flow on interdunal flats.

Individual drains have usually a mixture of specific functions:

* Solely transmitting of (surplus) water
* Collecting flow from tributaries
* Collecting overland flow
* Interception of excess groundwater.
* Draining swamps

3.2 Design Criteria.

The drainage criteria used for the South East drainage system have been researched and reported by SEDB (1983). Apparently, the earlier design criteria were based on a study of the 1929 to 1950 flows in the Reedy Creek - Mount Hope system recorded at Furner and on the performance of earlier drains in the area. Later design criteria were modified with further experience and taking into account landholders opinions that drains had been made too large.

The criteria used for the different catchments are summarized in Table 2.

TABLE 2: DESIGN CRITERIA FOR SOUTH EAST DRAIN CATCHMENTS

Catchment	Runoff (mm/day)
Reedy Creek (South of Furner)	9.4
Bellingers Swamp	4.7
Drain M - K & L	7.6
Bray, Drains L & K	7.5
Blackford, Kingston	5.5
Blackford subsidiaries	2.8

The design criteria are a balance of professional judgement, observed performance of drains completed and the degree of drainage desired by the local landholders (EIS, 1980). For example, the runoff figures were reduced for the most recently constructed drains e.g. Bakers Range Drain Enlargement where the design figure varied from 4.7 mm/day for the Mount Burr Heath area, 2.8 mm for the Trihi Lagoon area, down to as low as 1.0 mm/day for some northern portions of this drain catchment area.

The South East Drainage System differs distinctly from overseas drainage schemes in the following aspects:

* Despite the lack of natural slope the South East drains are relatively shallow. According to SEDB (1983) it would have been considerably cheaper to construct deeper but narrower drains. Deeper drains would have required relatively less cross sectional area and thus less excavation. The bridge length and costs would then have been less and also the land requirements. The drains were generally designed keeping in mind landholders' preference for shallow drains; a compromise was generally made between their preference and the higher costs of construction.

* The main drains are long and the total channel storage is less than one percent of the design run off.

* The spacing between the laterals is very great. This means that in winter the watertable is too shallow for improved pastures and cereal crops. The growth of those plant species would be severely limited by waterlogging.

3.3 Change in Hydrologic Regime.

Previous investigations at Conmurra and Konetta show that in the western portion of the drainage catchments, the leakage from the confined aquifer causes the watertable to rise in late summer.

Schrale and Sinclair (1978) estimated that at Konetta the leakage from the artesian aquifer into the watertable aquifer is between 50 and 100 mm/year. The same phenomenon is evident from the data collected from the Conmurra weir investigation by Till and Armstrong (1974).

With the onset of winter rains, soils in the flats become saturated and then percolation accelerates the initially slow rise of the watertable. When the watertable reached the surface, ponding would commence along with a slow NW movement of water.

Where drainage is provided, the water table will rise to the invert and the lateral will then commence to flow. In wet spells the watertable will continue to rise and reach the surface for a short period; then overland flow towards the laterals occurs. However in some areas, particularly where grades are steeper and soils relatively low permeable, overland flow may occur during heavy rainfall even before the watertable reaches the surface.

After a rainfall event the watertable decline commences in the area immediately adjacent to the drain; the rate of sideways lowering of the watertable depends on the horizontal permeability of the strata.

In early spring the watertable falls below the invert of lateral drains and they cease to flow. The sub drains flow for a longer time whilst the (deep) main drains, west of West Avenue Range maintain a baseflow due to groundwater interception throughout the summer.

3.4 Change in Pasture Composition

In the past the interdunal flats were continuously flooded during winter and perennial pasture species commenced growing only by mid spring and kept growing throughout the summer. The pasture composition on the flats has changed following the provision of drainage. There are still areas remaining where the watertable is shallow and where strawberry clover and other perennial pasture species with tolerance for waterlogging have kept growing in the same way.

The perennial grass species on the interdunal flats have been replaced by annual varieties which commence growing after the first autumn rains and dry off by early summer. Despite their shorter growing period, the yield of the winter and spring pastures by far outweighs the production of the perennials. Of course, this does not imply that the 'natural' change over to annual species compensates for the pasture production losses due to over drainage.

The change from summer pasture growth to predominantly spring growth only may have been perceived by the land holders as a negative effect of drainage.

3.5 Pasture Water Use and Carrying Capacity

The water balance method was used to estimate pasture water use under the hydrologic regime on the interdunal flat at Konetta.

Variable	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Rainfall	21	22	28	56	64	84	96	88	73	55	48	36	671
Pan evaporation	233	208	166	102	60	42	48	64	84	113	139	203	1462
Crop factor for pasture	0.59	0.46	0.45	0.47	0.53	0.50	0.56	0.68	0.78	0.78	0.80	0.63	
Potential water use of pasture	137	96	75	48	32	21	27	44	64	88	111	128	871
Rainfall - Pot Past water use	-116	-74	-47	+8	+32	+63	+69	+44	+9	-33	-63	-92	
Water storage in rootzone (max 30mm)	-30	-30	-30	-22	0	0	0	0	0	-10	-20	-30	
Profile storage by elevating wt. (max 100mm)	-100	-100	-100	-100	-90	-27	0	0	0	-23	-76	-100	
Drainage/Aquifer recharge							42	44	9				95
Calculated Pasture water use	21	22	28	48	32	21	27	44	64	88	111	70	436

TABLE 3: WATERBALANCE OF PASTURE AT KONETTA (Units: mm/month)

The average monthly rainfall and potential water requirement of annual pasture are compared in Table 3. The pasture normally commences to grow in April when the season breaks. In an average year the winter rainfall exceeds pasture water use from May to September. The surplus water initially replenishes the rootzone which has an estimated water retention capacity of 30 mm. Thereafter percolation will cause the watertable to rise. The water storage in an approximate 1m fringe above the watertable is estimated to be 100 mm. The calculations show that runoff will normally occur only between July to September. During October the pasture uses the rainfall and capillary rise from the initially shallow, but gradually falling watertable. In a normal year, water stress occurs from mid October onwards and most pastures dry off in early December.

The annual evapotranspiration is calculated to be 436mm/year. The annual water use for dryland pasture production is about 340mm/year because the 100mm summer rainfall on the then dormant pasture is not effective.

In general the water use of well growing pasture is a good indicator for its dry matter production. French (1987) suggested that the dry matter production of active growing pastures under dryland farming conditions in South Australia can be estimated as:

$$YDM\ (pasture) = 25x(ET-70)$$

in which:

YDM is the dry matter production in kg/ha, and

ET is the pasture water use in mm.

Therefore it is estimated that pasture with a water use of 340 mm/year produces 6750 kg DM/ha/year.

The carrying capacity of land is commonly expressed in units of dry sheep equivalents (DSE) per hectare. The fodder required for all-year-round grazing of one DSE is equivalent to 600 kg DM/year. This means that the carrying capacity of pastures on the interdunal flats is about 11 DSE/ha in a year of average rainfall.

3.6 Annual Pattern of Drain Discharge

As expected, the flow in drains depends on the annual rainfall and its distribution through the year. The peak flows occur during wet winter months when extensive ponding on the flats would have occurred prior to the construction of drains. The monthly flows of the major drains in Figure 10 clearly show the same seasonal pattern of drain discharge. The bulk of the run off from all drain catchments occurs from August to October each year.

Fisher and Saunders (1983) analysed the hydrographs of various catchments to determine the groundwater component of drain flows. A typical example of their analyses is given in Figure 11. The drain flow reduces rapidly when the rains cease in a 'normal' spring. This means that the bulk of the winter flows originate from overland flow. Normally the watertable commences to recede by mid September (SAGRIC, 1984) and thereafter the origin of drain flows is mainly groundwater.

The groundwater component for Drain M is plotted in Figure 12 against the annual drain flows for 1972 to 1982. The groundwater component for this drain seems only to double in an extremely wet year. Although different in height, the configuration of the hydrographs for those wet years is the same as shown in Figure 10.

Fisher and Saunders (1983) calculated that the average baseflow from December to June is normally less than 9 percent of the annual discharge. It is noted that this percentage of annual flow will be considerably less in wet years when very large volumes of winter discharge occur. Furthermore, the summer flows are dependent on the conditions in the catchment e.g. depth of the drain invert, the hydrological characteristics of the upstream groundwater storage and the presence of springs e.g. on the western side of the various ranges.

In Appendix 1 the annual and winter discharge of several drain catchments are plotted against the rainfall for these periods. The estimated rainfall retention i.e. evapotranspiration (mainly pasture water use) and aquifer recharge for the catchments is summarized in Table 4. The graphs in Appendix 1 suggest that drain flows occur when winter rainfall exceeds the retention value for the catchment.

TABLE 4: RAINFALL RETENTION IN SOUTH EAST DRAIN CATCHMENTS

Drain catchment	Rainfall Retention (mm)	
	Annual	May - Oct
Stony Creek	600	460
Bakers Range	640	410
Reedy Creek	580	390
Drain L	530	370
Blackford	480	330

3.7 Volume and Salinity of the Drain Flows

The annual discharge and quality of the South East surface waters were assessed during the E&WS (1986) study and the results of this inventory are summarized in Table 5.

The annual discharge of the South East drains averages at 230,000 Ml per year; more than 80 percent of the flow is low salinity water and is potentially suitable as an irrigation supply. The large volume of good quality water has to be discharged to avoid flooding of the low lying areas during winter. These winter flows can not be economically stored in large dams because of the low relief and high permeability of the soils and underlying strata. Consequently the economic returns of major (public) investments into dams are doubtful, particularly because large volumes of shallow, low salinity groundwater are abundantly available in the South East.

Table 5: MEAN QUANTITY AND QUALITY OF THE SOUTH EAST SURFACE WATERS

Volume unit = 1,000Ml/year

Streamflow Unit	Salinity (mg/l)	Mean Annual Flow		Divertible#		Used	Not Used	
Upper SE natural water courses e.g. Tatiara & Naracoorte creek	0-1500	13)	13	0		13	0)	0
	1500-5000	0)					0)	
	>5000	0)					0)	
South East Drains	0-1500	179)	230	39)	90	36	3)	53
	1500-5000	30)		30)		1	29)	
	>5000	21)		21)		0	21)	
Coastal Springs	0-1500	68)	153	153		0	68)	153
	1500-5000	85)					85)	
	>5000	0)					0)	

\# Divertible volume is the volume that can be practically stored and/or available as summer flow.

3.8 Options for Drain Flow Conservation

The following options of drain flow conservation may be considered in areas with poor yielding bores or where the groundwater is too saline for agricultural purposes.

(i) Off-stream ring dams

The winter flows could be stored in these 'above ground', on-farm dams constructed at sites where clay is available for lining. Large ring dams for storage of irrigation supplies are used in the upper catchment of the Darling River.

(ii) Weirs and adjacent underground storage

In winter the watertable on the flats is usually near the surface and underground storage near the drains is not available until the watertable recedes in spring. By using a weir, a portion of the spring and early summer flows can potentially be stored underground and retrieved by pumping from the drain in summer. However, in areas with highly permeable strata the accumulated groundwater will also move around these weir structures.

(iii) Retard groundwater discharge by raising weir in late winter

This means that by raising drain water level in time, the watertable in the area upstream of the weir will recede at a relatively slower rate and thus enhance pasture production. As in option (ii), pumping from the drain it will also function as a collector of the stored water.

Some water conservation is currently achieved at Bool Lagoon and in the natural storages. At present about 3,000 ha is flood irrigated from the drains when flows are available in late spring.

The most notable of these is the flood irrigation system developed by Mr. W.P. Macdonald for the property "Cluain", Hd. of Coles. Water moving northwards in the Bakers Range drain reaches Sheepwash Swamp on the eastern side of the Bakers Range on Section 4, Hd. of Coles. Water is diverted from the Swamp through a cutting equipped with control gates to a network of channels at a lower level in the western interdunal plain. From these channels water is flooded over the pasture and moves off in a north westerly direction. Flood irrigation continues from July through to December or earlier depending on the seasonal conditions. In this way the water which enters the Bakers Range Drain south at say Mount Burr in winter is delivered 30 km north until mid summer.

3.9 Significance of Spring and Summer Flows for Irrigation

Most land holders on the interdunal flats recognise the benefit of removing the surplus rain during winter, however they consider the drainflow after mid September as water wasted. McCourt (1985) proposed that a series of dams (i.e. weirs?) be built in the drains and thus allow a minimal amount of flow to the sea.

During a wet spring the drain flows can be quite substantial. In the following, spring and summer flows are calculated for an average year; the magnitude of these flows is compared with the irrigation supplies elsewhere in the South East.

The average groundwater component for the total drain flow was calculated to be 60 000Ml/year (E&WS 1984) of which 20 000Ml occurs normally from October to May.

On the basis of the hydrograph partition in Figure 11 it is estimated that a McCourt scheme would yield about 38 000Ml of low salinity water. This is equivalent to the volume required for 3 800ha of flood irrigated pasture ie. equivalent to about half of the area irrigated in the Padthaway Proclaimed area. It therefore seems that the significance of the spring flows is over-estimated in the land holders' perception.

No doubt, the main and sub drains intercept groundwater because of their deeper invert and the pasture production on land along the main drains is reduced due to over drainage. This aspect is discussed further in the following chapters.

4. BENEFITS AND COSTS OF DRAINAGE

4.1 General

Drainage, land clearing and establishment of agriculture are closely interwoven and so is the funding from State and Federal Government sources and the land holders' input in the form of labour and private investment. The overall result is obvious, but - if attempted - it would be difficult to apportion the benefits according to each source of funding for land development.

The main advantage of the South East Drainage Scheme is the improved productivity of the interdunal flats due to the removal of surplus water and the discharge of salt.

In this chapter the benefits of drainage are compared with the cost of minor land subsidence, the production loss due to over drainage, and the considerable annual cost of the drainage scheme.

4.2 Higher Productivity

The drainage system removes surplus water from an estimated 381,000 ha of land normally flooded in winter and now developed for permanent agriculture. The steep rise in sheep and cattle numbers since 1960 (See Figure 9) clearly demonstrates that drainage is a prerequisite for grazing of the flats. Over the years animal breeding, improved animal husbandry and better pasture management also contributed to the production increase.

Flood control has given reliable agricultural production and has led to intensification of landuse by sub-division of large holdings. In addition, the higher portions of the eastern flats can now be used for growing crops. For example, the profitable oil seed and grass seed production on the flats between Naracoorte and Lucindale would not exist without the provision of effective drainage.

The 1987 gross margin of the different farming activities in the South East are presented in Table 6. The gross margin is defined by Mowatt (1987) as the difference between the annual gross income and the variable costs directly associated with the type of farming activity. The variable costs do not include charges for the farmer's management, his own labour nor interest and repayment on loans. The type of farming practiced on the interdunal flats are mainly grazing of sheep and beef cattle which has a (weighted) gross value of about $180 per ha. The value of the agricultural production of the drained land is thus estimated as $68 million/year, or about 38 percent of the value of regional livestock production (See Table 1).

TABLE 6: SUMMARY OF GROSS MARGIN FOR FARMING ACTIVITIES IN THE SOUTH EAST

(Source Mowatt, 1987)

Type of Farming Activity		Gate Value of the production ($/ha)	Gross Margin ($/ha)	Gross Margin ($/dse)
Livestock	Merino Wether Flock	183	100	14.22
	Prime Lamb Flock	221	141	14.12
	Beef Herd	106	85	11.32
	Angora Goat Flock	279	200	26.62
	Cashmere Goat Flock	170	94	12.58
Cropping	Wheat	226	119	
	Barley	134	75	
	Lucerne Hay	1104	583	
	Lucerne Seed	275	552	
	Phalaris Seed	1050	683	
	Subclover Seed	780	240	
	Rapeseed	353	220	

Furthermore, a portion of land on the interdunal flats is now cultivated in late spring for cash crops under full irrigation e.g. lucerne seed, vines, sunflower. Drainage is the key for mixed farming and increased financial return per hectare. These extra gains are not quantified in this global economic analysis of the South East Drainage Scheme.

4.3 Removal of Salt

A report by the South East Water Resources Investigation Committee (SEWRIC, 1978) gives the following salt removal by the 4 main drains during 1971-1976 (See Table 7). As mentioned in that report, the rainfall was above average and the salt removal may have been over estimated by 28%.

Salinity data from E & WS (1984) were used to determine the total salt load removed by the drains.

TABLE 7: SALT DISCHARGE BY THE DRAINS

Drain catchment	Ave Salt Load (tonnes/year)
Blackford	238,000
Drain L	151,600
Drain M	103,400
Reedy Creek/Mount Hope	25,300
	510,700
Reduced by 28% (if relevant)	373,500
Millicent Drains	20,400
Eight Mile Creek Drains	211,300
	605,200

The removal of salt by the drains is therefore probably between 600,000 and 750,000 tonnes per year.

In Appendix 2 the salt removal by the drains for a number of catchments is calculated by using the available salinity/discharge data. In addition, the annual quantity of 'cyclic' salt i.e. salt contained in rain was calculated by using the Hutton (1976) relationship between rain water salinity and distance from the coast. The results are summarized in Table 8.

TABLE 8: ESTIMATED SALT BALANCE FOR DRAIN CATCHMENTS

Drain Catchment	Salt Load (Tonnes/yr)		Ratio
	Drain	Rain	
Blackford	165,000	5,200	31.7
Drain L	17,400	3,000	5.8
Drain M	20,200	5,800	3.5
Reedy Creek	18,700	6,100	3.1
Stony Creek	4,400	1,500	2.9
Wilmot	12,000	2,900	4.1

Though the above calculations are somewhat approximate, it seems that the drains remove considerably more salt than annually deposited as cyclic salt. The drains desalinize the shallow soil strata and thus provide a better plant environment on the interdunal flats.

4.4 Peat Subsidence due to Drainage

Permanent lowering of a watertable has led to land subsidence which is caused by two well understood processes: (i) Compression of clay and peat soils, and (ii) Slow oxidation of organic matter.

Land subsidence up to 300 mm was reported by Armstrong and Watson (1974) to occur in the Eight Mile Creek area where extensive peat flats were reclaimed near the coast. It is understood that some subsidence of the peat soils was also found in the Conmurra area.

4.5 Production Loss due to Overdrainage

The network of artificial channels dug deep enough to provide the desired level of drainage in winter may give over drainage of the land immediately along the drains in summer.

The aspects of over drainage are discussed here for the three drain categories identified earlier on the basis of their function:

(i) Laterals

Till and Armstrong (1975) concluded from the Conmurra Investigations that the seasonal pasture production is statistically not related to the depth to watertable and therefore to the distance from the shallow lateral drain. Watertable data for this typical flat shows that variations in depth to watertable with distance from the lateral occur usually in early spring when the pasture is not yet stressed.

The results of the Conmurra study show that pasture production is largely dependent on the seasonal conditions i.e. the winter rainfall and its distribution during spring and early summer. Furthermore, spatial variability of the soils, soil fertility and pasture composition seem to be important factors for the production on these shallow soils with a calcrete layer restricting root penetration.

(ii) Sub mains

These drains are usually situated on the westerly side of the interdunal flats. They follow the former flood courses and connect depressions which have highly organic (peaty) soils usually with a shallow often saline watertable. Due to the small northwesterly gradient these drains have a relatively deep invert. Many of these have a small but saline baseflow in the summer. In the strict sense, some over drainage also occurs along these drains but the overall lowering of a saline watertable has probably improved the pasture growth in summer.

(iii) Main drains

These high capacity drains across the flats are usually wide and on average about 2 metres deep. The weir (site) investigations show that the main drains may lower the watertable for up to 1 to 1.5 km either side. The 1980 and 1981 sets of data for Mount Bruce weir site shows that pasture production near the drain is about 20 percent lower than at 300 m distance from the drain.

The magnitude of the production loss due to over drainage along the main drains was assessed by adopting the following criteria:

- The dry matter production of unaffected pasture is 6750 kg/ha i.e. equivalent to a carrying capacity of 11 DSE/ha.

- The land use along the drains is grazing of sheep which has a gross margin of $14 per DSE. (See Table 6).

- The loss of pasture production due to over drainage is 20% near drains with a 2m deep invert. The effect tapers off linearly with distance from the drain and is negligible at 1 km distance. The weighted loss of pasture production over the 1 km wide strip on each side of the drain is then 10%.

TABLE 9: ESTIMATED AREA OF OVER DRAINAGE ALONG THE MAIN DRAINS

Main drain	Distance along drain (km)	Land holdings along drain number	Land holdings along drain total area (ha)	Overdrained Area Total (ha)	Overdrained Area Average portion of farms (%)
Reedy Creek/Mount Hope Drain	21.7	24	7761	2595	33.4
Drain M	63.0	42	25353	7445	29.4
Wilmot Drain	15.0	14	9606	2548	26.5
Bray/Biscuit Flat Drain	12.6	6	6885	2040	29.6
Drain L/K	33.4	25	15230	3600	23.6
Symon Petition Drain	7.1	15	3732	1275	34.2
Reedy Creek Div. B. Drain	5.7	11	1473	705	47.9
	158.5	137	70040	20208	28.9

The SEDB has maps showing the so called "benefitted areas" i.e. the land that has improved as a result of drainage; these areas have been identified by the South Eastern Drainage Appeal Board.

Recently Pettingill (1987) determined the benefitted areas situated one kilometre from the centre line of the main drains. He expressed the overdrained area as a percentage of the total area of the farms along the main drains.

It is calculated in Table 9 that a total area of 20208 ha along the main drains is affected by over drainage. The resulting loss of pasture production is then equivalent to $311 200 per year. This estimated loss is shared by a total of 137 landholders along the different main drains. The number of holdings with over drainage is plotted in Figure 13 against the total area (size) of those farms. Most (100 of the 137) farms affected have a size between 100 and 1000 ha. About 60 percent of these farms have a size between 100 and 400 ha.

The over drained areas, expressed as a percentage of the total farm area are also plotted in Figure 13 against the farm size. It seems that the percentage of the farm area over drained decreases almost inversely proportional to the farm size, (Note the (horizontal) scale for the farm size is <u>not</u> linear).

As expected, the percentage area affected is very high for the less than 100 ha farms along the main drains. Most of these are probably isolated portions of larger farming enterprises. This is less likely for the 100 farms in the category between 100 ha and 1000 ha. It seems that these farmers bear about 70 percent of the estimated financial loss due to over drainage. On the other hand, in the absence of drainage the carrying capacity of their farms would have been very much less because of extensive flooding in winter. It needs therefore to be recognized that those properties that are assumed to have production losses due to over drainage during dry periods, generally receive the greatest benefit from drainage during wet periods because they are usually situated on the lower portions of the flood prone land abutting the main drains.

4.6 Annual Costs of the Drainage Scheme

The capital required for the construction of drains, bridges, roads and other structures was made available as State and Federal Government grants, funds and through private investment. The total Government expenditure has accumulated to about $20 million. The South Australian Government provided about $18 million for the construction of the 'comprehensive' drainage system between 1949 and 1972 (See Figure 9).

To estimate the annual capital cost of the South East Drainage Scheme the $18 million expenditure has been capitalised in 1987 values. Assuming that the construction techniques would have remained the same, then the 1987 construction cost would have been $108.2 million. Taking the lifespan of the drains as 100 years, and the 'real' interest of 7 percent then the annual capital cost is $7.56 million per year. The operating cost of the SEDB is currently about $440 000/year. Therefore the total annual costs of the SE drainage system is probably about $8.0 million/year; this amount has been fully provided by State Treasury since the abolition of drainage rates in 1980.

4.7 Evaluation

The following picture for the economics of the South Eastern Drainage Scheme has emerged from assessments for the benefits and costs of drains and weirs.

* The total ('actual') cost for the Drainage Scheme is estimated to be about $8.0 million per year in 1987 values.
* The gross value for farming the 381 000 ha of drained land is about $68 million per year.
* The financial loss due to over drainage is about $310 000 or less than one percent of the gross returns.
* The financial loss due to over drainage is predominantly borne by about 100 farmers with medium size properties along the main drains in the western portion of the catchments.

5. OVERVIEW OF WEIR INVESTIGATIONS

5.1 General

The opinion of landholders that weirs are effective means to combat over drainage has led to a number of field investigations on the influence of weirs to maintain ground water levels in land along the drains.

Weirs in drains can be used to influence the water table of adjacent land in two ways:

(i) Restore the declining water table in spring

By raising the weir in late spring the receding flows in the drain are banked up for some distance. In this way a 'line' source of water is created for replacing the volume of ground water removed by the drains during the preceeding month or so. The site and configuration of the ground water mound resulting from the weir depends thus on the baseflow rate, aquifer transmissivity and the field topography.

(ii) Delay the seasonal fall of the water table

The weir is raised in late winter so that the resulting water body ('plugging' the open drain) decreases the slope of the water table towards the drains. In principle, the water table at the weir site should then decline at a rate similar to pre drainage conditions. By raising the weir early it will influence the water table over a relatively greater area. Some groundwater will move around the weir; this almost unavoidable 'water loss' depends on the transmissivity of the water table aquifer and its local gradients.

In the past 25 years the SEDB has given approval to various landholders for a total of 32 private weirs to be constructed on either a permanent or temporary experimental basis. Only 13 of these weirs have been operated with any regularity; it seems that landholders at the other sites consider that the benefits do not outweigh their efforts for continued operation of the weirs.

5.2 Weir Site Locations

Over the past three decades a total of 10 investigations into experimental weirs or weir sites have been conducted. Most water table data are kept on computer files by the Mines and Energy Department. However most of this data has not been evaluated.

The location of the experimental weirs and investigated sites is given in Figure 14. Each structure was inspected in late November 1986. Most weirs are in the coastal area where the drains usually maintain a small baseflow throughout the summer. There are no storage weirs in the Blackford Drain because of its high salinity. Except Miegel's weir, all weirs still in use are in the downstream catchment of Drain M which has a permanent and low salinity baseflow and where the soil conditions tend to be more favourable.

Following the adoption of the EIS report in 1980, Cabinet approved funds for the construction of 3 weirs in the downstream section of Drain M. The overall objective of constructing these modern weirs in Drain M was to investigate once and for all whether weirs can correct over drainage. In consultation with the local landholders and other government departments the SEDB selected the following sites (See Figure 14):

* Mount Bruce weir

This site was selected by the landholders as being typical for the conditions on the interdunal flats. At the time it was recognized that the soil conditions were not favourable. However it was decided to construct the weir as a compromise of two objectives:

(i) replacement of the decayed drop structures in that relatively steep section of Drain M.

(ii) investigation into the effect of raising the water level on pasture production under soil conditions typical for the interdunal flats of the South East.

* Magarey Lane and McCourt weirs

These two weirs were built about 3 km apart almost near the end of Drain M.

The Magarey Lane weir is located at a particularly favourable site, just down stream of the tributary Symon Petition Drain. The topography is relatively flat and consequently this major structure backs up water in both Drain M and Symon Petition Drain for a considerable distance. The soil conditions are also more favourable than at the Mount Bruce site because extensive pockets of peat occur near Magarey Lane. The soils in the low-lying areas have usually a thick top layer of black organic clay with good capillary rise in early summer.

Mr McCourt's weir is at a good site due to the large peat flat just upstream. Water is retained by this weir to a high level in the relatively free draining peat and thus enhances the pasture growth on this area during spring and early summer. Throughout the summer water is pumped from the drain for supplementary irrigation of 240 ha of pasture and early summer crops. Pumping lowers the water level behind the weir but after pumping ceases the water level is quickly restored by inflow of groundwater. The owner of some peat flats has stated that at times the watertable is held too high by the weir; his land is sometimes too wet for grazing in spring and hay making in summer.

It is noted that the original surface levels prior to drainage indicate that the peat flats in this area subsided up to 0.45 metres after the original drain was constructed in 1922.

Nitschke (1987) points out that other weirs besides those shown in Figure 14 have been constructed:

* Two weirs privately constructed near the upstream end of Bakers Range Drain, one by Mr. McCourt and one by a group of landholders downstream of the above.

* Two small weirs on Reedy Creek Division C Subsidiary Drain were apparently constructed about 12 years ago to retain water in swamps upstream of the weirs.

* The Callendale Regulator in Drain M is used to retain water for the benefit of landholders near the end of winter.

* Many drop structures have been constructed where steep grades are encountered in drains as they pass through the various ranges. Most are left with the stop logs in place in the sills throughout the year and act as shallow water retaining weirs 0.6 to about 1.2 metres high. The drop structures assist in holding up ground water levels through the ranges and the adjoining flats. The accumulative effect of these could be considerable.

5.3 Summary of Previous Work

* 1952-1954: Mount Hope-Reedy Creek weir.

This 2 m high, concrete weir was built on the limestone floor of the low gradient, 25 m wide drain and is located about midway between the Woakwine Range and Reedy Creek Range.

The seasonal water table fluctuations around the weir site were monitored by the Mines Department over 4 years: two years before and two years after the completion of the weir. It was reported that the Department of Agriculture monitored the pasture production but these results have neither been published nor filed. Steel (1958) concluded that the drain affects the water table during the winter for approximately 1200 metres either side. Little change was observed since the installation of the weir, except that the water table recession was somewhat slower; the effect on local recharge in summer extended to possibly between 600 to 800 m distance from the drain.

* Late 1960's: Miegel's private weir

This simple weir was built by a private landholder in Drain K near Conmurra. In 1980-84 the Mines and Energy Department (DME) monitored a net work of observation wells. The results show that the regional watertable sloped towards the drain throughout summer and that the weir gave some localized recharge. The weir is still in use, and the landholder is convinced of its benefits.

* 1969-1970: SEDB (major) weir at Conmurra

This 3 m high weir was built by the SEDB in Reedy Creek-K (sub) drain, which is about 10 m wide at that site. Two years after completion the upstream farmers could no longer agree on the desirable drainlevel in summer; apparently a salinity problem and flooding in the lower peat flat caused crop and pasture damage. Landholders have operated the weir in recent years and water is ponded at a low level which has practically rendered the weir ineffective. Lack of agreement amongst these landholders gives some indication of the diverse management requirements of landholders affected by the weir.

* 1970-1976: Conmurra weir investigations

Two small weirs were built in the (parallel) laterals AV-K21 and AV-K23. Till and Armstrong (1974) found that immediately around the weir the water table recession was retarded by 4 to 6 weeks in early spring. However, by that time the water table is already below the (shallow but hard) calcrete layer and consequently capillary rise to the root zone is small. After the first year all sites for pasture production measuring were fumigated, resown and fertilised. A high quality data set is available on water table fluctuations, production and composition for 3 seasons; also soil chemical analyses for the final year. A multi variable, computerized analyses of these data seems warranted to complete this thorough study.

* 1974-1975: Bowman's weir in Reedy Creek - Division B

The SEDB monitored almost weekly the water level in two wells, one upstream and one downstream of the weir. The weir had little effect on the water level in adjacent wells.

* 1978: Computer modelling of weir effect

A simple modelling study was undertaken by MacIntosh (1978) to similate the weir effect on the local water table. It was found that for conditions typical for the interdunal flats, the weir would not affect the water table regime at distances greater than 1 km from the weir.

* 1979-1984: Survey of weir sites.

The release of the draft EIS report generated a renewed interest in the use of weirs. The SEDB encouraged the three Departments to assess the benefits of weirs by monitoring the watertable regime around existing and temporary weir structures.

. Williams experimental weir

An experimental weir consisting of sandbags and a covering plastic was temporarily erected in Reedy Creek Drain Division B, near Section 79, Hundred of Riddoch. This weir was installed on 26/11/79 and removed on 7/5/80. A total of 9 piezometers were monitored by the SEDB from October 1979 to December 1981. Results show that the experimental weir was erected too late in the season because most groundwater had already been removed by the drain. The weir resulted in some recharge only immediately around the site; overall the effect was minimal. No permanent weir has eventuated at this site.

. Callendale proposed site

DME monitoring of 11 wells near the bridge crossing drain M at the common boundary of Hundred of Fox and Hundred of Coles. The effect on the water table was insignificant. No weir construction has eventuated to date.

. McArthur proposed site

DME monitored 8 wells in the vicinity of where Mount Hope drain crosses the Woakwine Range (Hundred of Rivoli Bay). This site is about 7 km downstream from the Reedy Creek/Mount Hope weir; to date . no weir has been constructed at the investigated site.

* 1981-1983: Konetta Lysimeters

The Konetta lysimeter station was established by the Engineering and Water Supply Department in 1971 with the objective to determine the actual water use of pastures on the interdunal flats. During the installation of the six 2 metre deep tanks the shallow calcrete layer was broken and then backfilled. The calcrete backfill was no longer a barrier for the Phalaris roots to reach the water table and consequently the experimental data collected between 1971 and 1978 were distorted (Schrale and Sinclair 1978).

By using tensiometers it was established that the Phalaris grass in the lysimeter extracted water from the layers below the broken calcrete. This means that the root environment in the lysimeters is comparable to the conditions in a 'deep' profile. On this assumption the lysimeter facilities were modified to determine the effect of watertable depth on pasture water use.

In order to assess the relationship between depth to watertable and pasture production the 6 lysimeters were paired and the watertable in them was maintained at 300 mm, 600 mm or 900 mm below the surface throughout the year. (See Figure 15).

The pan evaporation, pasture water use for each depth to watertable are plotted in Figure 16 and 17 for the summer and winter seasons of 1982 and 1983. The results show that in winter the pasture water use is practically independent from the depth to watertable. At that time of the year the rainfall and soil water availability can meet the pasture water requirement. (See Table 3).

In summer however, the pasture water use is inversely proportional to the depth to the water table since the capillary rise then governs the water supply to the rootzone. The water use of summer pasture with an unrestricted water availability in the root zone is equivalent to about 75% of pan evaporation.

During the winter months the soil in the lysimeters with a 300 mm deep water table was waterlogged. Consequently, pasture growth was minimal in the second winter season. In both years, strawberry clover emerged in spring and grew throughout the summer. It seems that the watertable must not be deeper than 300 mm for active growth of strawberry clover and associated grass species.

* 1980-1985: Mount Bruce weir

DME monitored monthly a network of test wells at the Mount Bruce weir site from 1979 to 1985. The results show that by December each year the influence of the weir on the watertable is limited to 0.1 m in elevation at 1 km distance from the drain and to about 2 km upstream from the weir.

The Department of Agriculture measured the 1980 and 1981 pasture production in 10 cages situated near the DME piezometers. It was noticed that there is fractured calcrete at shallow depth in the soil profile. In late November each year dry patches of pasture on scalds occur within a few metres from dense stands of 'knee high' Phalaris. Despite the great variability, the results seem to show that the pasture production at 300 m from the drain was about 20 percent higher than that at about 10m distance. It seemed that in those years the weir had not at all restored the reduced pasture yields due to overdrainage. On the other hand, the landholder had not established a pasture with deep roots in order to optimize the benefits of the raised watertable in early summer. The soil profile consisting of sandy loam over shallow calcrete would have little capillary rise anyway.

* 1980-1985: Magarey Lane and McCourt weirs

With the aim of determining the effect of the weirs on the groundwater levels, the DME monitored the water level and salinity in a regional network of wells and a local network of wells around the weir sites for a 5 year period. No agronomic measurements were made at these weir sites.

The salinity fluctuations of the drain flow and wells at relatively short distances from the Magarey Lane weir are plotted in Figure 18. The summer flow of the major drain is moderately saline. The plots show that the salinity of the observation wells has risen by about 50 percent since the weir has been in operation. Capillary rise from the raised water table may increase the salinity in the root zone on the peat flats, similar to that experienced in the peat soil upstream of the SEDB weir at Conmurra.

The water level data were used by the E. & W.S. Dept (1985) to prepare periodic maps showing the extent of the groundwater mound i.e. the areas in which the watertable was within 1 metre of the soil surface. It was found that the development of a groundwater mound is highly dependent on the seasonal (rainfall) conditions. This can be clearly seen in Figure 19 in which the decay of the groundwater mound is plotted for the different seasons.

The May to October rainfall seems to be a good indicator for the extent of the groundwater mound. By extrapolating the 4 areas the decay of the groundwater mound was estimated for a year of average seasonal rainfall i.e. 438 mm between May to October.

* 1981-1985: Narrow Neck weir

In 1981 the Millicent Council rehabilitated the Narrow Neck weir in Drain 1B. A network of about 20 wells was monitored by DME from early 1981 to early 1985. Unfortunately the weir failed and there was opposition to the erection of a new weir by the farmers cropping the peat soils along the tributories, Hatherleigh Drain and Drain 20B. A weir was proposed several years ago; the site was investigated and a weir design was completed, but at the time the Millicent Council decided not to proceed with the work.

5.4 Landholders' Attitude towards Drains and Weirs

At various times, particularly in dry years, farmers have expressed the opinion that their land is over drained. Their attitude towards the drains was often reflected in the comments made during public meetings and field days. Till (1981) conducted a questionnaire on the effects of weirs and drains amongst the landholders around the Mount Bruce and Magarey Lane weirs. According to the farmers the benefits of drainage are:-

"Enabled better winter pasture through surface water being removed".
"Cleared excess water during cold wet winter months".
"Eliminated water-logging of the lower and heavier country during wetter months."

In the farmers' opinion, the undesirable effects of the drains are:-

"Country dries out too quickly during late spring and early summer"
"Clears water too fast in spring"
"My property (near drain) is one of the first in the district to dry off"
"The drain is too deep and takes the underground water away so I lose spring growth".

The survey results reaffirmed that the farmers recognize that drains are needed for permanent agriculture in the interdunal flats, but they consider that the main drains adversely affect the productivity of adjacent land.

The landholders around the (then) proposed weir sites were also questioned by Till (1981) regarding their expectations of the weir effects. The majority expressed the opinion that the effects of the weirs would be:

- either beneficial or extremely beneficial.
- that they would benefit their own property and the local district.
- that the long term effects of the weirs could be predicted easily and that the effects of installing the weirs would be apparent within a short period of time and in most seasons.

The benefits they saw to be most important were an increase in carrying capacity in late spring and the ability to produce better pastures, in particular the ability to grow strawberry clover and Phalaris close to the drains. They expected the installation of weirs to have little overall effect on their farm management but would increase the number of stock that they might be able to carry. Their comments about the effects of weirs and drains were as follows:

"I'd like to see more weirs put in to all drains of any size so as to hold up the flow of the water. This should slow up the flow of underground water and build up the water table".

"Unrestricted flow of the weirs must be eliminated if the problem of reduced summer pasture growth is to be overcome".

"Weirs will help overcome the problem caused by deep drains having lowered the ground water table causing pastures especially perennial species to dry off earlier than normal during the spring".

"Weirs are a good attempt to patch up the mistakes made in cutting the drains so deep in the first place that they have over drained the land".

Till (1981) foresaw the difficulty that it will be far easier to show the effects of the weir on water tables than to measure the effects on pasture growth. The effect of weirs on pasture growth is likely to be a limited extent, of short duration, and to occur only in those years when pasture growth can be affected by soil moisture content in spring. He anticipated that the problem facing the experimentalist in this situation is to reconcile the expectations of the landholders that weirs will have a beneficial effect on their farm management, carrying capacity and pasture growth on one hand, and the theoretical expectation that the response of pasture growth to variations in water tables is likely to be limited in extent and difficult to measure. Unless the reconciliation of these two attitudes occurs the landholders are likely to be unconvinced by any evidence of experimental work which gives a contrary result, and they will continue to agitate for installation of weirs.

Following the completion of the three new weirs periodic farm walks were held at critical times in late spring and summer of the early 1980's to encourage the landholders near the weirs to share their experiences amongst themselves and with government officers. The farmers participation was low in good years but in the 1982/83 drought most attended and their expectations of weir benefits was remarkably greater. The Magarey Lane farmers claimed that the water levels on their properties had been consistently higher and the preferred strawberry clover had returned in the low lying areas.

The landholders at Mount Bruce were surveyed by telephone in early December 1986 for their opinions regarding the weir benefits over the past 5 years. These interviews are summarized in Appendix 3. The farmers thought that the weir retards the seasonal decline of the watertable but most had difficulty in stating that pasture production has increased since the installation of the weir.

A postal survey on weir benefits was conducted amongst the Magarey Lane farmers. The results are summarized in Table 10. The farmers indicated that the weir has led to a longer growing season for a considerable area of pasture. The higher water levels have reduced the cost of pumping for irrigation and the pool of McCourt's weir is used for 240 ha of supplementary irrigation.

6. ESTIMATED BENEFITS OF DRAIN M WEIRS

6.1 General

As stated before, the overall objective of the experimental weirs in Drain M was to investigate whether weirs can correct the overdrainage. In the past 5 years these large weirs have been operated by 'trial and error' i.e. compromise in spring and early summer between maintaining high water levels in the drain and-at the same time-allowing sufficient discharge to minimize the risk of widespread flooding due to freak rain and thunderstorms.

It is difficult to assess the benefits of the weirs because their effect on pasture production cannot be measured as a single variable. The difference in pasture production/carrying capacity during the years before and after the weir construction is concealed in the variations due to seasonal growing conditions and consequent changes in grazing practice. For this reason the benefits of the Mount Bruce weir have been estimated by assuming the 'best possible case'. The benefits of the Magarey Lane and McCourt weir was derived from the seasonal groundwater mounds reported by E. & W.S. (1985) and from the results of the recent farmers' questionnaire.

Landholder	Benefits	Area (ha)	(DSE/ha)	Longer growing season (weeks)	Raised watertable & purpose from/to(m)	Type of benefit	Comments
Guy Wheal	not sure	0	-	-	-	-	neighbours claim they have benefits
David Snook	yes	120-140	1.2			extra pasture growth	still green patches
Ian Leopold	yes			3-4	0.6-0.9m rise	extra pasture growth	90 acres went under water for 1st time after 20 years suggests: raise weir in August.
Bill Gregurke	yes				3.6/2.2	less power for irrigation of the 50 acres	no extra growth on peat-flats: these are now only wetter.
Peter Gregurke	yes	15-30	3-5		0.6 m rise	extra pasture growth	suggests: remove all boards in winter to minimise waterlogging of low lying areas.
David Brown	yes	150-200		6		extra pasture growth	
Ralph Bowman	no	-					
Michael McCourt	yes	500				600 acres of centre pivot irrigation	

TABLE 10: SUMMARY OF FARMERS SURVEY ON BENEFITS OBTAINED FROM THE MAGAREY LANE WEIRS (FEB 1987)

A major drawback of weirs in drains was reported by Nitschke (1987). It has been noticed that in the past few years that weirs cause increased siltation and weed growth in the upstream section of the drain. This has resulted in considerable increase in the drain maintenance costs which have been allowed for in the following analyses.

6.2 Mount Bruce Weir

As discussed earlier, the measurement by Agriculture Department officers in the 1980 and 1981 season show that the weir had not led to restored pasture yields in the vicinity of the drain. Similarly, the recent telephone survey of the Mount Bruce farmers (See Appendix 3) indicates that the effect of the weir on pasture production is not evident.

The construction cost of Mount Bruce Weir in 1980 was $89 000, which is equivalent to $156,000 in 1986 prices. According to the SEDB superintendent the cost of operating and supervision of the Mount Bruce weir was $3500 in 1986. Nitschke (1987) pointed out that this section of Drain M must be retained in a very good condition so that flows from Bool Lagoon and Baker Range Drain can be passed without causing flooding in the downstream section of Drain M. The weir has led to the growth of weeds e.g. Triglochin procera, which are difficult to control. In addition, deposition of silt has occurred in this section of the drain. These extra maintenance costs may amount to $2500 per year.

Accurate field measurements are lacking and therefore the magnitude of this weir's benefits were assessed by assuming that the following (probably optimistic) conditions apply:

(i) The groundwater mound at the weir site is 3 km long and extends to 1 km distance each site from the drain in an average year.

(ii) The pasture production in the 3 km long and 2 km wide strip is improved by 10 percent over that entire area.

(iii) The carrying capacity of the land around the Mount Bruce weir is typical for the South East i.e. 11 DSE/ha.

(iv) The weir has a life span of 60 years.

The gross annual return as a result of the restored pasture production is then:

$$\frac{10}{100}\ \frac{(\%)}{(\%)} \times 600\ (ha) \times 11\ (DSE/ha) \times 14\ (\$/DSE) = \$9200 \text{ per year.}$$

The annual cost of the weir are \$3500 + \$2500 = \$6000 per year.

The Return on Investment is then: $\frac{\$9200 - \$6000}{\$156000} = 2.1\%$

However the weir has a finite life span and thus the capital has to be written off over that period. This aspect is incorporated in the economic concept of 'Internal Rate of Return on Investment' (IRRI) (i.e. the net return on investment after allowing for the diminishing value of the weir. It is calculated that IRRI for the Mount Bruce weir is 0.7 percent.

It seems that even under the above favourable assumptions the estimated benefit of the weir is practically nil. The estimated low benefit seems to be in agreement with the farmers' opinion about the doubtful benefits of the Mount Bruce weir as expressed in the telephone survey.

On the other hand, as mentioned earlier in Section 5.2 this weir was also required for flow regulation in this relatively steep section of Drain M.

6.3 Magarey Lane/McCourt Weirs

6.3.1 General

From the onset, these weir sites were favoured because of the relatively low topographic gradient, the entry of Symon Petition Drain into Drain M, soil profiles with better capillary rise and location just downstream of areas with permanent spring flow adding to the baseflow of Drain M. In addition a large peat flat is situated between the two weirs. Mr. McCourt is to be commended on the choice of the site and his foresight to proceed with the construction of his weir.

The E. & W.S. (1985) report shows that the effects of the two weirs on the water level regime are closely interwoven. For this reason the weirs are considered as one unit in the two different methods of assessing the benefits of the weirs.

6.3.2 Theoretical estimate

The E. & W.S. (1985) report gives maps showing the gradual decline of the groundwater mound, i.e. the area with a less than 1 m deep watertable attributed to the weirs during the 4 seasons between 1981 and 1985. These (limited) results plotted in Figure 19 were used to estimate the decline of the groundwater mound in a year with average rainfall between May and October.

The extra pasture production resulting from the extended growing season is estimated by making the following assumptions regarding pasture water use (ET):

(i) no weir:

- depth to water table greater than 1.5 m
- no extra pasture water use

(ii) within area of groundwater mound:

- average depth to watertable is 0.9 m
- pasture water use is 0.3 of potential pasture water use (ETO)

(iii) ETO is 600 mm over the 5 summer month (November - March incl.)

(iv) The French (1987) transformation of pasture water use into dry matter production (See Section 3.5) applies.

The extra dry matter production (YD) during summer on the land within the groundwater mound is then:

$$YD = 25 \frac{(0.3 \times 600 - 70)}{1000} = 2.75 \text{ tonnes of dry matter (DM) per ha}$$

over the 5 summer months.

Using the extrapolated curve in Figure 19, the extra pasture production during each summer month of an average year can then be calculated as:

Month	Extra pasture production
November	1 400 ha. month growth
December	1 000 ha. " "
January	800 ha. " "
February	650 ha. " "
March	500 ha. " "
TOTAL	4 350 ha. month growth

The extra dry matter production during the summer is then:

$$\frac{4350}{5}\frac{\text{(ha. month growth)}}{\text{(months/summer)}} \times 2.75 \frac{\text{(tonnes)}}{\text{(ha)}} = 2392 \text{ tonnes/summer season.}$$

The gross return of the extra pasture production on the land with an elevated water table is then:

$$\frac{2392 \text{ (tonnes DM)} \times 14 \text{ (\$/DSE)}}{0.6 \text{ (tonnes DM/DSE)}} = \$55813 \text{ per year}$$

Additional is the beneficial use of drainage water for the 240 ha of supplementary irrigation by centre pivot. This total investment of about $200 000 (in 1987 prices) was made some years ago when the attractive depreciation schedule for irrigation equipment was still applicable. It is estimated from information provided by the landholder that the income from this investment is about $30 000 per year.

The total cost of the Magarey Lane weir in 1980 was $172 000, which is equivalent to $302 700 in 1987 prices. The SEDB provided for the cost of the design, the sheet piling and reinforcing steel for the McCourt's weir and the landholder paid for the cost of the other building materials, machinery and (farm) labour. It is estimated that the total construction cost for the McCourt's weir would have been $30 000; this is equivalent to $52 800 in 1987 prices.

The SEDB superintendant indicated that the cost of weir operation, supervision and maintenance was about $6750 in 1986. It is estimated that the extra maintenance cost for this drain section may amount to $10 000 per year.

The Return on Investment for the two weirs is then:

$$\frac{(55813 + 30000 - (6750 + 10000)}{(302700 + 52800 + 200000)} = 12.4\%$$

6.3.3 Empirical estimate

In this case the results of the farm survey (See Table 10) were used for assessing the weir benefits. It is estimated that the weirs have led to an additional production on say 1000 ha with an increased carrying capacity of 3 DSE/ha. The gross margin of this agricultural production is then:

1000 (ha) x 3 (DSE/ha) x 14 ($/ha) = $42000 per year.

This is to be combined with the $30000 profit from the centre pivot irrigation.

The Return on Investment for the two weirs is then:

$$\frac{(42000 + 30000 - (6750 + 10000)}{(302700 + 52800 + 200000)} = 13.7\%$$

6.3.4 Internal Rate of Return

As discussed earlier, the Internal Rate of Return on Investment (IRRI) is the more appropriate concept for the economic evaluation of the investments into the weirs. For this purpose the following assumptions have been made:

(i) The (net) return from the weirs and the centre pivot is $69 000 per year.

(ii) The Magarey Lane weirs and the centre pivot irrigator have a life span of 60 years and 20 years respectively.

Using the IRRI methodology it is calculated that the net return on investment for the Magarey Lane weirs and centre pivot is 12 percent.

6.4 Evaluation

Even by assuming rather optimistic conditions, the return on the Mount Bruce investment is calculated to be practically nil. In contrast to this, the net return for the Magarey Lane and McCourt weirs is estimated to be about 12 percent. This is a good result in comparison to other public investments into water diversion works e.g. the irrigation schemes in the Riverland.

The large investment by Mr McCourt into his weir and associated centre pivot irrigation was opportune particularly in those years when the attractive depreciation schedule was still applicable. In addition, the (supplementary) irrigation area allows the landholder to market his stock when the market prices are better. The 240 ha of irrigation also allows him to retain breeding stock during droughts.

Under the favourable conditions of low salinity drain flow and (peat) soils the weir effect on the watertable was only equivalent to an increased (probably restored) pasture production of 850 ha. It seems that despite the lack of suitable sites and the high construction costs, numerous weirs in the main drains will not make up for the loss of pasture production on the 20200 ha of over drained land because the drain flows after mid September are too small.

The significant benefits of the public investment into the Magarey Lane and McCourt weirs are obtained only by some 10 landholders around this excellent site.

Due to the favourable conditions at Magarey Lane, the weir benefits are probably considerably greater than for many other sites suggested by the landholders. The benefits of this weir should therefore not be used for the justification of investment into weirs at other sites.

It can be seen that over the years the SEDB together with a few landholders have invested a substantial amount of money and labour into efforts to maintain groundwater levels in the drainage area.

7. CRITERIA FOR WEIR SITES

7.1 General

Most of the main drains in the coastal half of the SEDB administered area have a small base flow throughout the summer months. This flow results from groundwater interception and springflow entering the drains e.g. in the western side of the West Avenue Range, and controlled releases e.g. from Bool Lagoon and Baker Range regulator.

By now the landholders will have identified the most suitable weir sites since many temporary structures have been built over the past three decades.

This chapter summarizes the general requirements for potential sites for weirs to be used for either maintaining/raising the groundwater levels along the main drains, or for water harvesting in areas where suitable groundwater supplies for irrigation are absent.

7.2 Site Requirements

The following aspects need to be considered when searching for potential weir sites:

* Considerable baseflow of low salinity.

  The salinity of the drainflow should not exceed 2500 mg/l; salinities of less than 1000 mg/l are preferred.
* Soils with good capillary rise (e.g. peat).

  This means that farming land with shallow, unfractured calcrete are potentially not suitable.
* Low aquifer transmissivity.

  The groundwater flow around the weirs is then minimal.
* Low tilt of topography.

  The groundwater mound is then likely to extend further up the drain.
* Opportunity for growing appropriate pasture and crops

  e.g. perennial vegetation, salt tolerant crops with deep roots.
* Availability of land suitable for irrigation.

  The option of water harvesting from the drain can be considered if the nearby land is well drained and the soils have a good water retention capacity.

It will be difficult to find sites which are ideal in every aspect; a ranking of the variables is probably required to select the best site from the options available.

Other factors for weirs to proceed are the ingenuity and entrepreneurial skills of the landholder(s), their financial resources and level of taxable income.

Landholder	Benefits	Area (ha)	(DSE/ha)	Longer growing season (weeks)	Raised watertable & purpose from/to(m)	Type of benefit	Comments
Guy Wheal	not sure	0	-	-	-	-	neighbours claim they have benefits
David Snook	yes	120-140	1.2			extra pasture growth	still green patches
Ian Leopold	yes			3-4	0.6-0.9m rise	extra pasture growth	90 acres went under water for 1st time after 20 years suggests: raise weir in August.
Bill Gregurke	yes				3.6/2.2	less power for irrigation of the 50 acres	no extra growth on peat-flats: these are now only wetter.
Peter Gregurke	yes	15-30	3-5		0.6 m rise	extra pasture growth	suggests: remove all boards in winter to minimise waterlogging of low lying areas.
David Brown	yes	150-200		6		extra pasture growth	
Ralph Bowman	no	-					
Michael McCourt	yes	500				600 acres of centre pivot irrigation	

TABLE 10: SUMMARY OF FARMERS SURVEY ON BENEFITS OBTAINED FROM THE MAGAREY LANE WEIRS (FEB 1987)

7.3 Potential Sites Identified

Potential weir sites west of West Avenue Range which may be explored further have been identified on the basis of soil type and distance from the drains.

The Wyrie soil association described by Blackburn (1959) as a peat, groundwater rendzina has a considerable capillary rise. The distribution of this preferred, low lying soil type is shown in Figure 20. The total area is about 15 000 ha and is scattered over 10 sites listed in Table 11. The volume, timing and quality for the summer flows of nearby drains was estimated for determining the development options for the potential weir sites.

The sites with the highest priority for further evaluation are:

(i) Narrow Neck

It is suggested that the options for improved water conservation in this large peat basin are further explored; the diversity of the landuses (spring sowing of oilseed crops vs pasture grazing) in this area may be a restraint.

(ii) Magarey Lane

The permanent flows in Drain M and the presence of peat soils suggest further scope for water conservation e.g. by using drop structures in Symon Petition drain and its major laterals.

(iii) Conmurra

The situation for drain flow conservation should be reassessed once more.

(iv) Eight Mile Creek

This site is outside the SEDB drainage area but the Eight Mile Creek area is administered by the SEDB on behalf of the Minister of Water Resources. The large flows of low salinity water seem to invite a further assessment whether the water management in this large peat basin can be improved for all year dairying and particularly for a higher production of consumption milk in late summer.

8. CONCLUSIONS

8.1 The main benefit of the South East Drainage System is the improvement production of 381 000 ha of flood prone land that is now used for permanent agriculture. The value of the agricultural production of this reclaimed land is estimated to be $68 million per year; this represents 38 percent of the value of the total livestock production in the South East.

8.2 A less obvious benefit is that the drains remove between 600 000 and 750 000 tonnes of salt per year from the catchments. This quantity of salt is several times that deposited by the annual rainfall. The drains reduce the salinity in the upper portion of the soil profiles and thus provide a better environment for plant growth on the interdunal flats.

8.3 Calcrete and limestone occur at shallow depth in the interdunal flats. At farmers' request most drains were constructed with a shallow and wide cross section but this increased the excavation costs. The wide drains in the coastal half of the catchments had to be excavated to about 2 m deep across the interdunal flats to provide sufficient drainage in the upstream areas.

8.4 Based on 1987 values the total annual cost of the South East Drainage System is probably about $8 million per year; finance has been fully provided by the State Treasury since 1980.

8.5 The average annual discharge of the South East Drains is calculated as 230 000 Ml per year. It is estimated that 140 000 Ml of the (mainly winter) drainflows is of low salinity and suitable for irrigation. Storage of these flows in large (publicly funded) dams is not practical because of the low relief, high cost and high permeability of the soils and underlying strata. In general, groundwater supplies are abundantly available in the Middle and Lower South East for irrigation.

8.6 About 10 percent of the annual flow occurs during the irrigation season. At present about 3 000 ha is flood irrigated with drainage water when flows are available in spring. It is estimated that another 3800 ha of pasture can be (fully) flood irrigated if the total drain flows after mid September each year were stored.

8.7 There are probably still a few natural areas suitable for on-farm storage of winter flows e.g. Sheep Wash Swamp along Bakers Range Drain.

8.8 To have maximum growth of strawberry clover in summer, the water table has to be kept to within 300 mm of the surface. To achieve these conditions in summer, the watertable has to be kept shallow during the winter months. This may result in waterlogging in winter and retarded growth in spring.

8.9 The base flow of the drains is relatively saline; thus weirs may cause salinization of the soils, particularly those with good capillary rise e.g. peats.

8.10 The results of previous field studies indicate that over-drainage occurs particularly along the main drains. It is estimated that the agricultural production of about 20200 ha along 159 km of main drains is affected by over drainage. The area of over drained land is less than one percent of the 381000 ha which has improved ('benefitted') as a result of the drainage works.

8.11 The value of the production loss due to over drainage is estimated to be $311000 per year. This (order of magnitude) estimate has been derived by making 'broad brush' assumptions. It should be clearly understood that there are many variable factors involved and thus the degree of over drainage will fluctuate widely along the main drains.

8.12 About 100 of the 137 holdings affected by over drainage have a land area between 100 ha and 1000 ha. This category of farmers bear about 70 percent of the estimated financial loss due to over drainage. Those properties that are assumed to have suffered during dry periods generally receive the greatest benefit from drainage during wet periods as they are on lower flood prone land.

8.13 Return on investment for the Mount Bruce Weir is estimated to be nil. The annual cost of this weir is seen as expenditure for improved flow regulation in this relatively steep section of Drain M.

8.14 The return on investment for Magarey Lane/McCourt Weirs is estimated to be 12 percent as a combined result of restored pasture production on the (peat) flats and water harvesting for 240 ha of centre pivot irrigation.

8.15 The large investment by Mr. McCourt into his weir and centre pivot irrigation was most opportune in the earlier years when the attractive depreciation schedule was still applicable. The considerable benefits from the Magarey Lane weirs should not be used for the justification of investment into weirs at other sites.

8.16 The construction of a series of weirs in main drains would be expensive and only partly remedy the over drainage losses on this land.

8.17 Because of the hydrological complexity and the number of variables involved, each weir proposal must be evaluated on its merits.

8.18 Since 1950 the South Eastern Drainage Board together with a few landholders have carried out a considerable amount of work in an effort to maintain groundwater levels in the drain catchments.

8.19 An alternative use for the saline base flow is diversion into the (scattered) wetlands and recreation areas, where practical and appropriate for the existing water habitat.

9. RECOMMENDATIONS

9.1 To investigate whether the effectiveness of the Mount Bruce weir can be improved by connecting in summer the pool behind the weir to the nearby sub drains (Avenue Creek-M Drains) which are situated on the eastern side of the dune range.

9.2 Further evaluation of earlier collated field data from the previous weir studies to provide the SEDB with additional information. This requires an interdepartmental working group to manage a project officer.

9.3 Further explore the following sites for improved conservation of drain flows: Narrow Neck, Magarey Lane, Conmurra and Eight Mile Creek.

9.4 To assess whether the existing but unused weirs can be upgraded at minimum expense.

9.5 To investigate whether Landsat satellite imagery can be used for easy monitoring of variations in pasture growth along the drains and weirs.

9.6 To assess the community benefits from diverting drainflows into the South East wetlands.

9.7 Proposals made by farmers along the drains for weirs to rectify over-drainage be considered on their merits. The South East Drainage Act allows landholders to petition the Board for drainage works and the

Board decides what contribution landholders will be required to make. This section of the Act could be applied for future weir proposals.

9.8 Whether or not the Government provides funds, if farmers want to construct weirs, then they be allowed to proceed at their own expense. The structures should meet the standards set by the South Eastern Drainage Board which has the overall responsibility for the drain flow management. Existing downstream use of the base flow may have to be considered before approval can be granted.

10. ACKNOWLEDGEMENTS

* Farmers' groups near the Mount Bruce and Magarey Lane weirs: their time and providing candid opinions.
* Mr Brian Du Bois, Technical Officer (Water Management): data processing, design and drafting of figures and assistance during the preparation of this report.
* Mr Jon Presser and Mr Graham Trengove, Agricultural Economists: suggestions and verification of the economic analysis.
* Members of the South Eastern Drainage Board: detailed comments on earlier drafts and encouragement throughout this study.
* Mr. J.E. Nitschke, former Chairman of the Board: his useful suggestions and the historical background, the philosophy and technical information used at the time of the design and construction of the South East Drainage System.

September 1987

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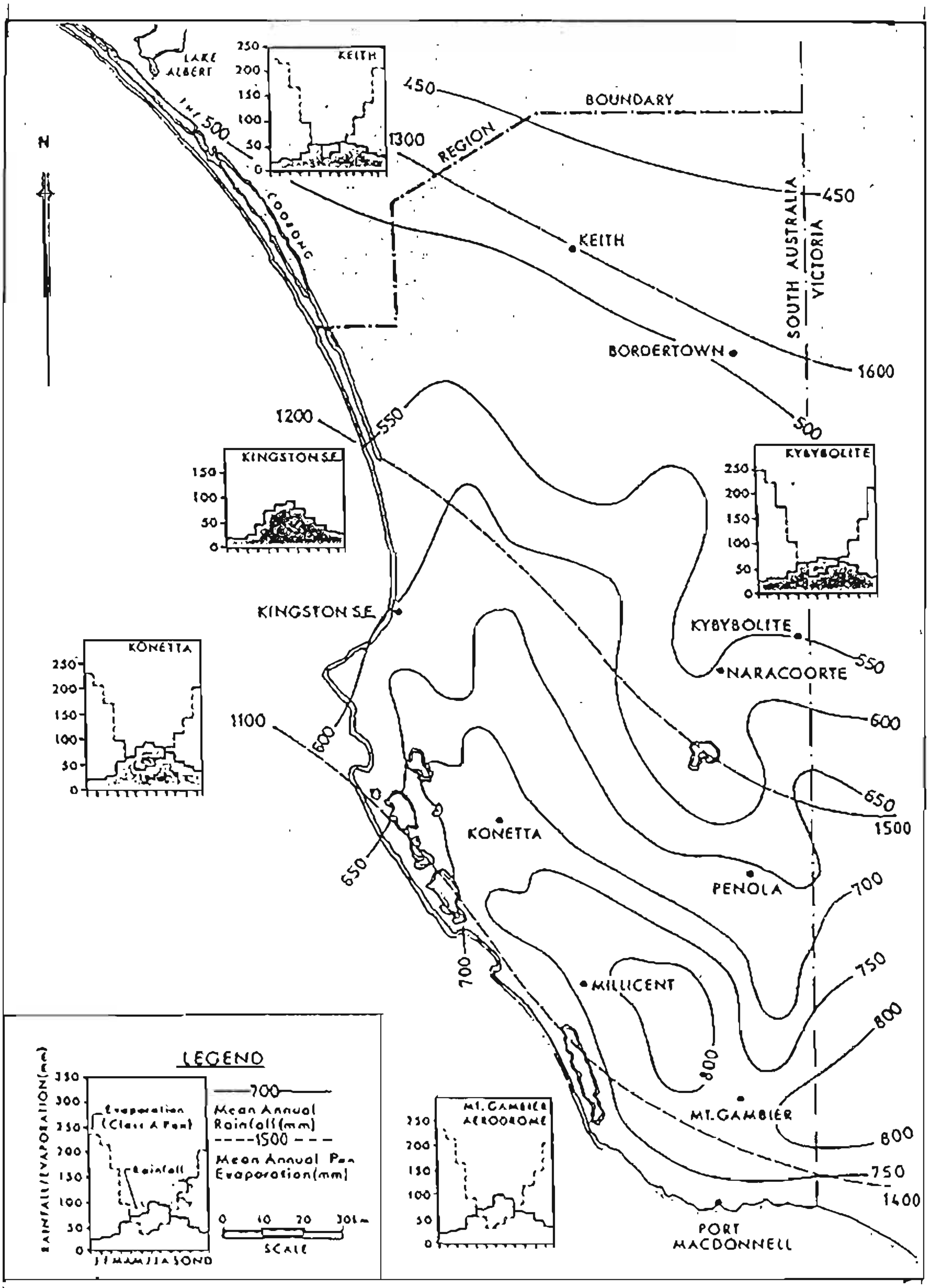
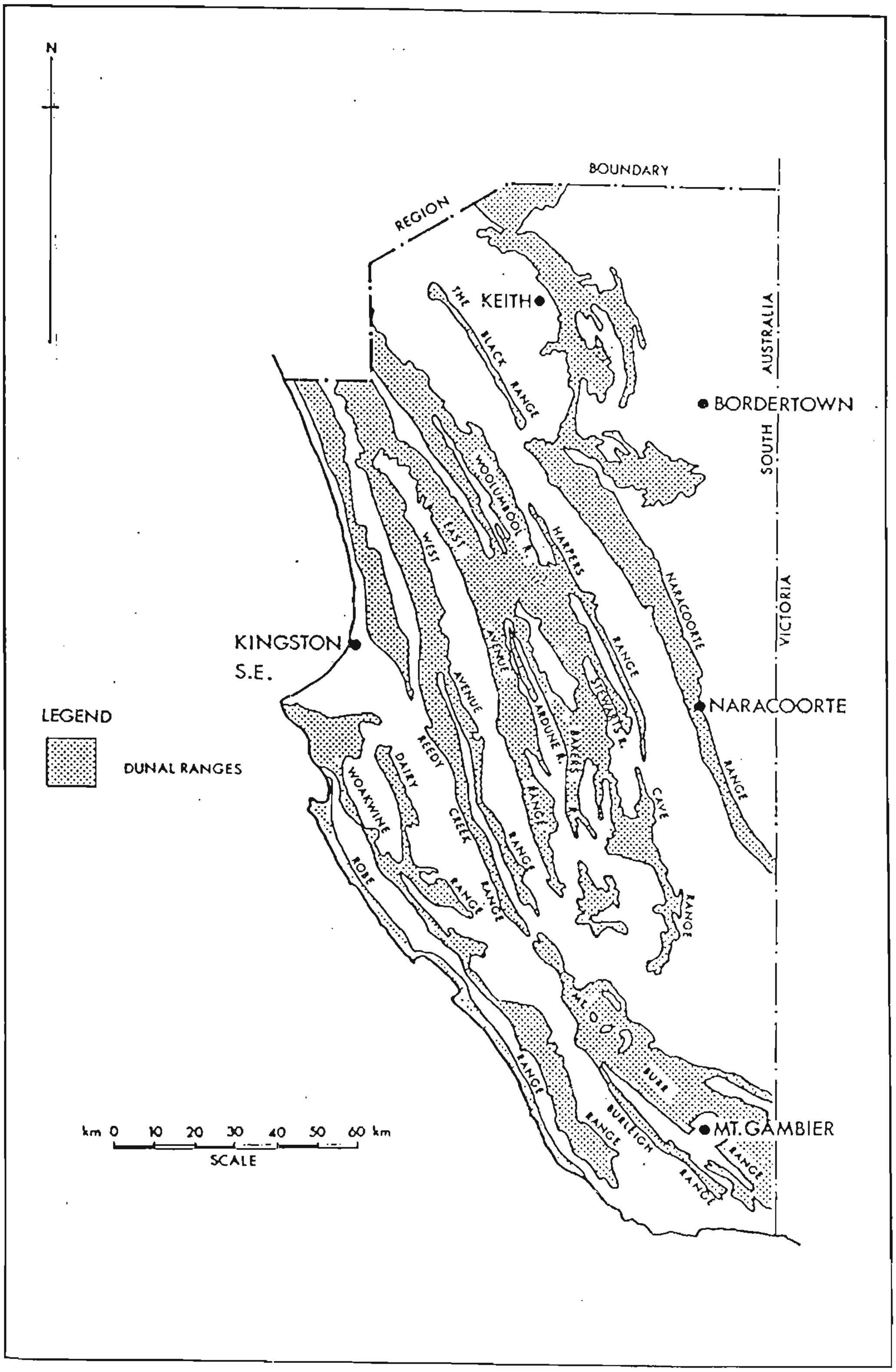


RAINFALL & PAN EVAPORATION

THE SOUTH EAST OF SOUTH AUSTRALIA

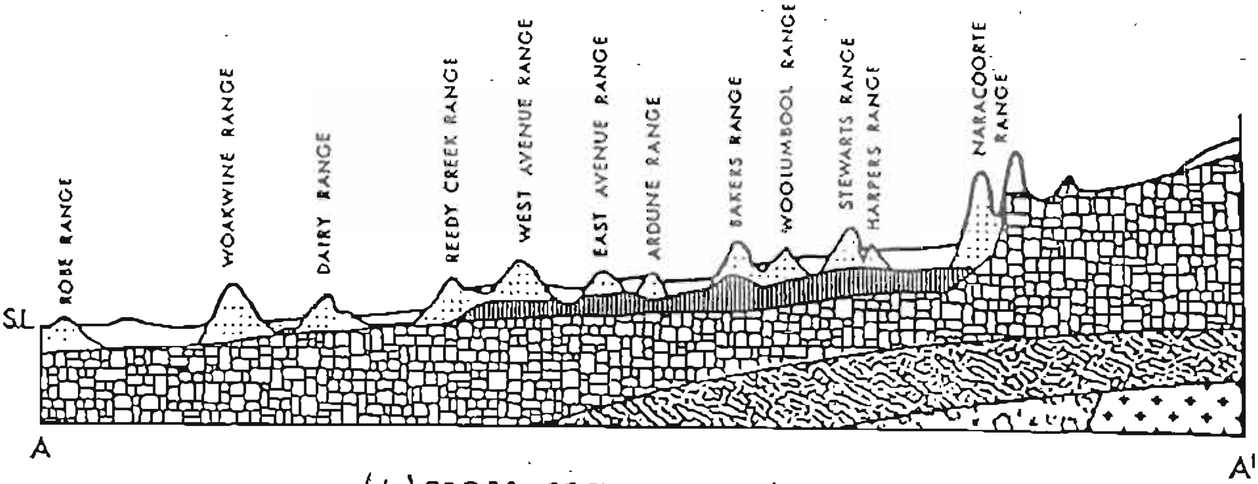
FIGURE 1



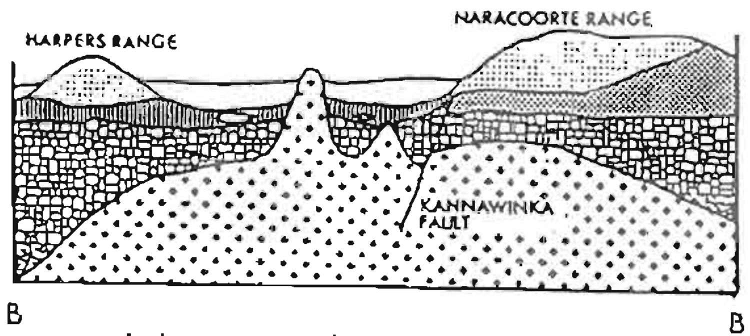
DUNE RANGES

THE SOUTH EAST OF SOUTH AUSTRALIA

FIGURE 2



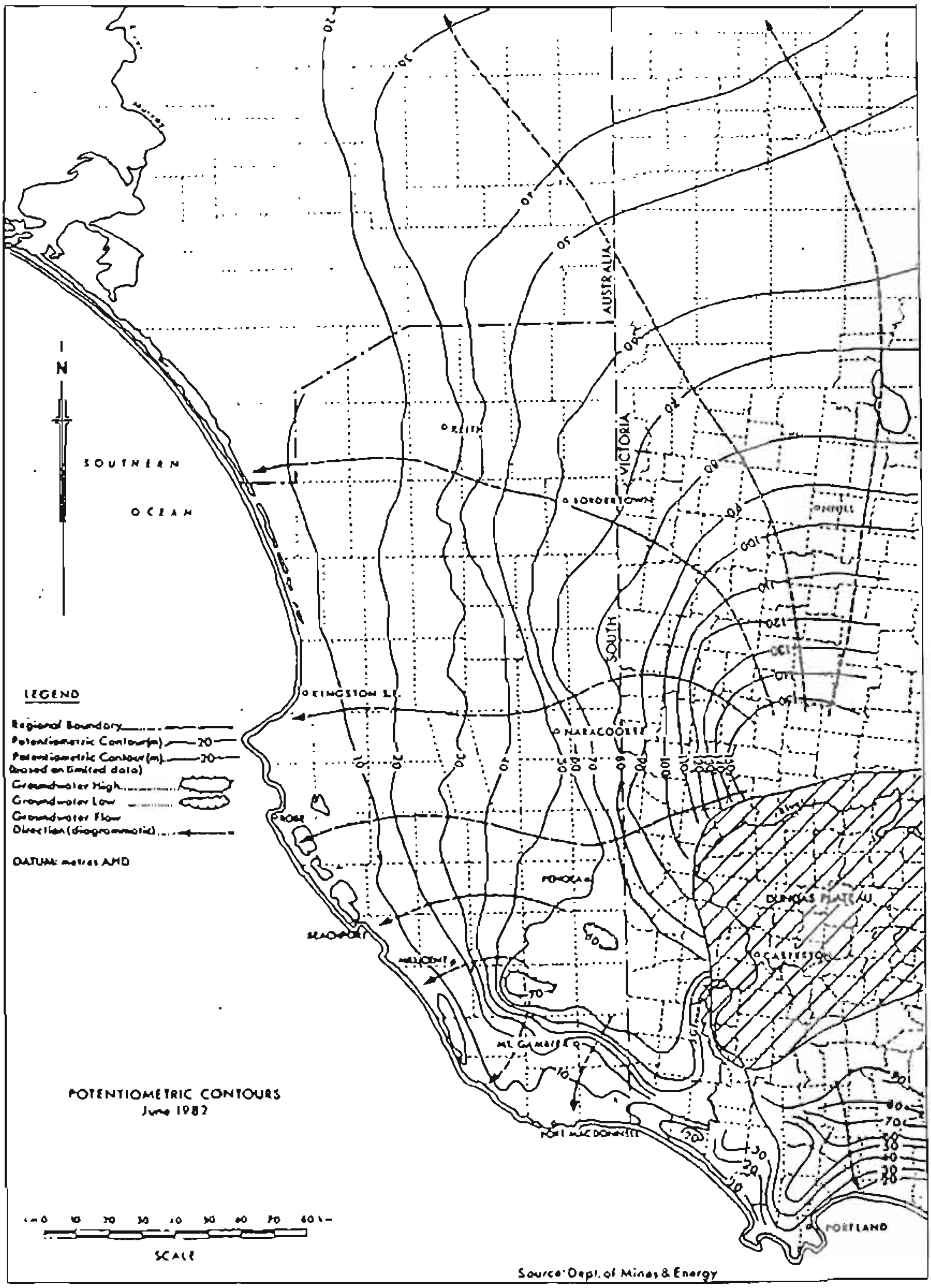
(b) CROSS-SECTION A - A'
(After Cook et al, 1977)



(c) CROSS-SECTION B - B'
(After Stadter 1982)

TOPOGRAPHIC CROSS SECTIONS

FIGURE 3

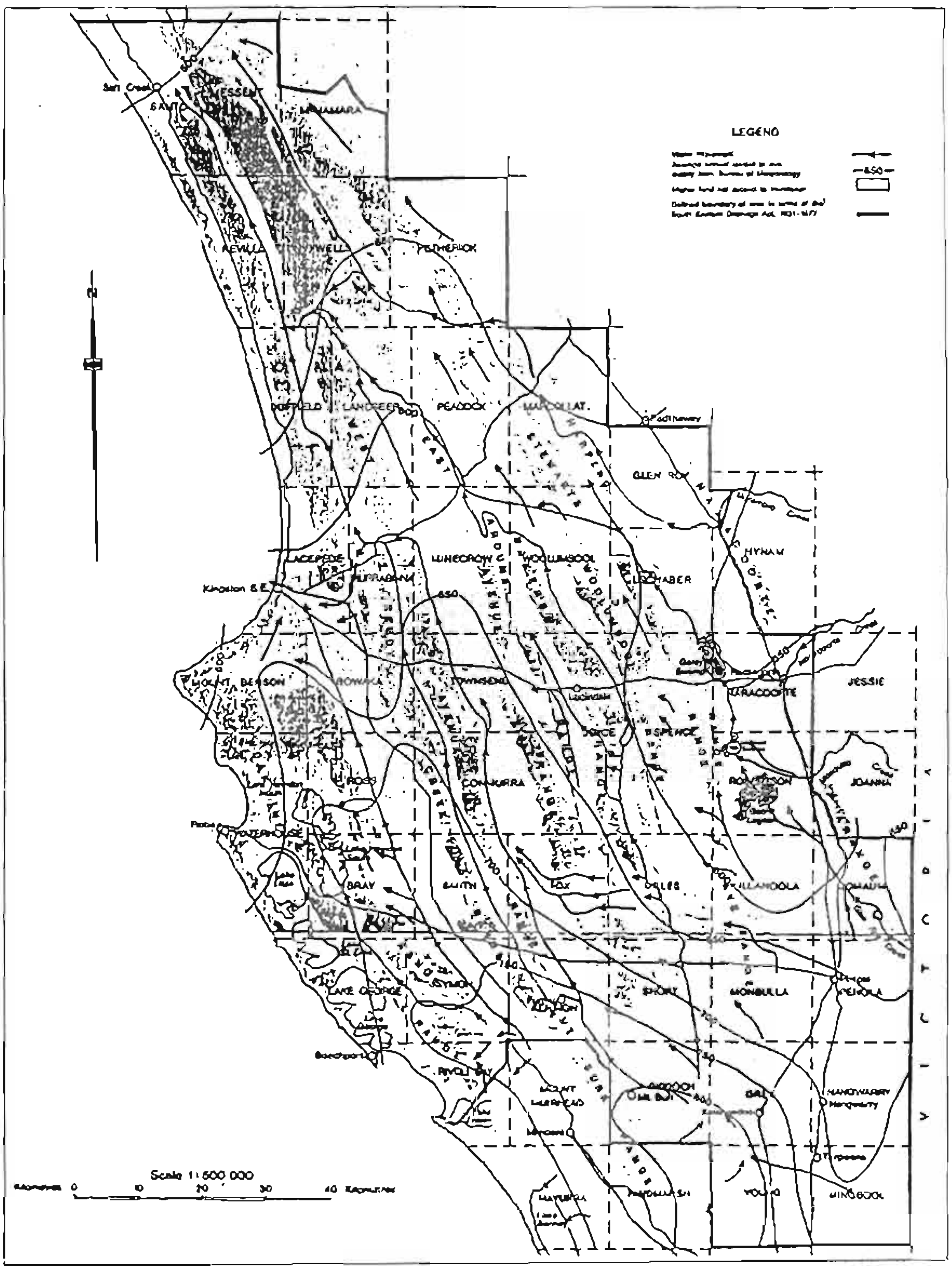


UNCONFINED AQUIFERS

FIGURE 4

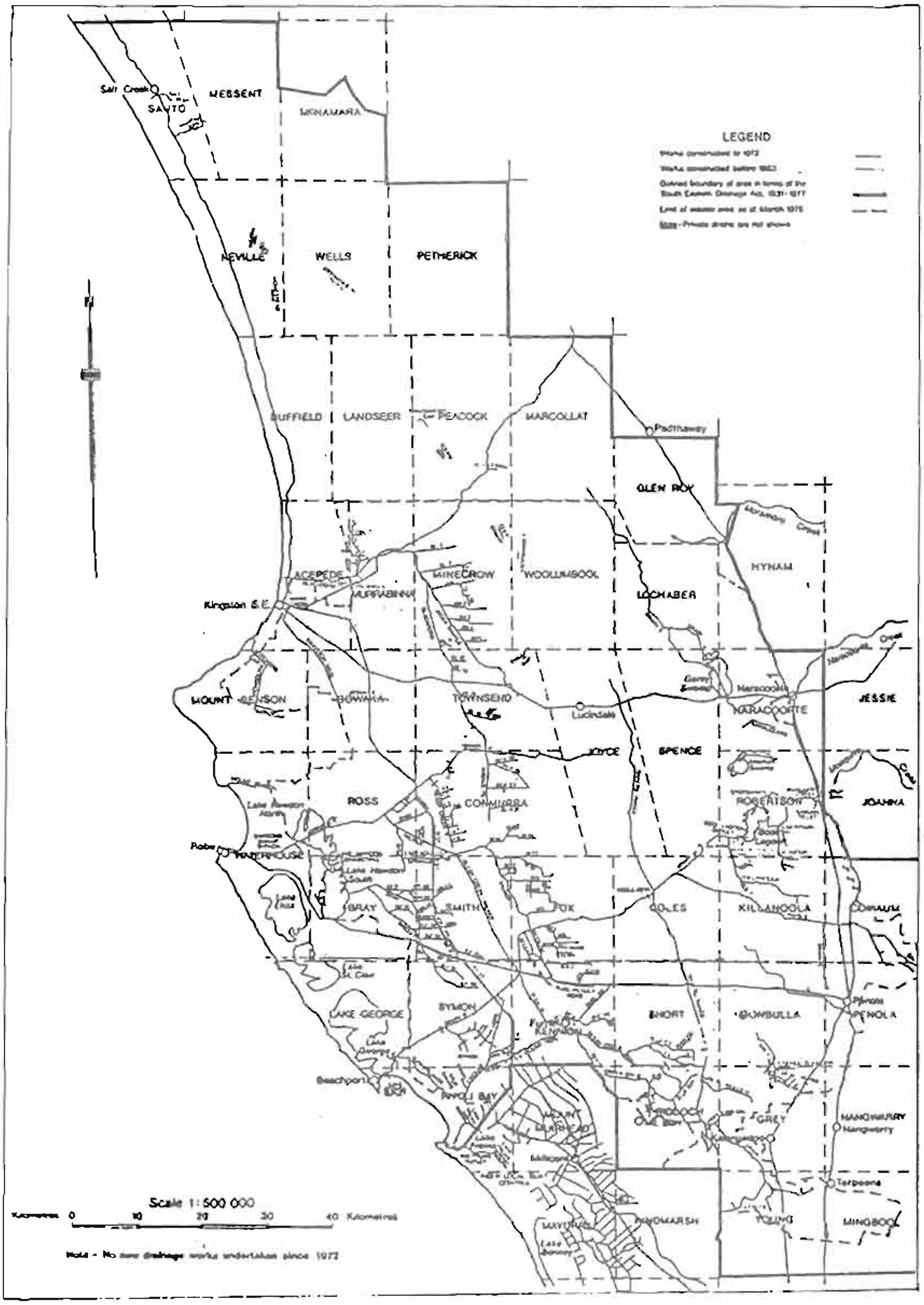
CONFINED AQUIFERS

FIGURE 5



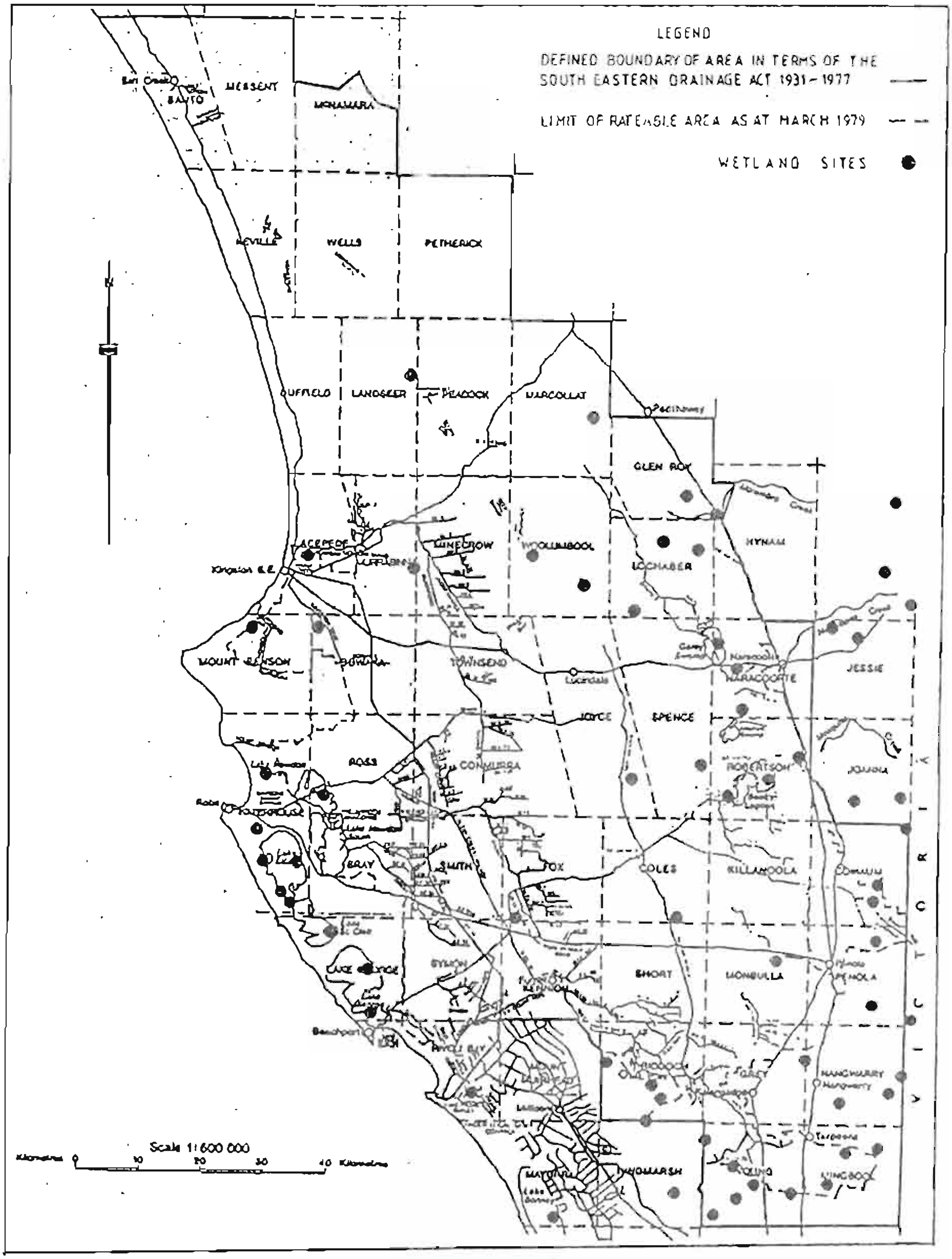
SURFACE WATER MOVEMENT

FIGURE 6



TOTAL DRAINAGE SYSTEM 1972

FIGURE 7



WETLAND SITES / DRAINS

FIGURE 8

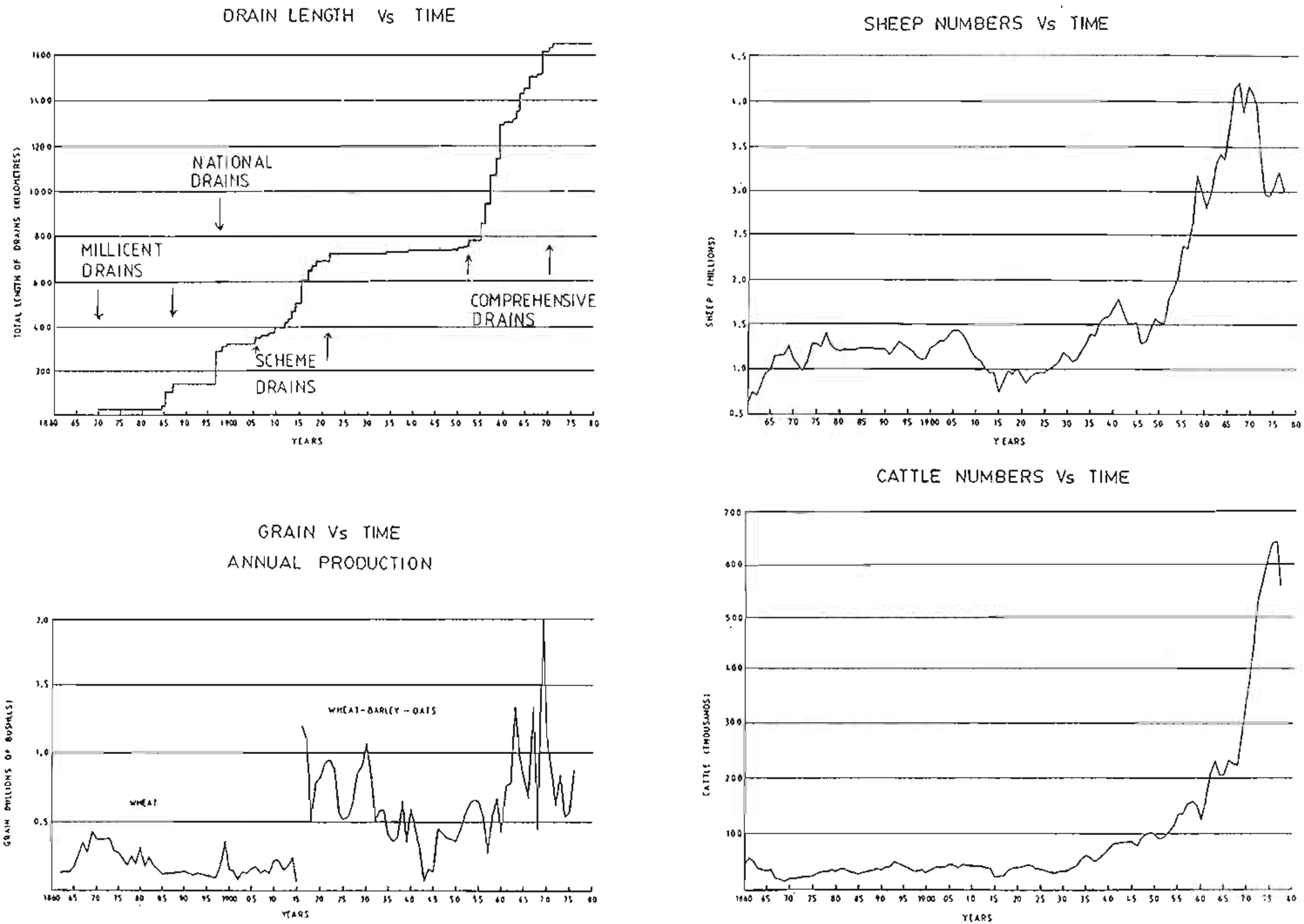

DRAIN LENGTH Vs TIME
NATIONAL DRAINS
MILLICENT DRAINS
SCHEME DRAINS
COMPREHENSIVE DRAINS
YEARS
SHEEP NUMBERS Vs TIME
SHEEP (MILLIONS)
YEARS
GRAIN Vs TIME
ANNUAL PRODUCTION
WHEAT-BARLEY-OATS
WHEAT
YEARS
CATTLE NUMBERS Vs TIME
CATTLE (THOUSANDS)
YEARS

FIGURE 9

PATTERN OF DISCHARGES

FROM VARIOUS DRAIN CATCHMENTS

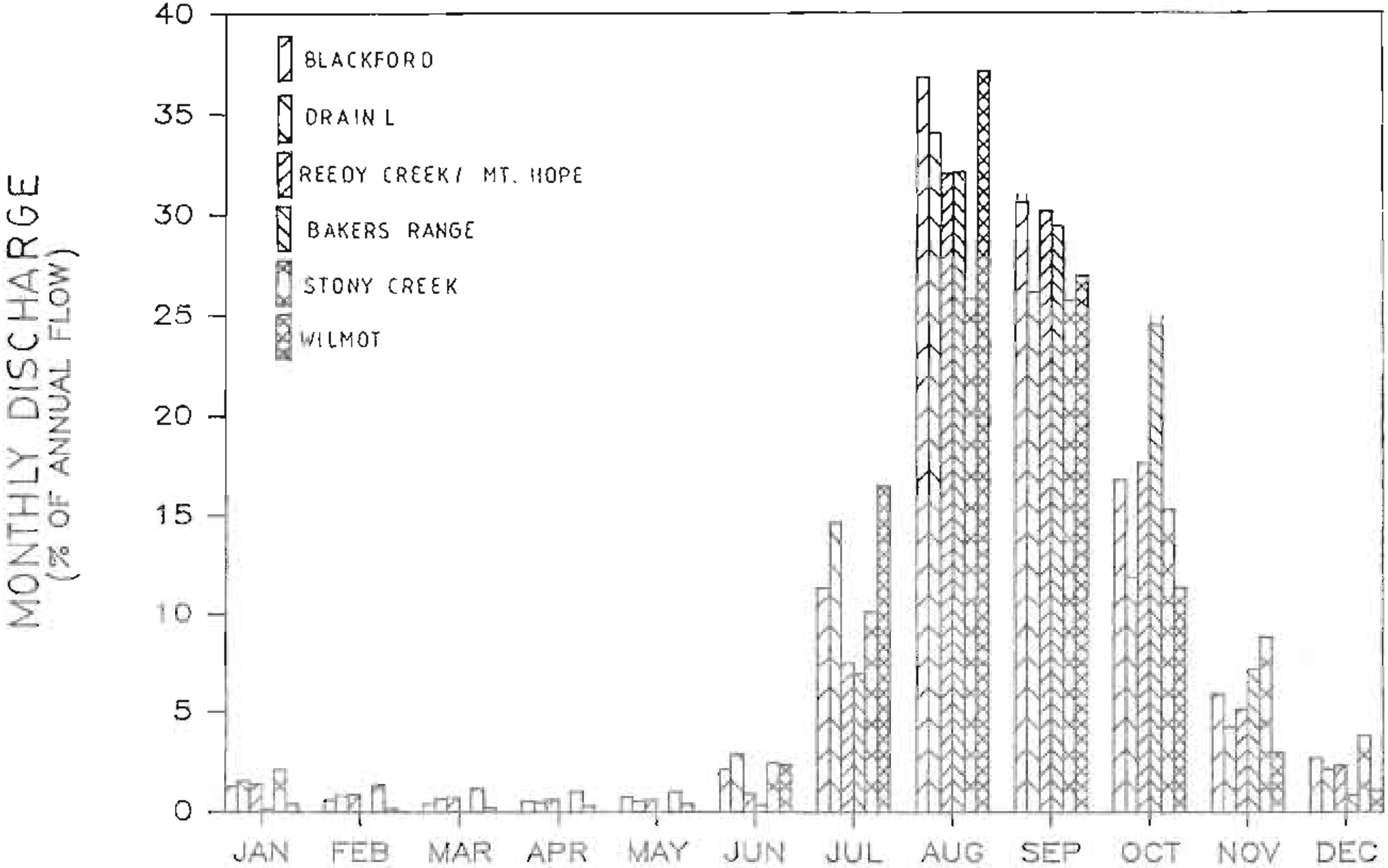
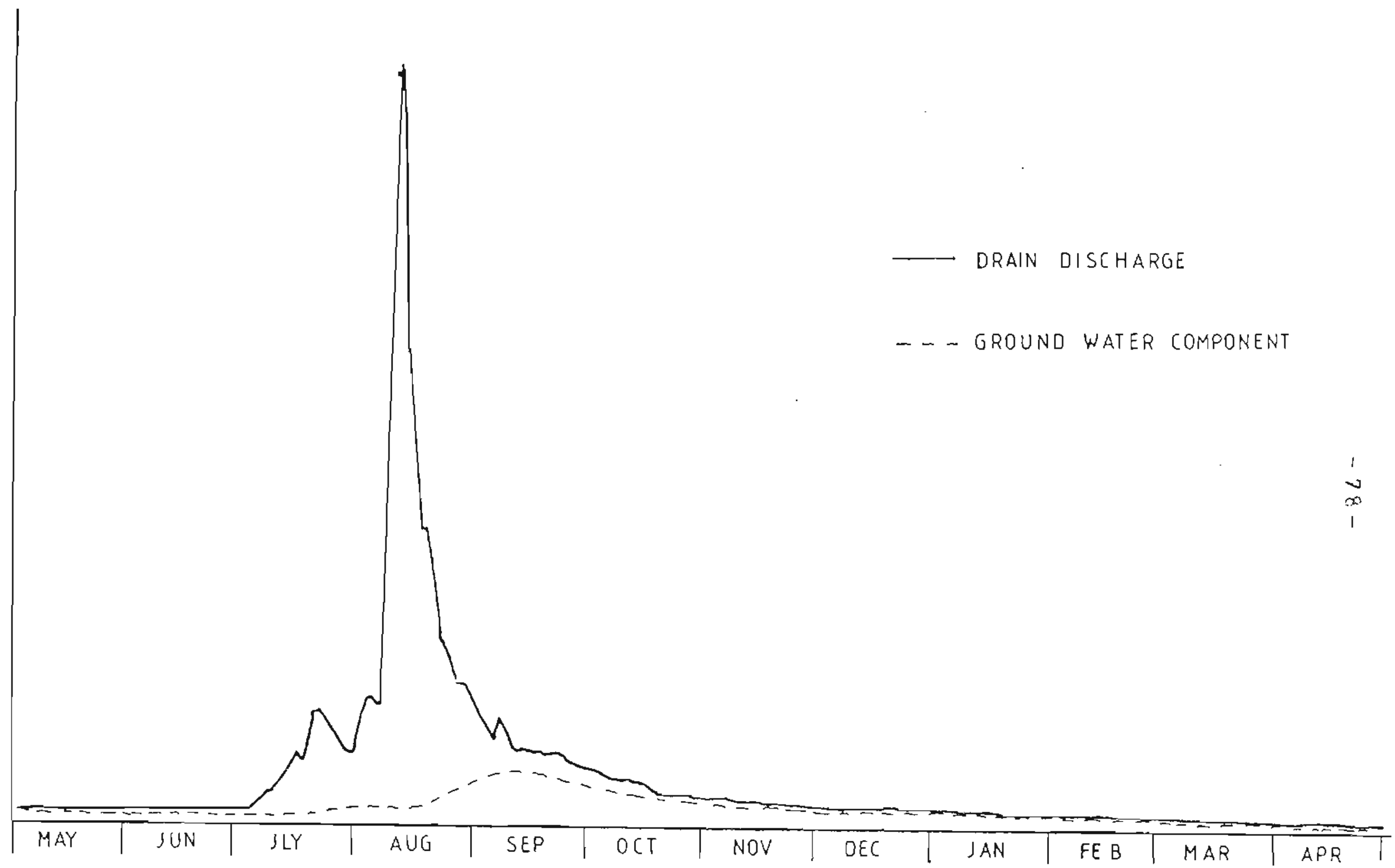
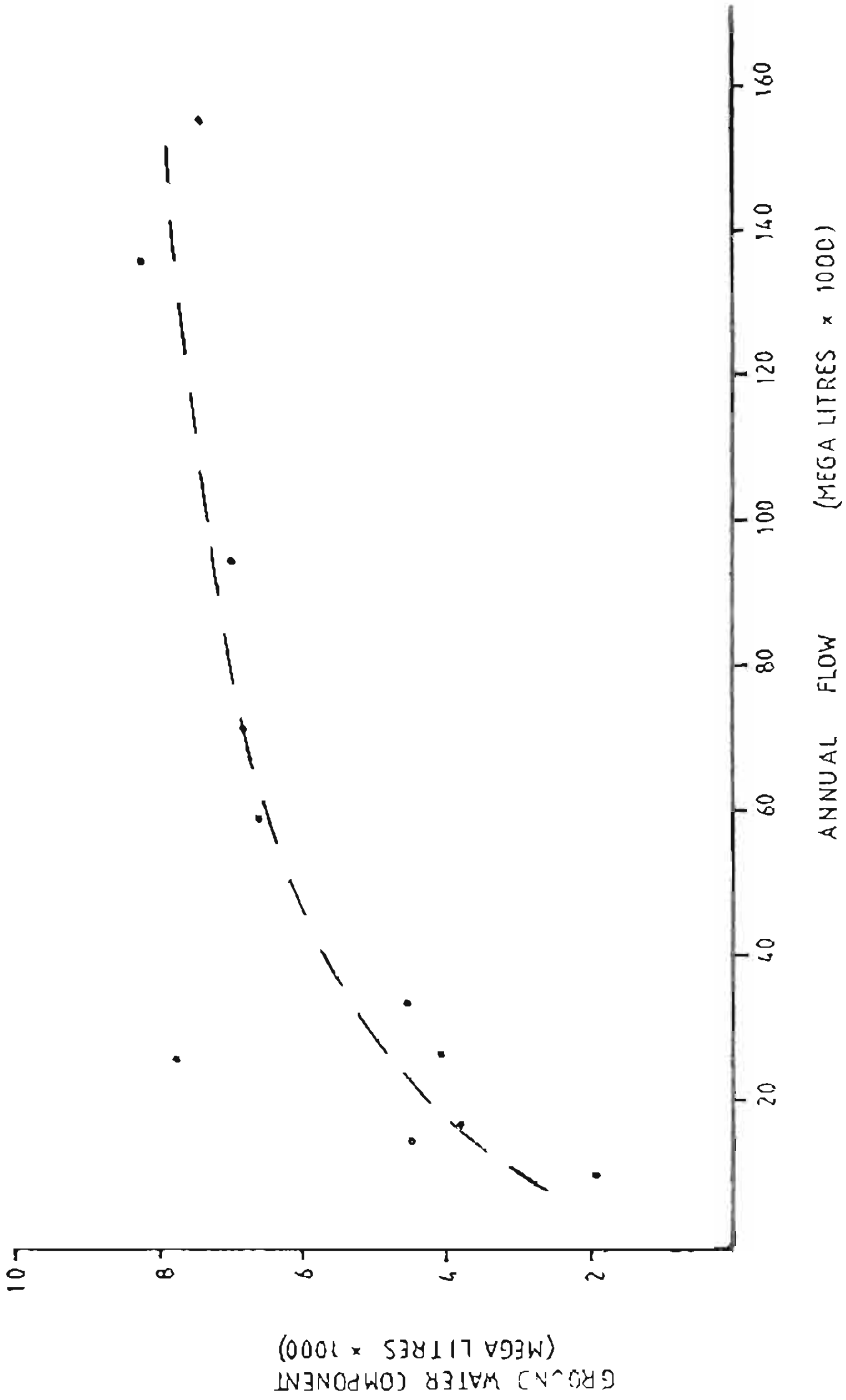


FIGURE 10

FIGURE 11

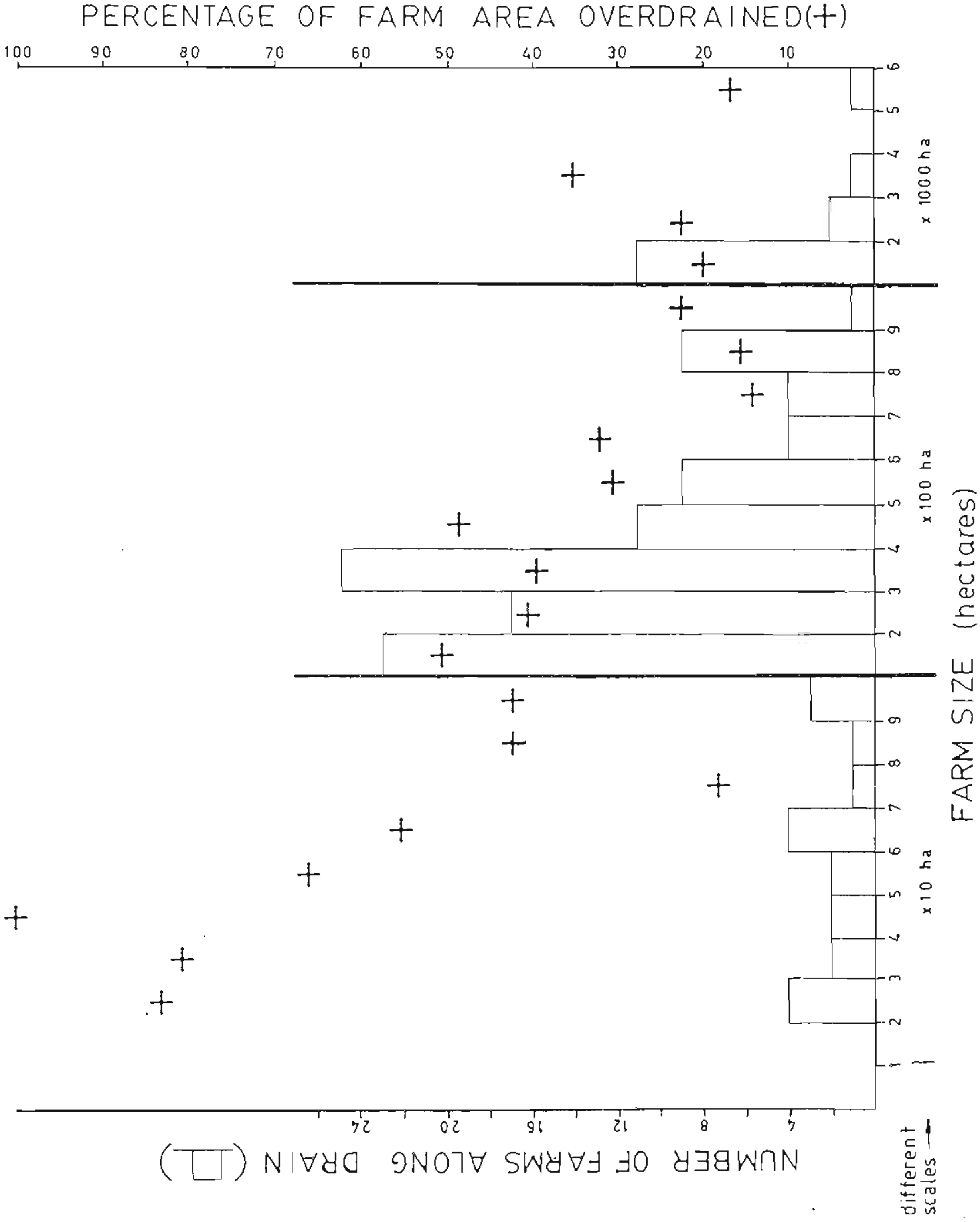
TYPICAL HYDROGRAPH FOR A SOUTH EAST DRAIN





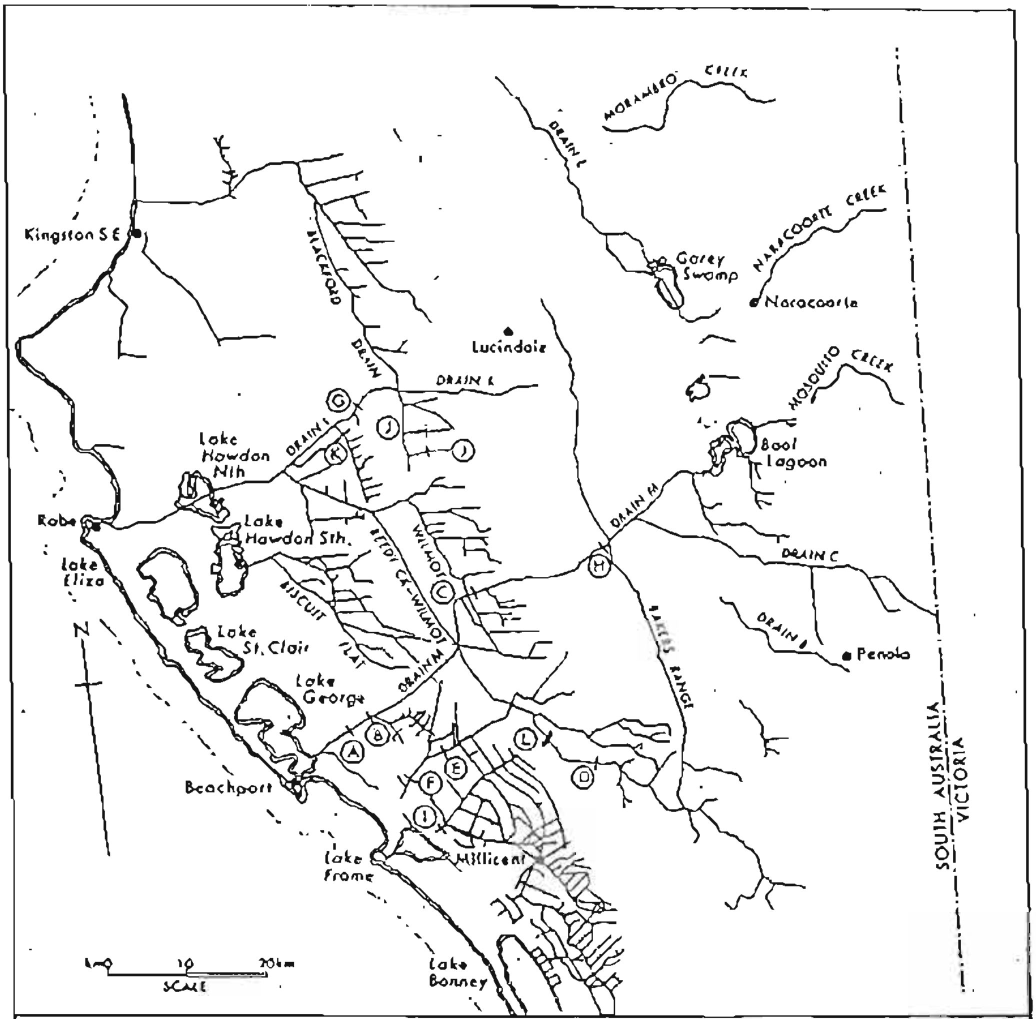
DRAIN M (1972 – 82)

FIGURE 12



NUMBER AND PERCENTAGE AREA OF FARMS AFFECTED BY OVERDRAINAGE

FIGURE 13



CODE	NAME	COMMENTS
Ⓐ	Mc Courts Weir	Drain M
Ⓑ	Magoreys Weir	Drain M
Ⓒ	Mt. Bruce Weir	Drain M
Ⓓ	Williams Site	Reedy Ck Division B (Site Only)
Ⓔ	Reedy Ck / Mt. Hope Weir	DME 1958 Experiments
Ⓕ	McArthers Site	Reedy Ck (Site Only)
Ⓖ	Miegels Weir	Drain K
Ⓗ	Callendale Site	Drain M Regulator
Ⓘ	Narrow Neck Site	Drain B (Site Only)
Ⓙ	Conmurra Weirs	Avenue Flat K21, K23 (O of Ag 1970 -)
Ⓚ	SEDB Weir	Reedy Creek (abandoned)
Ⓛ	Bowmans Weir	Reedy Creek Div B

LOCATION OF WEIR SITES

FIGURE 14

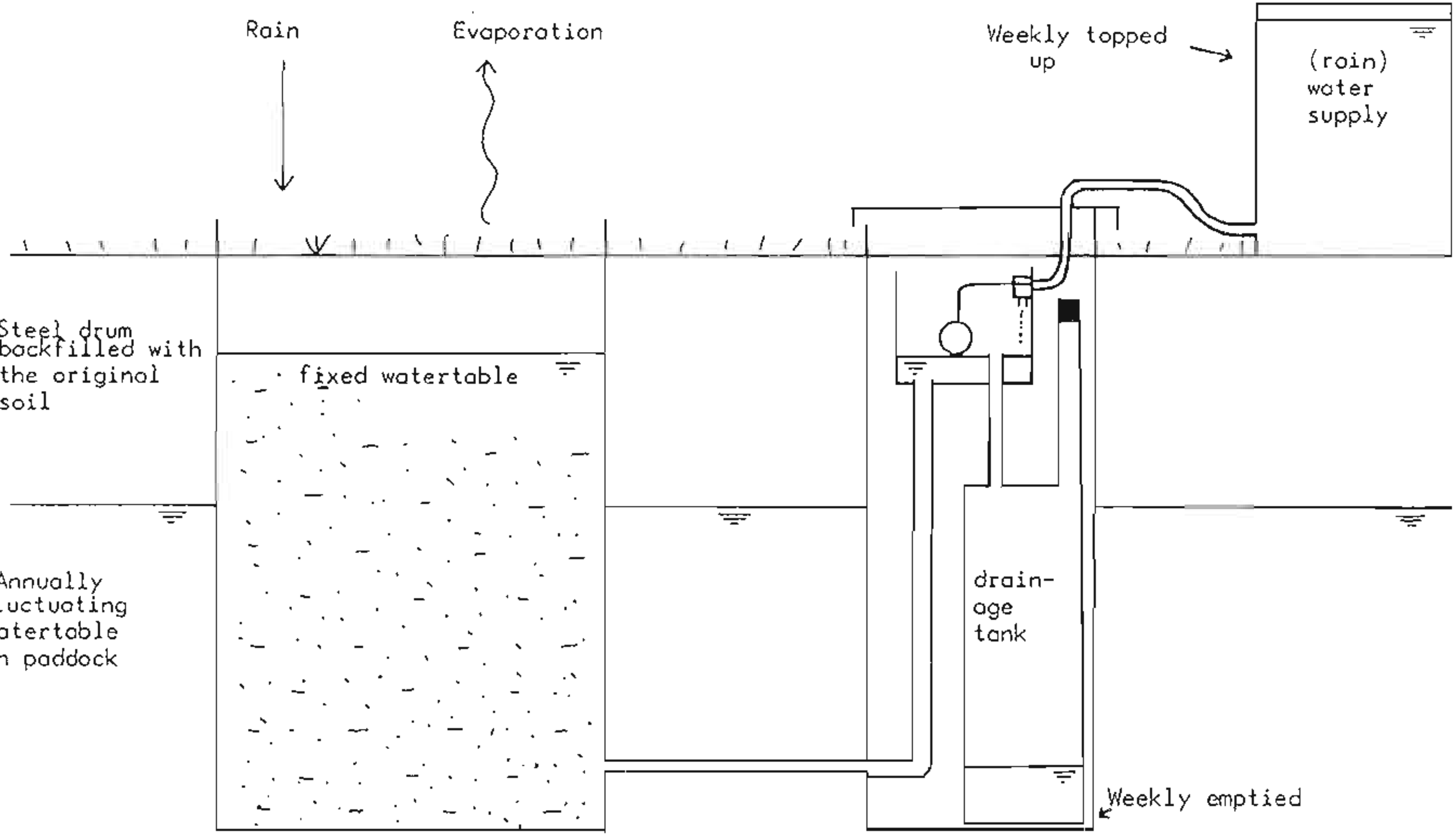
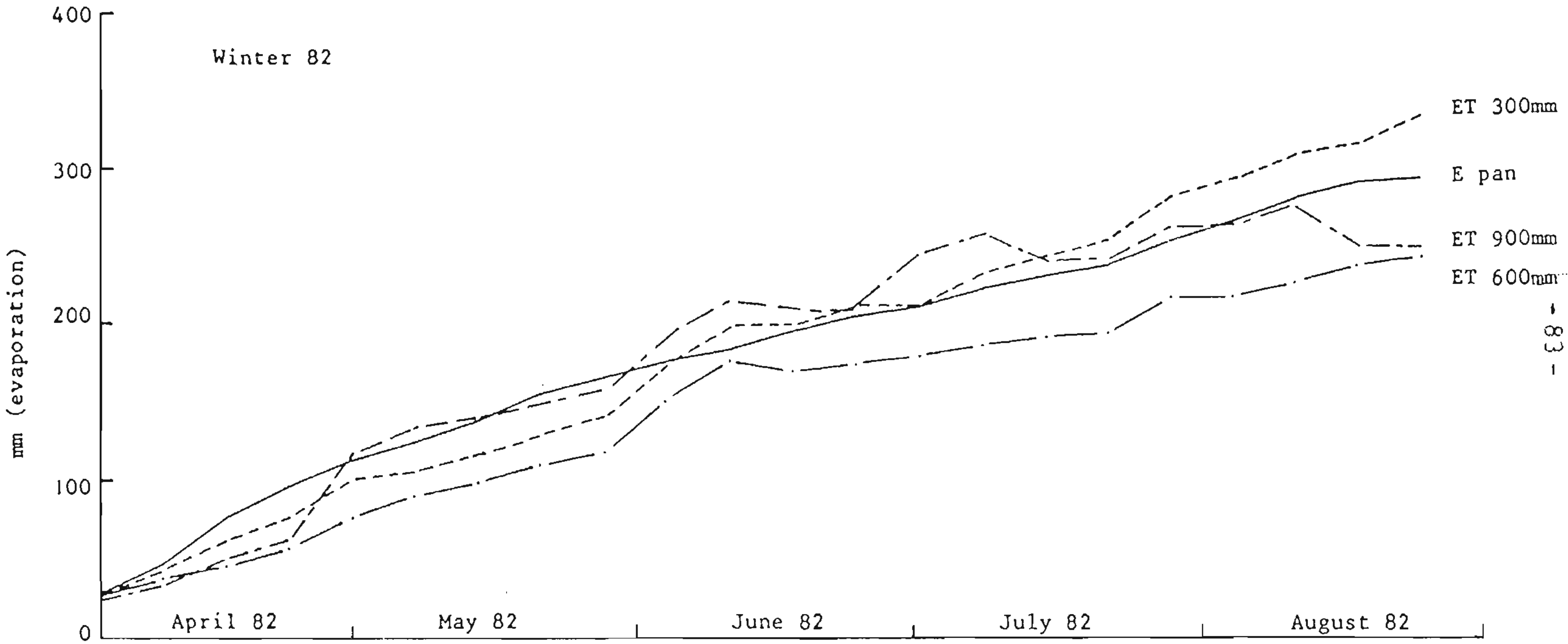


FIGURE 15

SCHEMATIC DIAGRAM OF A KONETTA LYSIMETER

FIGURE 16

KONETTA - CUMULATIVE EVAPOTRANSPIRATION - WINTER

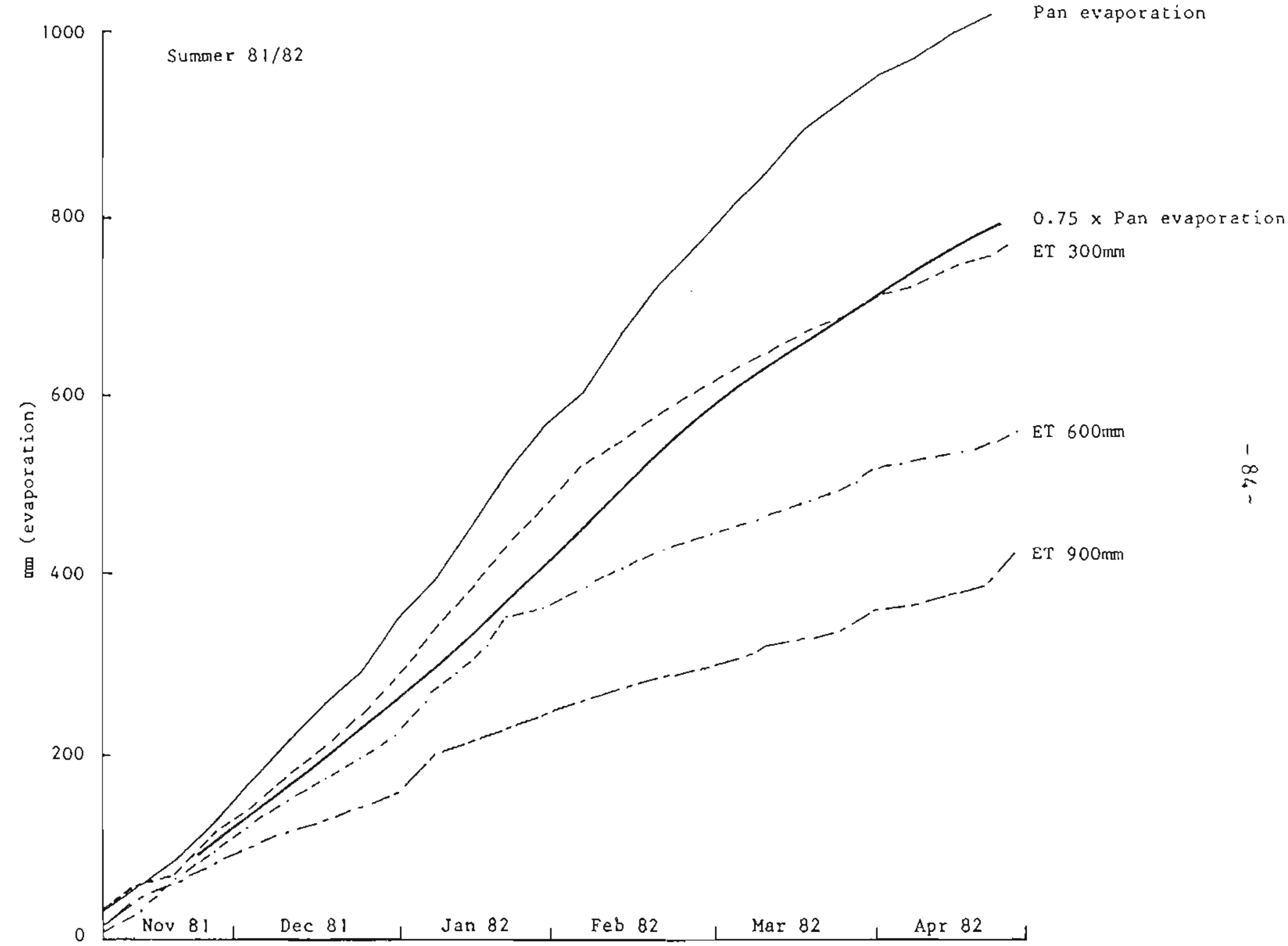


KONETTA - Cumulative evapotranspiration from the lysimeters in which a different depth to watertable is maintained.

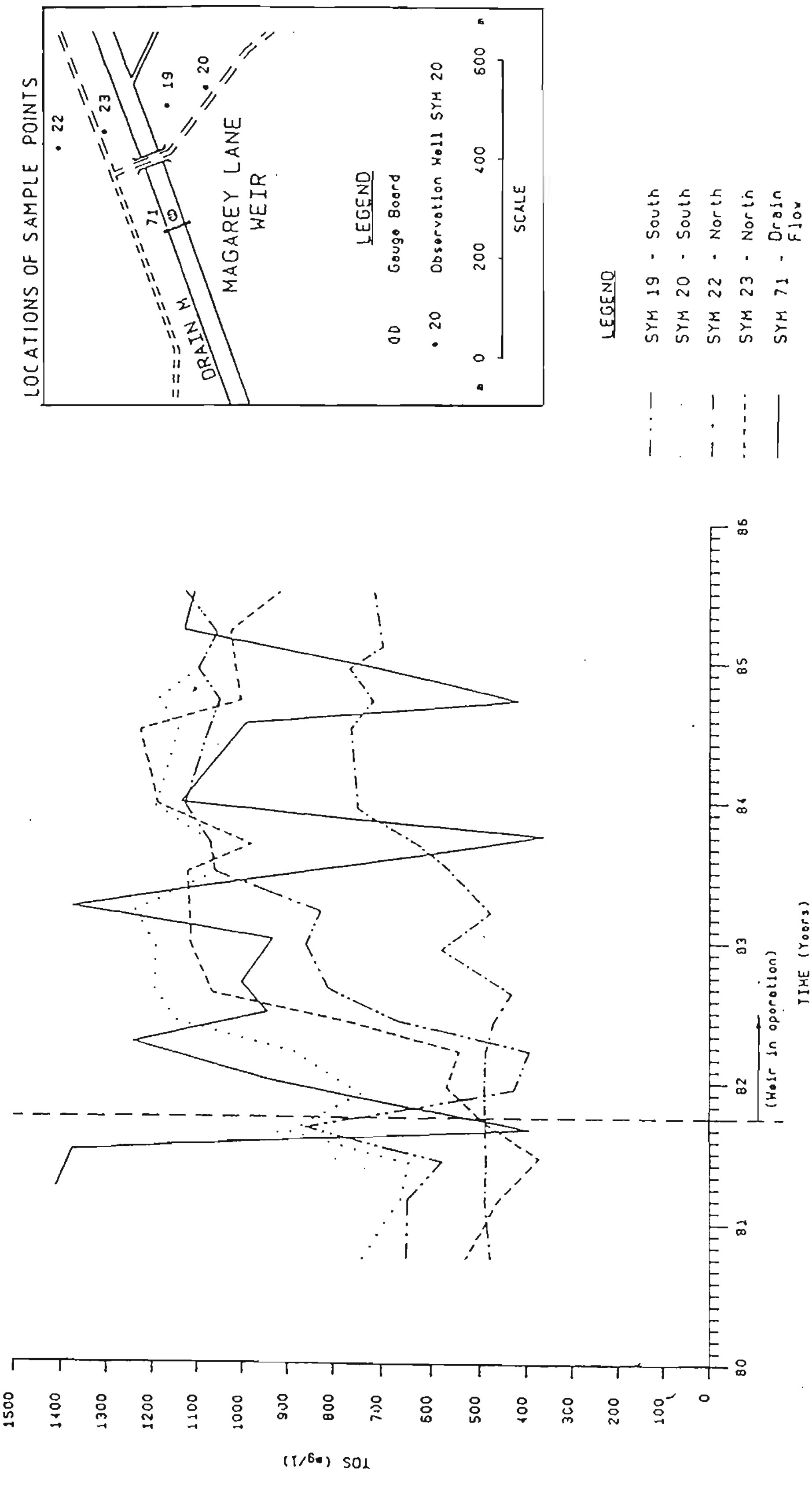
Note: Water use is adjusted for changes in storage due to minor watertable fluctuations.

FIGURE 17

KONETTA - CUMULATIVE EVAPOTRANSPIRATION - SUMMER

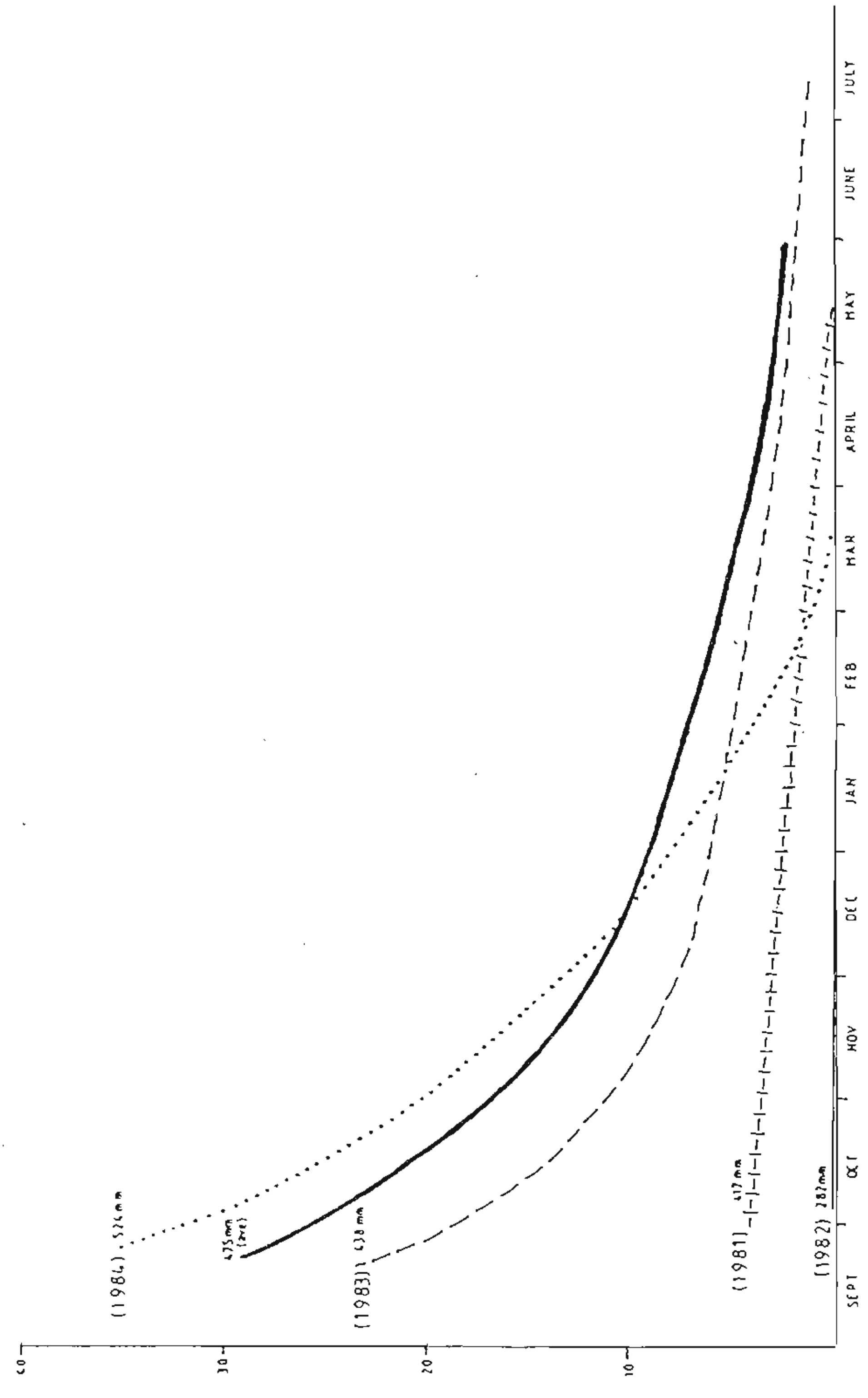


KONETTA - Cumulative evapotranspiration from lysimeters in which a different depth to watertable is maintained.



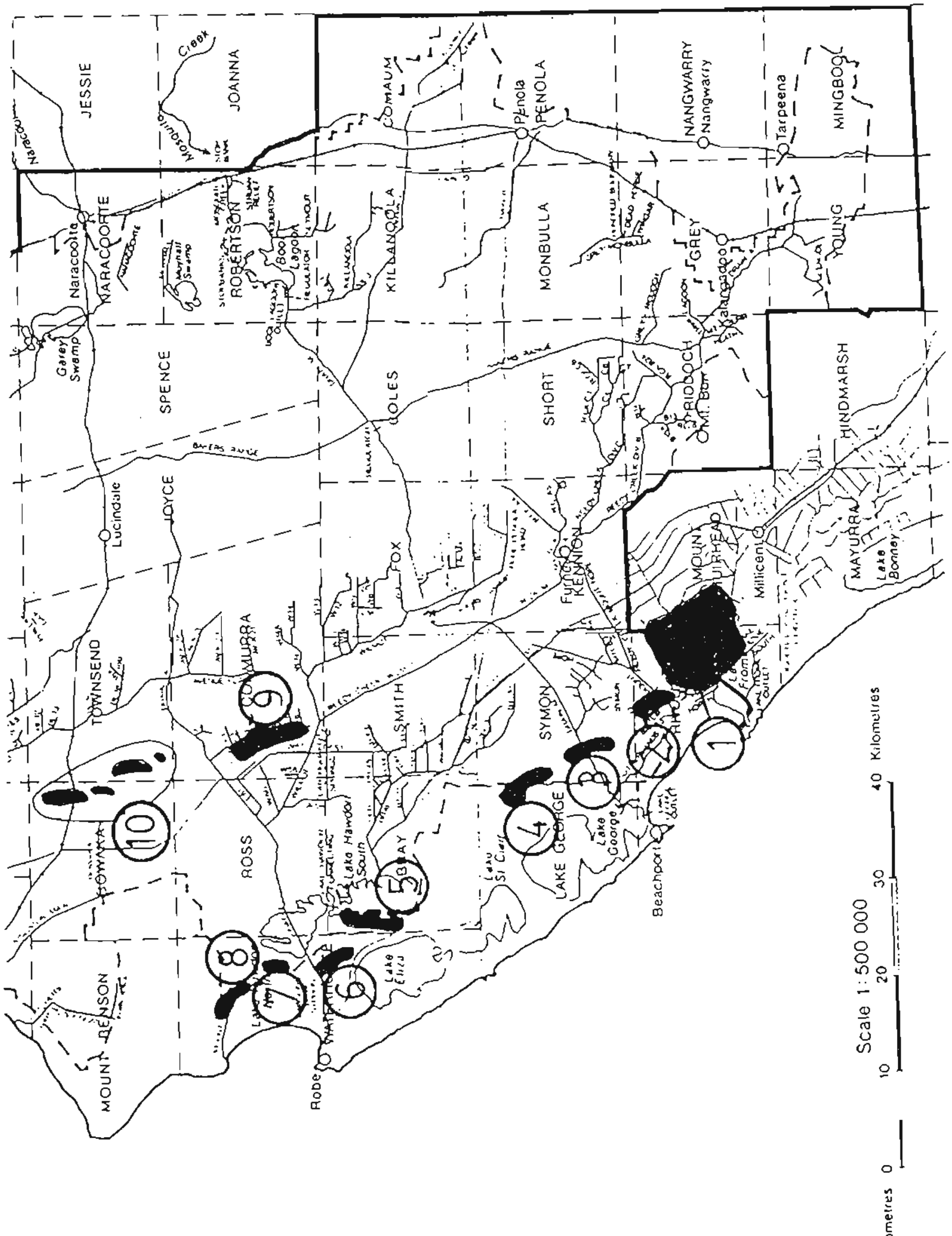
SALINITY INCREASE WITH TIME AT MAGAREY LANE

FIGURE 18



AREA of SHALLOW WATER TABLE
Vs WINTER RAINFALL (MAY - OCT)
Vs TIME

FIGURE 19



SITES WITH WYRIE PEATS

EXPLORED AS POTENTIAL WEIR SITES

FIGURE 20

APPENDIX 1: RAINFALL AND DRAINFLOW RELATIONSHIPS

1. Annual

The annual rainfall is plotted in the (top half of page) figures against annual discharge from different drain catchments.

2. Seasonal

The May-October rainfall is plotted in the (lower half of page) figures against the July-October drainflow.

3. Data base length

Length of drain flow record for some catchments is up to 15 years.

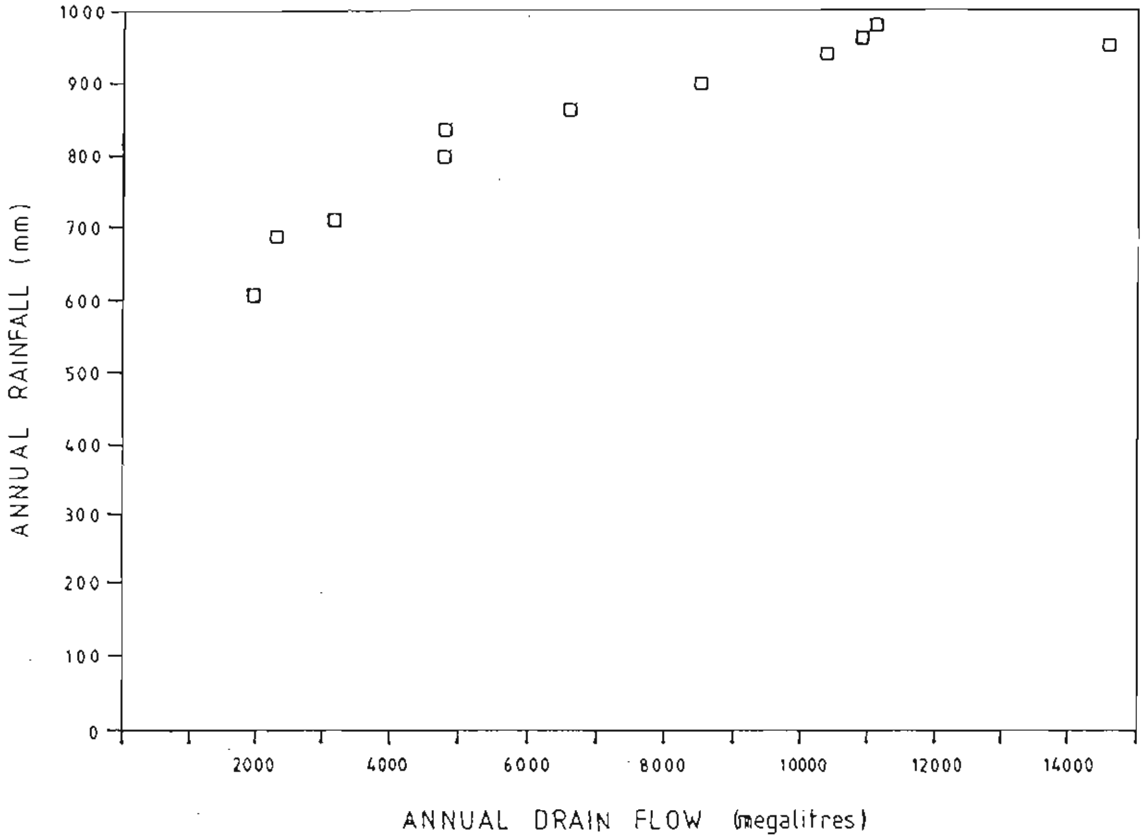
4. Results

The plots show that the bulk of the rainfall is retained in the catchments. It seems that in some years of low annual rainfall the annual drain flow component is practically nil. The estimated rainfall retention seems to be higher for the catchments in the Middle South East (See Table 1-1)

TABLE 1-1: ESTIMATED RAINFALL RETENTION IN DRAIN CATCHMENTS.

Drain catchment	Rainfall Retention (mm) Annual	May-Oct.
Stony Creek	600	460
Baker Range	± 640	410
Reedy Creek	± 580	390
Drain L	530	370
Blackford	480	± 330

STONY CREEK



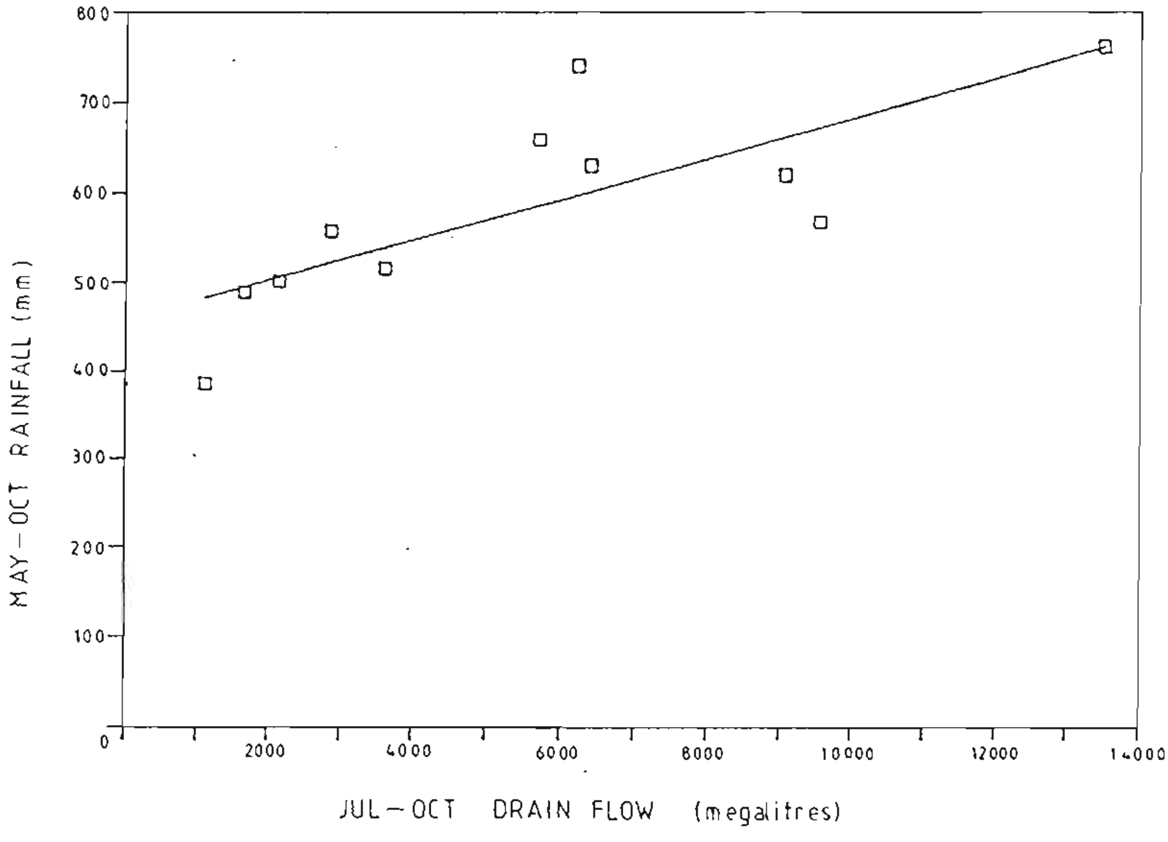
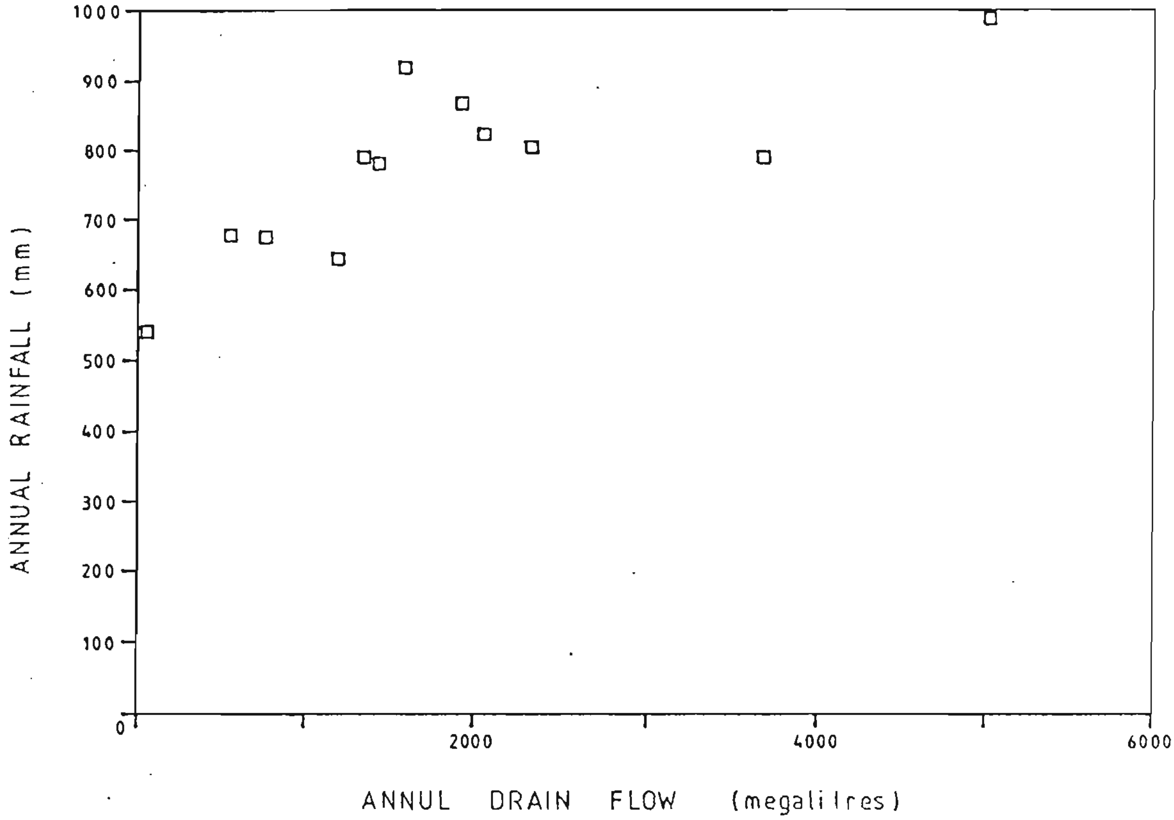


FIGURE 1-1

BAKERS RANGE DRAIN



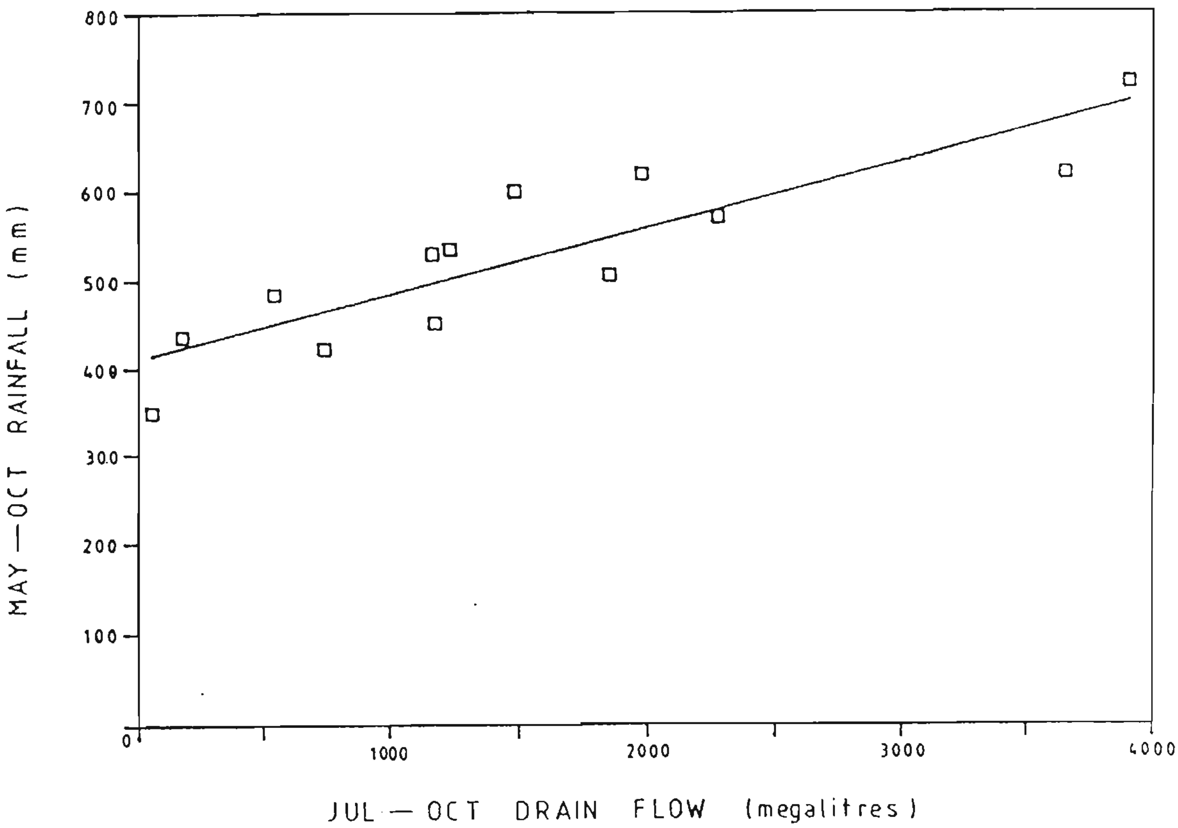
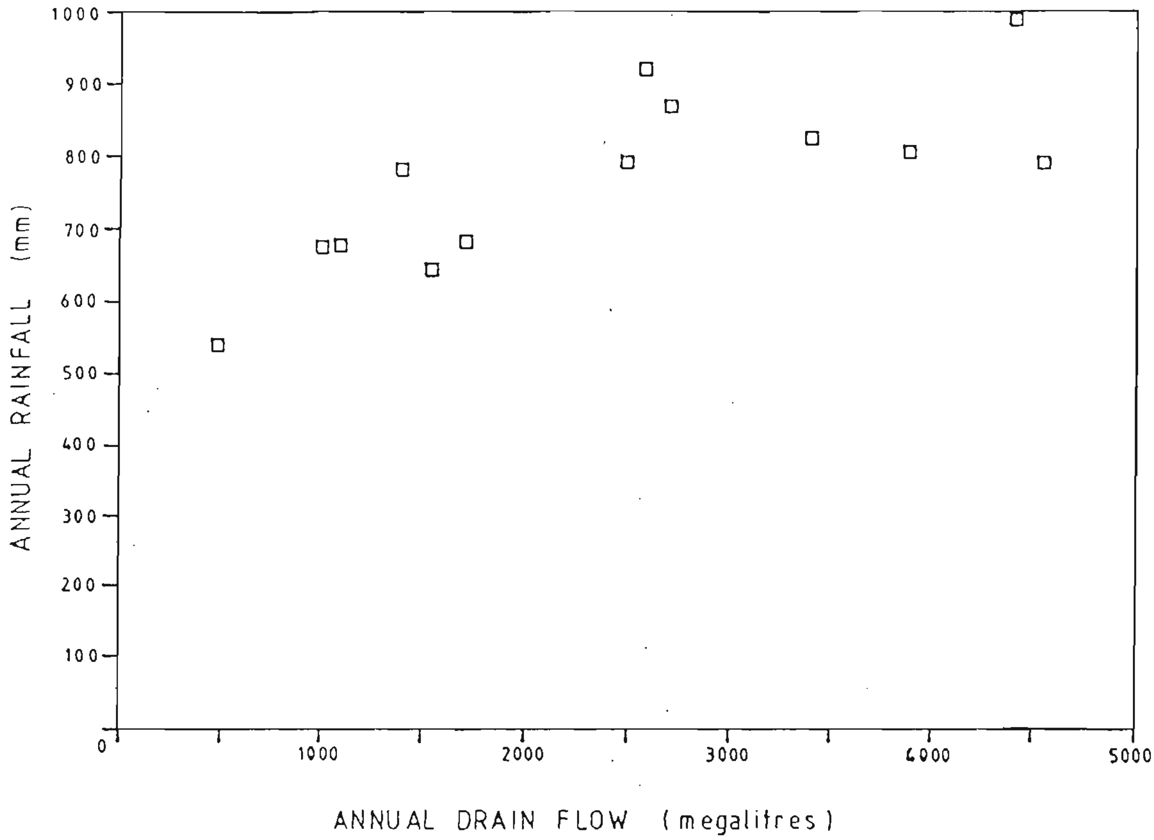


FIGURE 1-2

REEDY CREEK



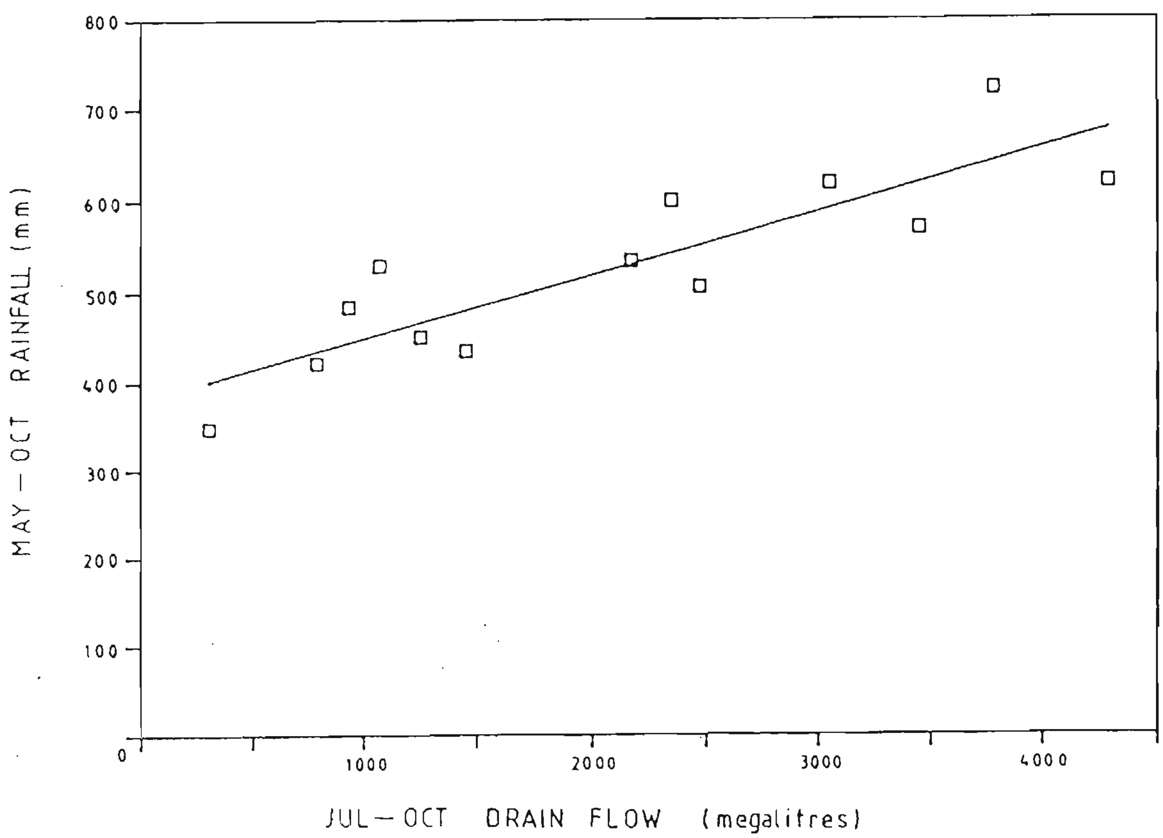
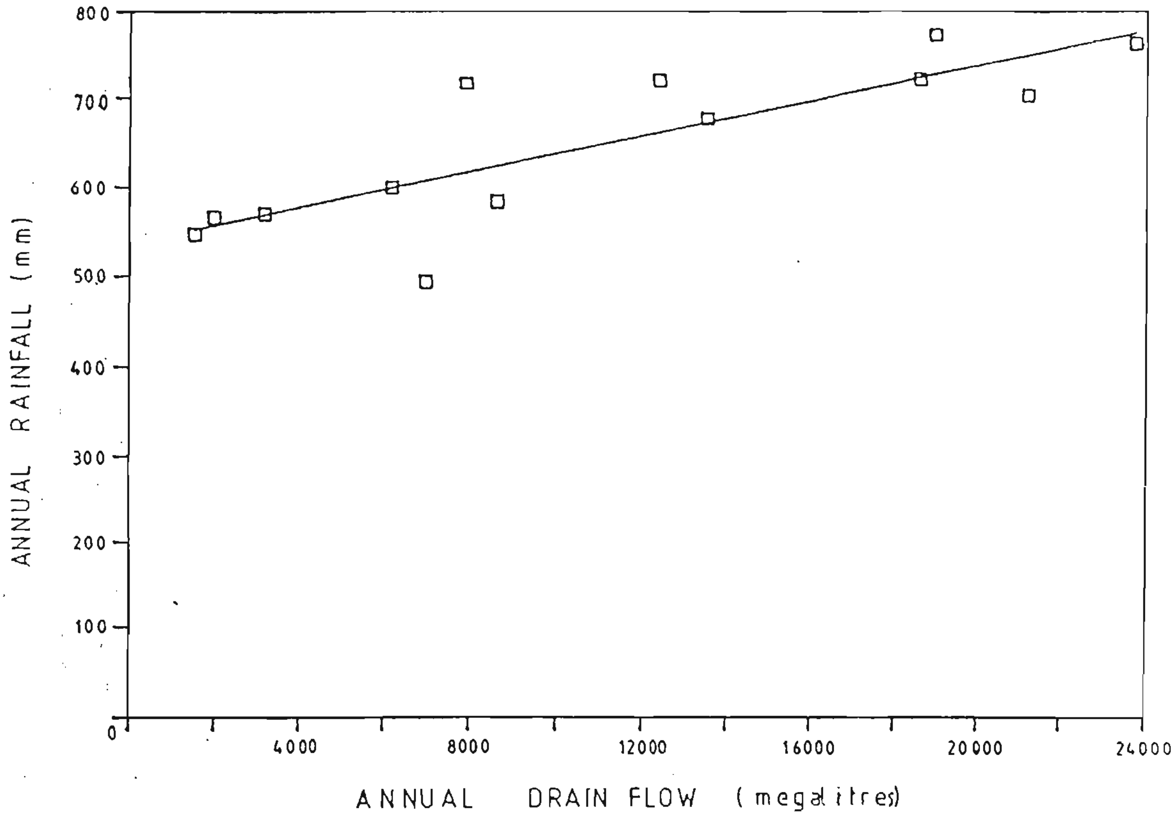


FIGURE 1-3

DRAIN L



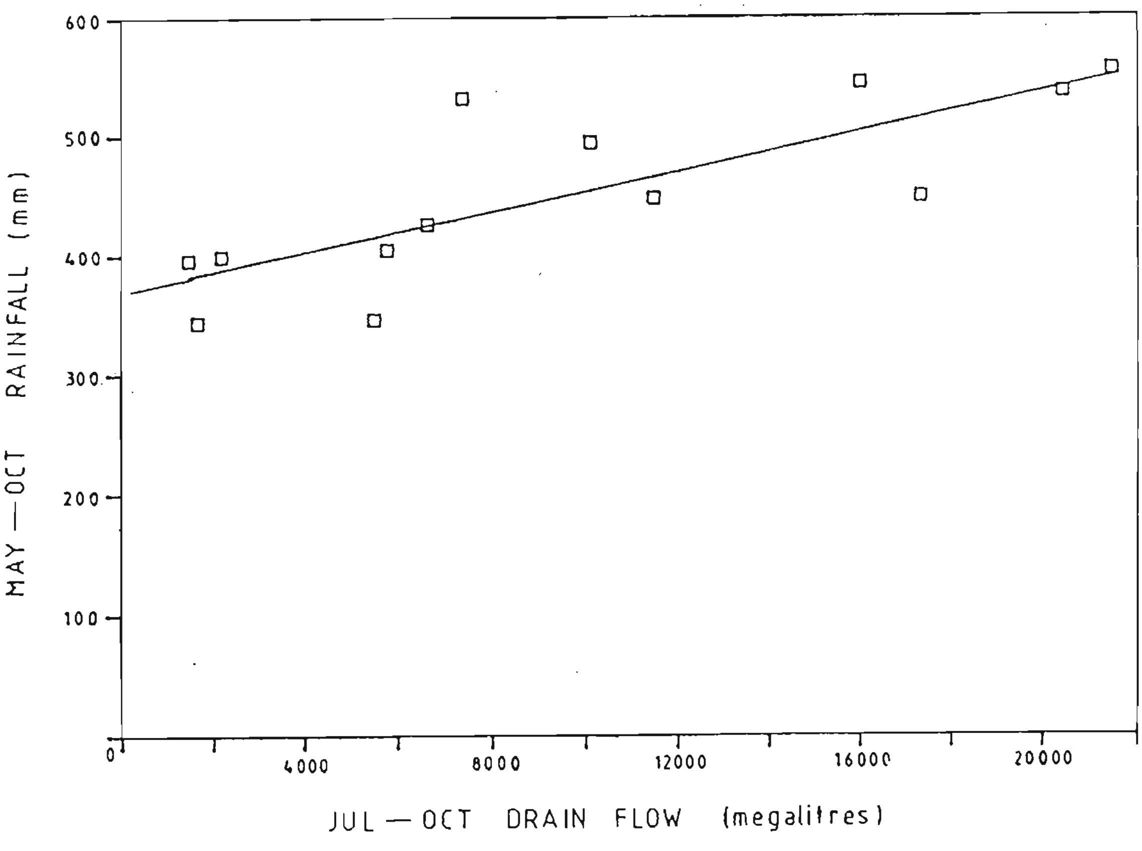
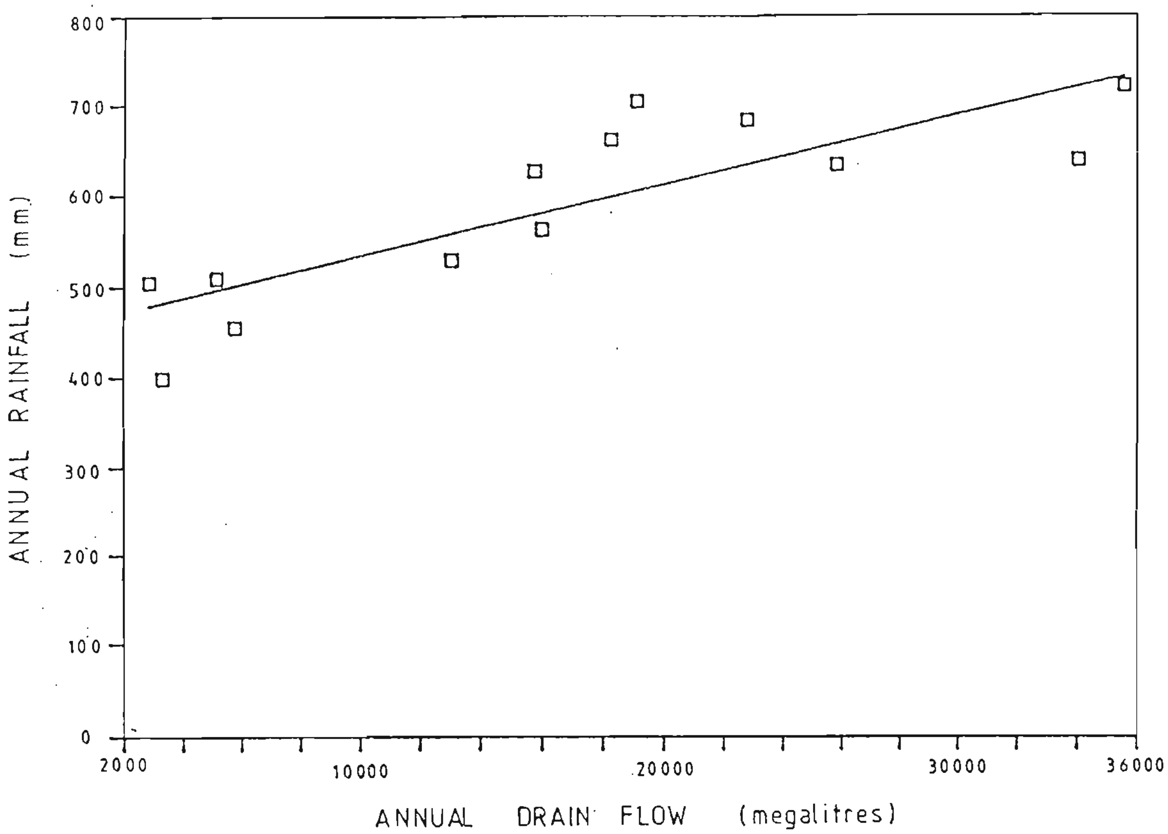


FIGURE 1-4

BLACKFORD DRAIN



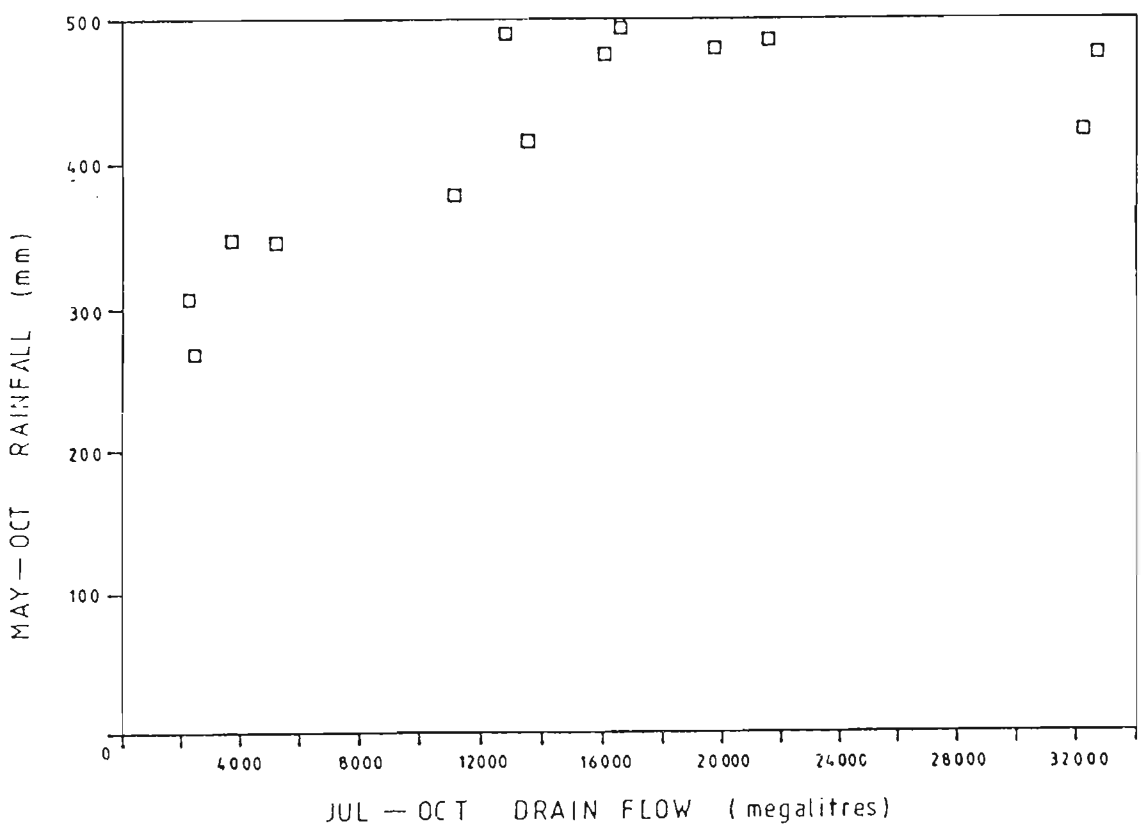


FIGURE 1-5

APPENDIX 2: ESTIMATION OF SALT LOADS FROM DRAIN CATCHMENTS

SALT LOAD DRAIN FLOW

1. Average conductivity was derived from plots of conductivity vs. flow produced by the State Water Laboratories. To these plots was added a line representing the flow above which 90% of the total volume is produced. The conductivities above the 90% line were averaged by eye, taking into account that there are few readings in the high flow range where salinity is lower.

2. By only using the conductivities for flow above the 90% limit partially accounts for the reduced salinities of high flows. Base flows represent only a small portion of the total volume. These baseflows with very high salinity readings at times do not affect the average conductivity.

3. The average conductivity was converted to salinity in mg/l using a table of conversions derived by the State Water Laboratories to South Australian conditions.

4. Average salinity was then used to derive salt load in drains.

SALT LOAD RAIN

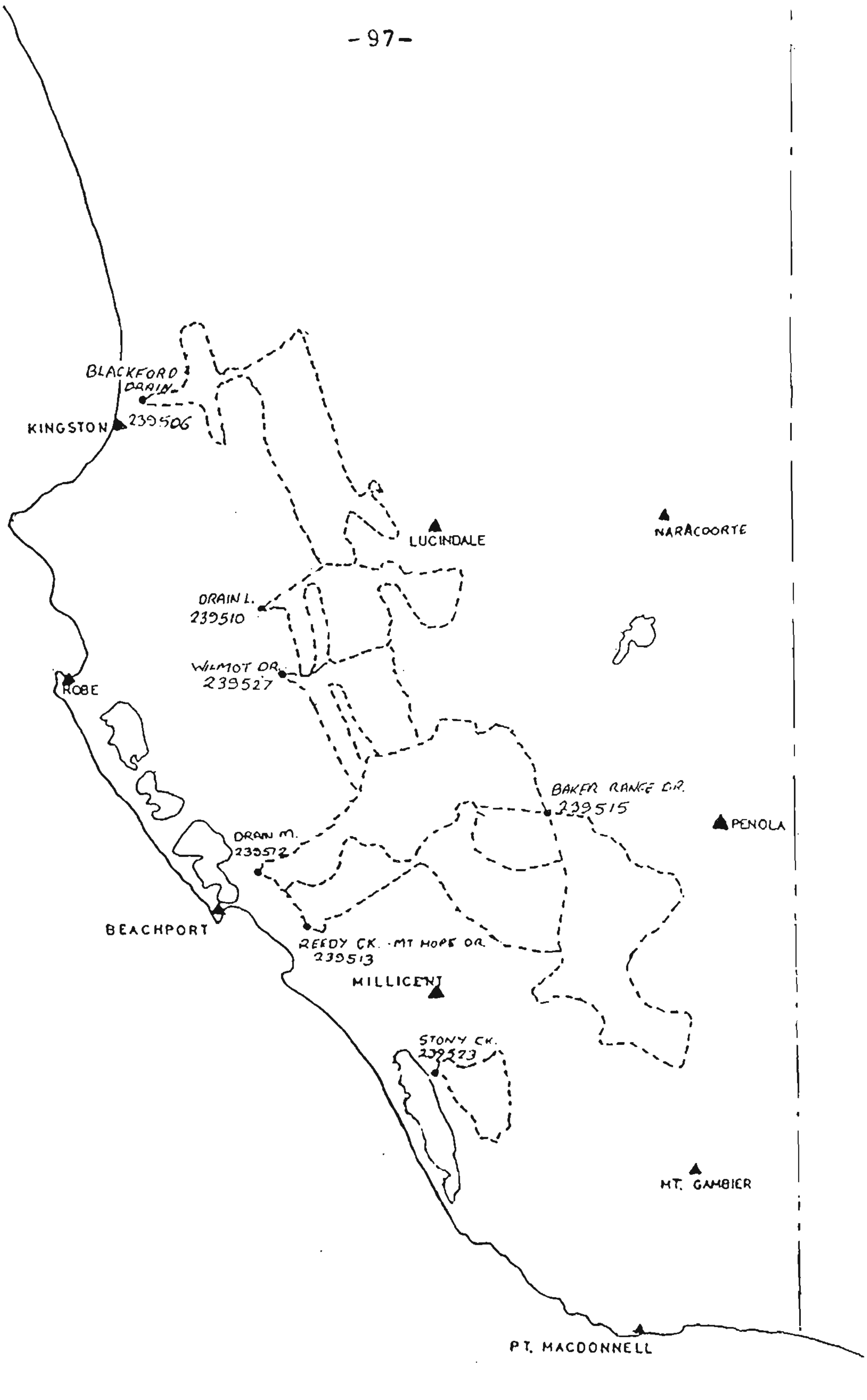
1. The salt load from drains was calculated using the Hutton (1976) relationship between rain water and salinity and distance from the coast. The distance from the coast to approximately the middle of each catchment was used.

TABLE 2-1: ESTIMATED SALT BALANCE OF DRAIN CATCHMENTS

Station	Av. Conductivity (uS/cm)	TDS of Av. Cond. (mg/l)	Av. Flow (Ml)	Salt Load (t)	Dist. from Coast (km)	CI- (mg/l)	TDS (mg/l)	Catchment Area (sq km)	Av. Rain - period of Record (mm)	Av. Volume Rain on Catchment (Ml)	Salt load from Rain (tonnes)	Ratio Drain Salt to Rain salt
	------SALT LOAD IN DRAIN FLOW				---------------SALT LOAD IN RAIN FALL							
Blackford Dr.	15000	10000	16500	165000	30	6.94	24.3	366	586	214476	5212	31.7
Drain L	2750	1565	11100	17372	40	5.89	20.6	192	648	124416	3023	5.7
*Drain M	1400	775	26000	20150	35	6.37	22.3	363	652	236676	5751	3.5
Reedy Ck.	1400	775	24100	18678	30	6.94	24.3	328	767	251576	6113	3.1
Baker Rge. Dr.	560	290	18300	5307	40	5.89	20.6	466	780	363480	8833	0.6
Stony Ck.	1100	605	7200	4356	15	9.82	34.4	73	830	60590	1472	3.0
Wilmot Dr.	1600	890	13500	12015	45	5.47	19.2	186	651	121086	2942	4.1

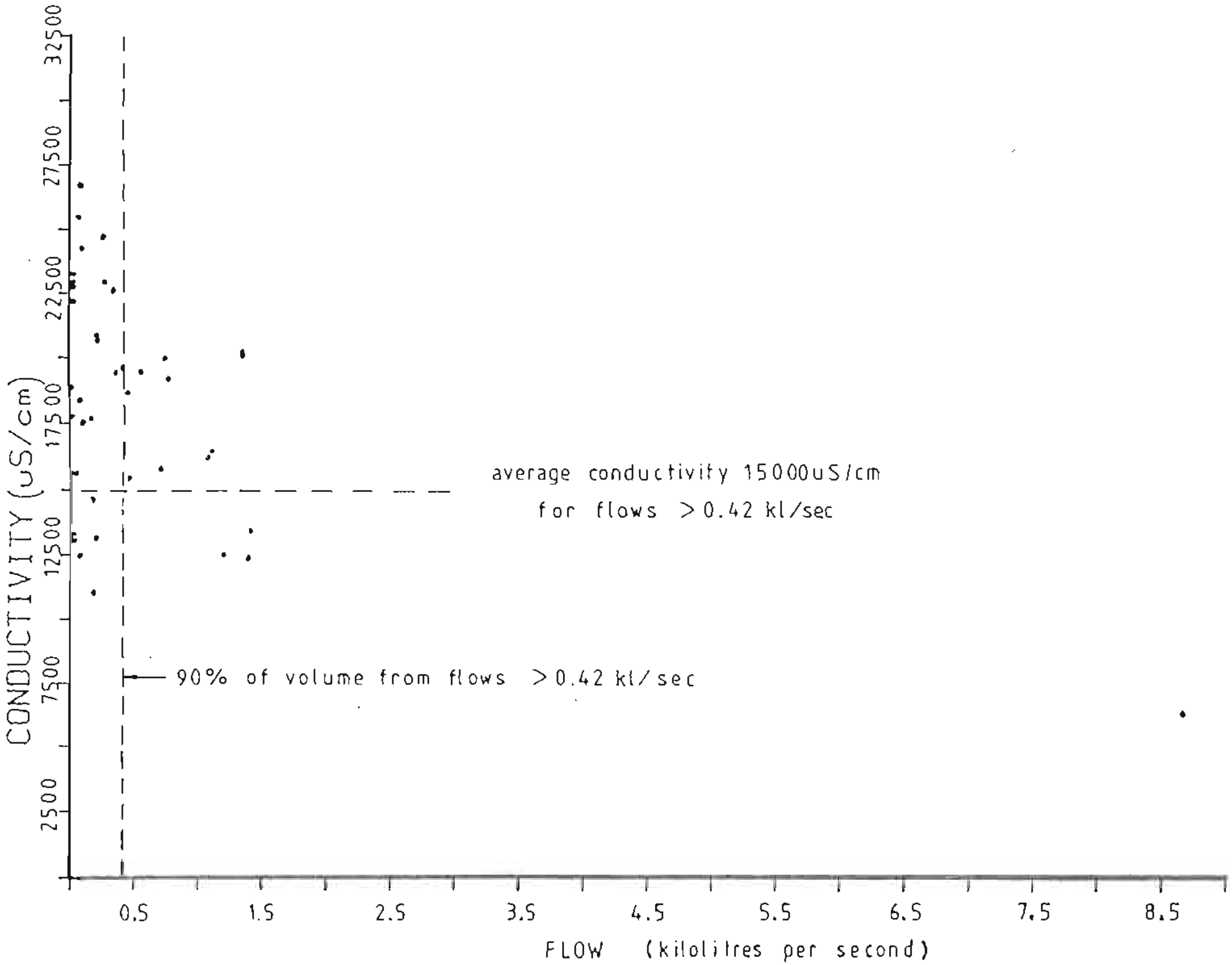
NOTE: Drain M - figures are for that part of catchment between the Woakwine and Callendale gauging stations.

Flow and rain data used is for period from 1972 to 1984.



DRAIN CATCHMENT AREAS

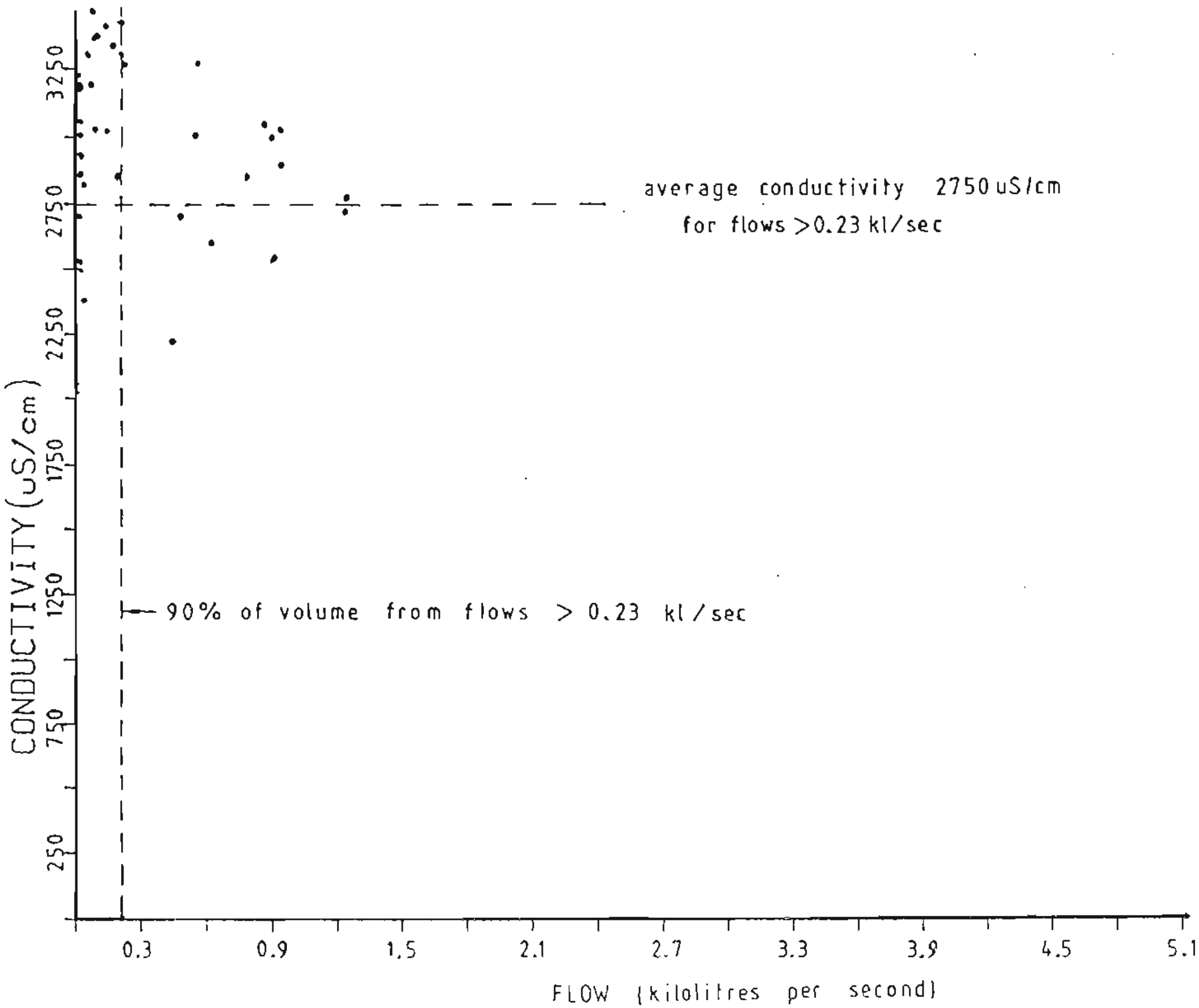
FIGURE 2-1



BLACKFORD DRAIN AMTD 4.0 KM GS239506

CONDUCTIVITY — FLOW RELATIONSHIP

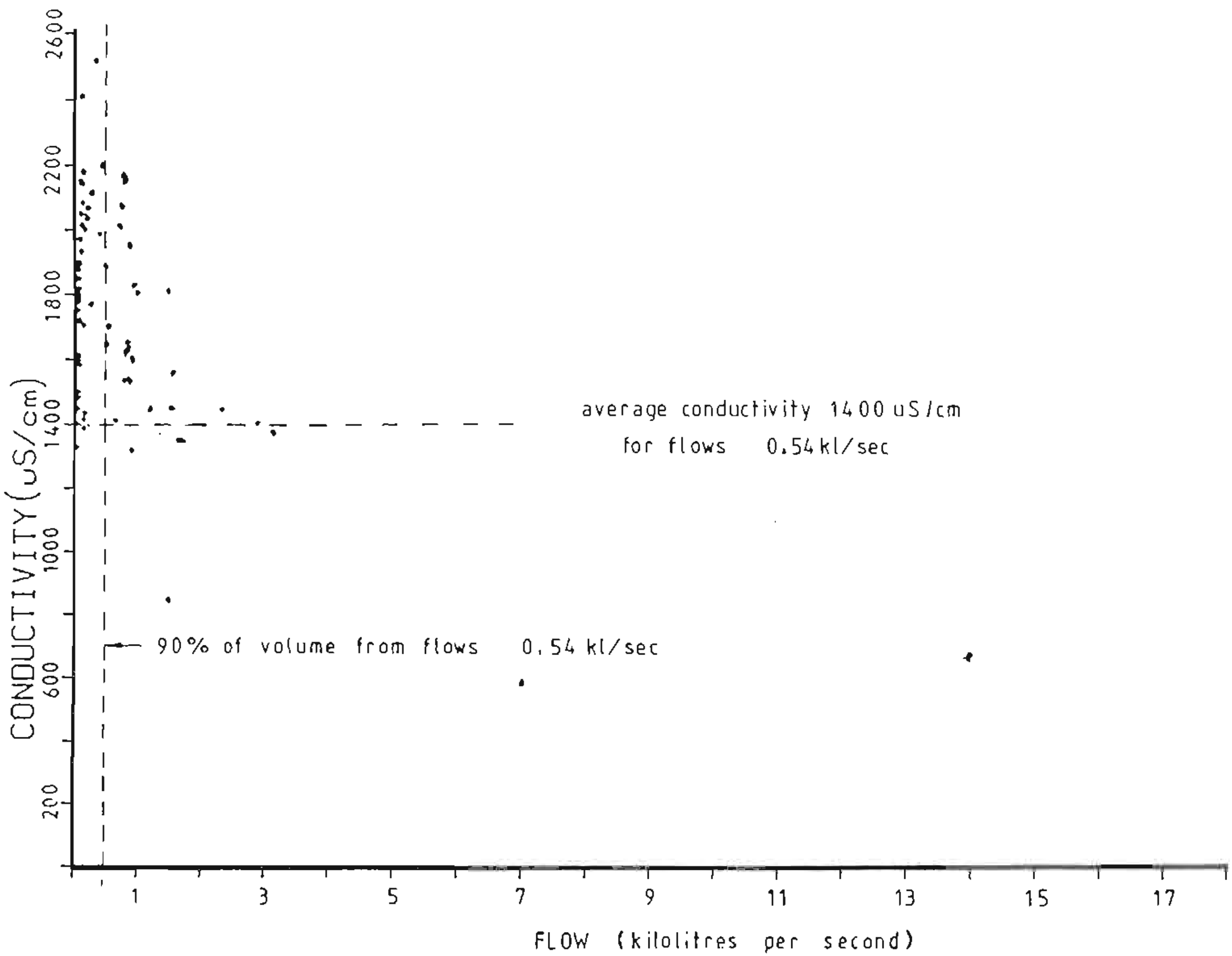
FIGURE 2-2



DRAIN L, U/S PRINCES HIGHWAY GS239510

CONDUCTIVITY — FLOW RELATIONSHIP

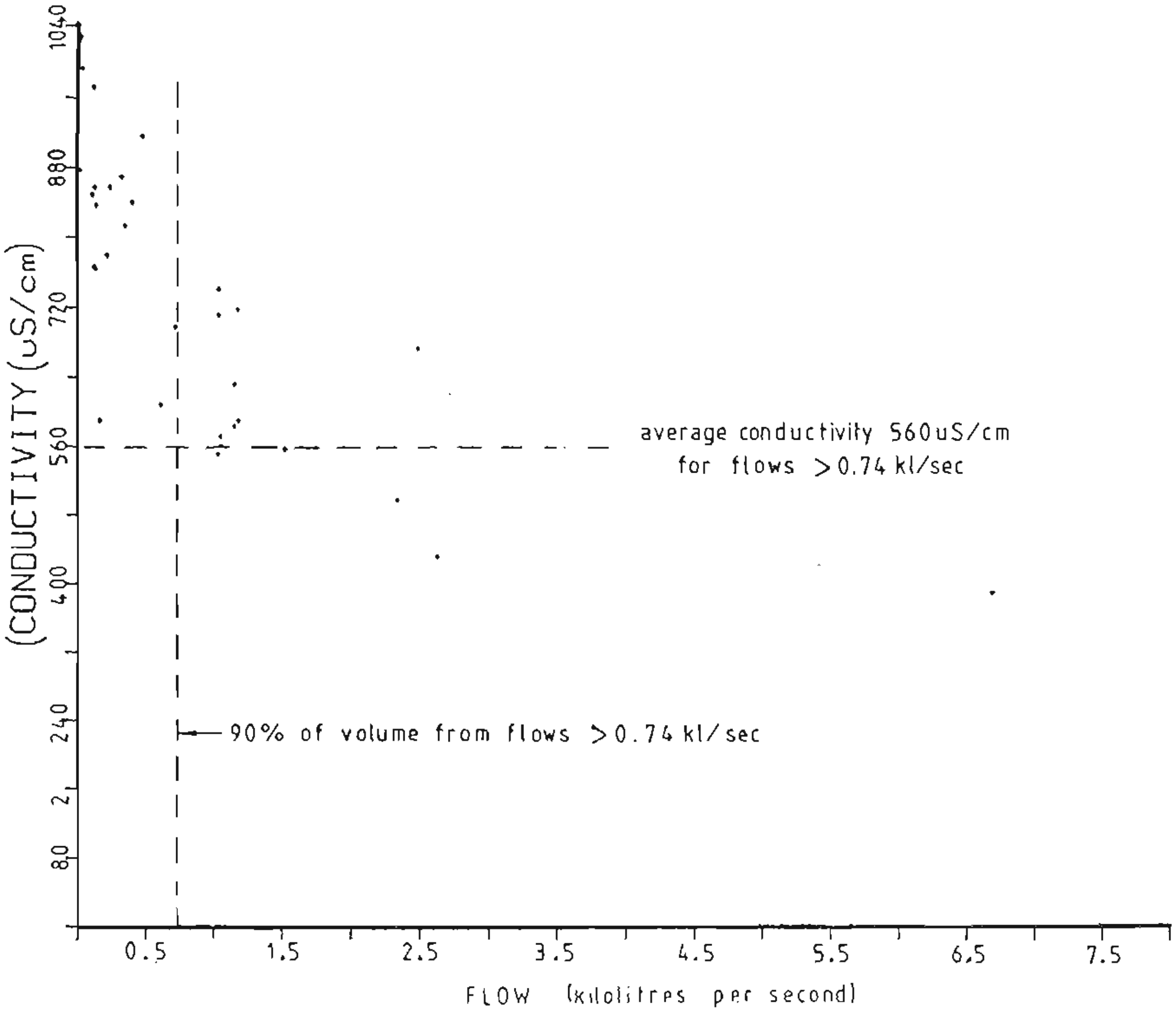
FIGURE 2-3



REEDY CREEK, MT. HOPE DRAIN GS239513

CONDUCTIVITY — FLOW RELATIONSHIP

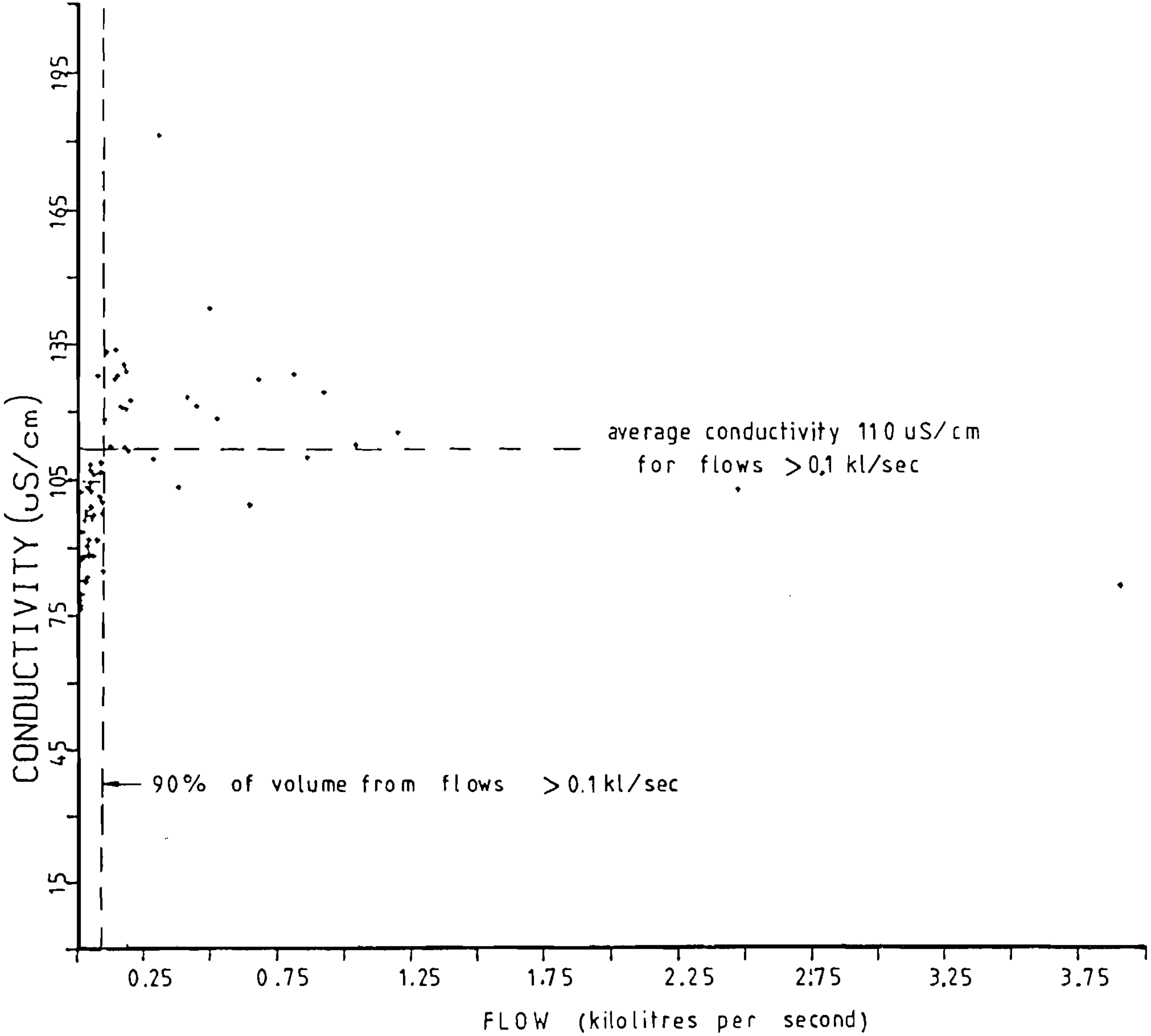
FIGURE 2-4



BAKERS RANGE DRAIN GS239515

CONDUCTIVITY — FLOW RELATIONSHIP

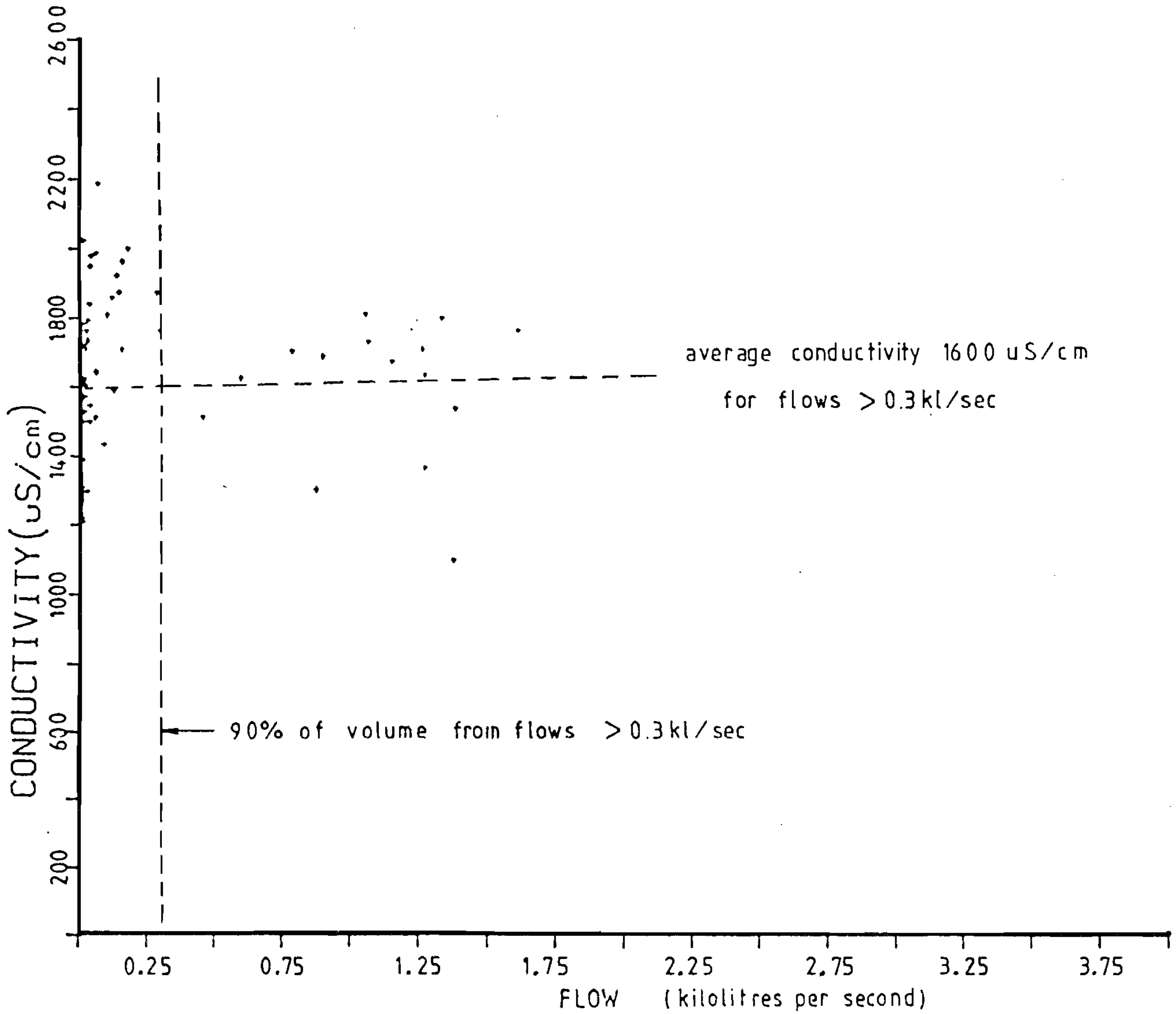
FIGURE 2-5



STONY CREEK, WOAKWINE RANGE GS239523

CONDUCTIVITY — FLOW RELATIONSHIP

FIGURE 2-6



WILMOT DRAIN, 9.2 KM FROM DRAIN L GS239527

CONDUCTIVITY — FLOW RELATIONSHIP

FIGURE 2-7

APPENDIX 3: SUMMARY OF TELEPHONE SURVEY OF 7 FARMERS IN THE VICINITY OF MT. BRUCE WEIR

JOHN ANDRE

- Weir slows down drying out period at end of spring.
- More effect on land to the south of drain.
- No effect on increasing stocking rate.

TREVOR OAKLEY

- Only benefits if the water level in the drain is kept to the top of weir.
- Prolongs green feed from 4-8 weeks.
- The effect is 1/2 to 1 km from drain, but only back to Fox lane (3 km upstream of weir).
- Need deep rooted plants to gain any benefit.
- Very difficult to quantify the benefit.
- Would be happy if there was no drain, but weir is some consolation.

BRIAN SKEER

- Often too wet in winter. Blames this on the boards at weir being left in too long.
- Seen no effect in late spring - early summer.

DAVID ALTSCHWAGER (son Tim)

Spoke to Tim

- Did not know of any advantages attributable to the weir.

SLIM ANDERSON

- Seen no effect from weir.
- More to be gained by blocking the outlet to Bellinger Swamp.

PHIL MURCH

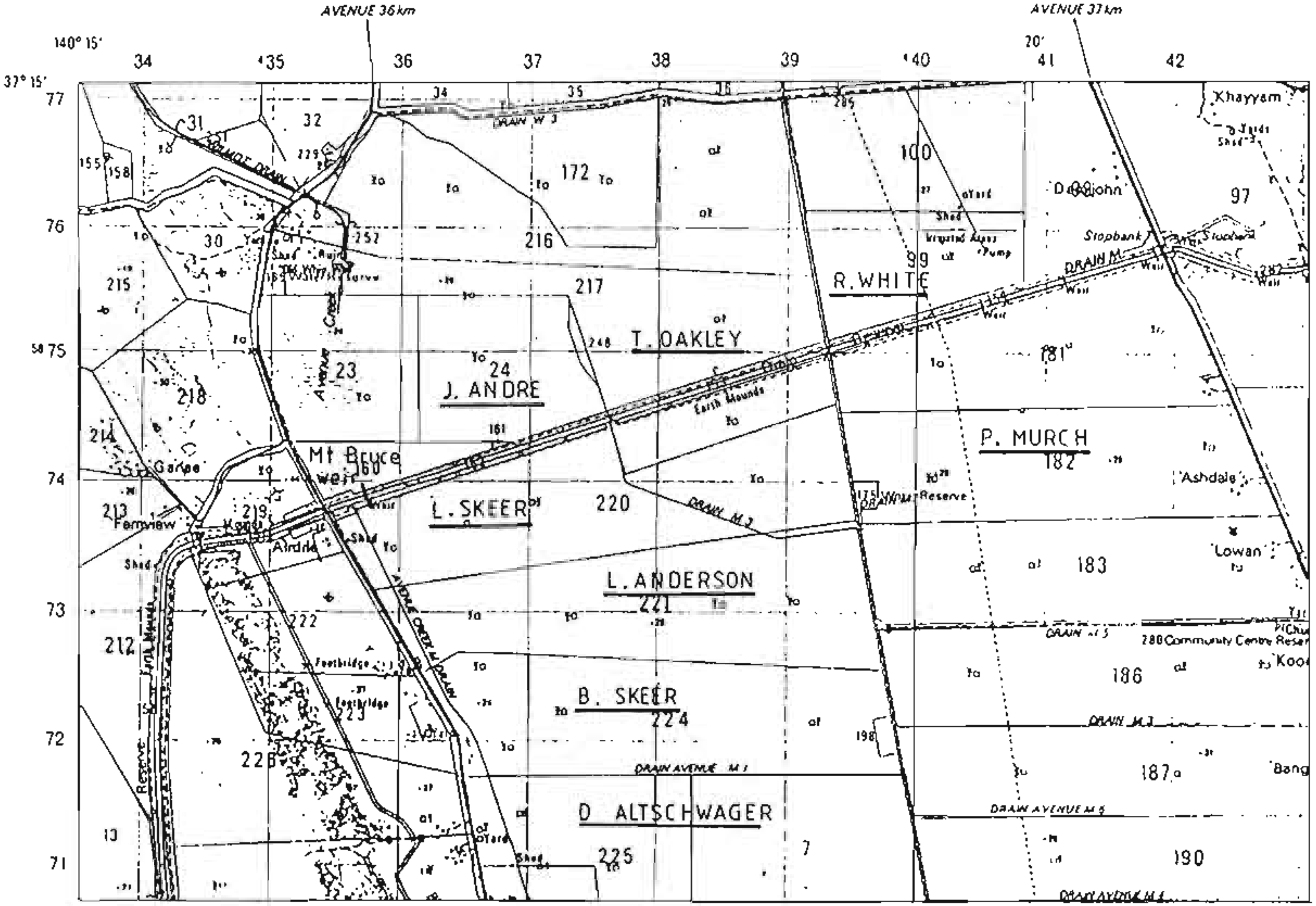
- Water does not stay in drain long enough at his end.
- Slightly more strawberry clover on home block.
- Some paddocks on a block to SW of his house do appear to be staying greener for longer periods.
- Overall little effect.

LANCE SKEER

- Improved country near weir and drain.
- Water table higher adjacent to drain.
- Effect lasting for 4 weeks.
- Hard to gauge the effect on stocking rate.
- Strawberry clover improving - up to 0.7 - 1.0 km from drain.
- Country is getting wetter in winter.
- Water at weir is advantageous for fire control as well as a source of water for fire trucks etc.

1:50 000 TOPOGRAPHIC SERIES

KENNION
SOUTH AUSTRALIA



LOCATION MAP

TELEPHONE SURVEY OF FARMERS

FIGURE 3-1

TECHNICAL REPORTS INDEX

No	Subject	Author/s
1	Agriculture in South Australia — A submission to the working group preparing a policy discussion paper on agriculture	Department of Agriculture
2	The Northfield Pig Research Unit — Annual Report to pig producers 1982	Department of Agriculture
3	Australian Merino Society tour of South America, 1981	B.C. Jefferies
4	Study Tour Report — Computer use in the Ministry of Agriculture and Fisheries (NZ)	J.H. Richardson Chief, Extension Services Division
5	Control of *Heliothis punctiger* on field crops — Preliminary trials of fenvalerate as a substitute for DDT on field peas	P.T. Bailey G. Caon P.I. McCloud R. Britton
6	Agronomic Evaluation Report — Irrigated sugar beet in the South East of South Australia	T.D. Potter D.C. Lewis
7	Glasshouse vegetable production in Western Europe — Overseas study tour report	Barry Philp
8	Report of the Vegetable Research Conference, New Zealand	I.S. Rogers
9	An input-output model of the South Australian Dryland Farming System (1) Model development	G.J. Ryland
10	Selenium in barley and grain legumes from Kangaroo Island	R.L. Davies
11	Research priorities in the Economics Division	Working Party to the Research Policy Advisory Committee
12	Study tour of agricultural waste management practices in Southern New South Wales and Victoria	C.M. Klingberg G. Schrale P.D. Harvey P. Deinum
13	River Murray Horticultural Crop Survey 1981 — Regional summaries and statistics	G.N. Thomas B.A. Smith
14	A report on the Australian Cashmere Industry	S. Ellis
15	Gross margins South East	N. Ward
16	The role of SAGRIC in marketing — Working Party Report	Department of Agriculture
17	Agriculture aspects of water management in Western Europe and Israel	M.R. Till
18	Progress report on the River Murray irrigation and salinity investigation programme	M.R. Till D.J. Plowman
19	Impact of videotex on agricultural extension — Report of a study tour to France, England, Canada and the U.S.A.	J.H. Richardson
20	Report on Pig Industry tour in Europe	P. Heap
21	Seed and pasture developments in New South Wales — Report of a study tour	R.S. Martyn
22	Proceedings of the Ovine Footrot In-service Training Course	M.J. Riley
23	Report on workshop — Research priorities for the cereal/sheep zone — A farmer's point of view	R.B. Wickes for Research Policy Advisory Committee
24	Damage to livestock caused by domestic dogs in Adelaide's urban fringe	Vertebrate Pests Control Authority
25	Agriculture in the South Australian economy	Economics Division
26	A study tour in Europe with emphasis on nutrition of horticultural and ornamental crops	J.B. Robinson
27	Report of a six-month simulation of a prestel-standard videotex data storage and retrieval system	M. Allison I. Graham
28	Report on a visit to the Federal Republic of Germany for the XXIst International Horticultural Congress, Hamburg	R.L. Wishart
29	Biological Sciences Group — 1981-82 report	Plant Industry Division
30	Proceedings of a fertilizer and salinity workshop for potato growers	C.M.J. Williams
31	Wind erosion on Eyre Peninsula, 1975-1979	K.G. Wetherby W.J. Davies W.E. Matheson
32	Review of research centres Report to the Research Policy Advisory Committee	Department of Agriculture
33	The water and salt balance of the Lower Murray swamps for the 1980-81 year	R.E. Desmier G. Schrale
34	Testing of onion cultivars for dehydration	I.S. Rogers R.D. Henderson
35	Cereal diseases in Victoria — Report on a visit to Victorian Crops Research Institute, Department of Agriculture, Horsham	J.A. Davidson
36	Future directions in extension	J.H. Richardson
37	Use of radio and press by farmers on Yorke Peninsula — A survey among members of the Agricultural Bureau	J.E. Both
38	Biological Sciences Report 1982-83	P.E. Madge
39	Dairy Research Report 1982	Northfield Research Centre, Animal Industry Division
40	Review of bovine brucellosis and tuberculosis traceback methods in South Australia	M.A. Reid B.L. Wilson N.M. Kowalick R.C. Robinson R.C. Butler
41	Introduction of dung beetles into South Australia 1970-1983	K.R. Henry
42	A review of the brucellosis and tuberculosis campaign in pastoral areas of South Australia	G.B. Neumann G.C. Curran
43	Irrigation requirements for almonds on the Northern Adelaide Plains	G. Schrale
44	Redevelopment of fruit blocks in the Riverland Region: An intertemporal programming approach	B.R. Hansen G.T. Oborne
45	Evaluation of irrigation equipment 1. Small low-level sprinklers	K.A. Watson
46	Structural changes in agricultural co-operation in Britain	D. Crabb
47	The extent and significance of water repellent sands on Eyre Peninsula	K.E. Wetherby
48	A look at the Californian Pistachio Industry	I.P. Bond
49	A direction finding and telemetry system for sheep in arid zone paddocks	M.C. Willcocks K.W. Sarkies
50	Sheep husbandry in South Australia	B.C. Jefferies
51	The recognition and treatment of dryland salinity	Ed. W.F. Matheson
52	An input—output model of the Southern Australian dryland farming system (2) Systems design and database	G.J. Ryland M.A. Petty R.I. Inglis
53	Biennial Report to pig producers 1984	Northfield Pig Research Unit
54	Report on apricot collecting expedition to Syria and Turkey	F.J. Gathercole
55	The commercialization of seeds of new cultivars of pastures and crops produced by publicly funded breeders in New Zealand	D.C. Ragless
56	A report on study tour of pea improvement work in USA and Europe, April—May, 1983	S.M. Ali
57	Gross margins for agricultural enterprises for Yorke Peninsula and the Mid North	R. Edwards
58	Merino strains in crossbred prime lamb production — Preliminary findings	D. Phillips A.W. Singh F.A. Dunstan
59	Ruminant Industry Research Review — Report to the Research Policy Advisory Committee	Working Party to the Research Policy Advisory Committee

Technical Report Index (continued)

No	Subject	Author/s
60	Proceedings of a Financial Management Workshop for potato growers	G S Ronan C. M J Williams
61	Readership survey of SAGRIC Gazette	M Allison A. A. Luks E. van Eyssen
62	Gross margins for the Southern Mallee of South Australia	H. Hannay M. A. Krause
63	Optimal location, number and size of grain handling facilities in South Australia: (1) Model development	P. D. Kerin
64	Redevelopment of fruit blocks in the Riverland Region: An intertemporal programming approach (2) User guide	B. R. Hansen
65	Feasibility of ovine footrot eradication in SA	Working Party Report
66	Dairy Research Report 1984	Northfield Research Centre, Animal Industry Division
67	Lot feeding of sheep through the 1982 drought	B. L. Ashton J. N. Hannay
68	Optimal location, number and size of grain handling facilities in South Australia: (2) (2) Road and queueing costs at handling facilities: 1983-84 harvest survey	P. D. Kerin
69	The River Murray Irrigation and Salinity Investigation Programme – results and future directions	P.J. Cole
70	Redevelopment of fruit blocks in the Riverland Region: An intertemporal programming approach (3) An application of the model	B.R. Hansen
71	The 5th International symposium on nitrogen fixation, Noordwijkerhout, The Netherlands 1983	P.R. Gibson
72	The Agricultural Chemicals Evaluation Scheme 1978-83	D I. Murrie D W. Stephenson
73	Designing cost efficient mains for irrigation systems	R.E Desmier
74	Gross margin budget guide book for Lower Eyre Peninsula	A J. Presser
75	Gross margins South East Region 1985	M. Milne P. Mowatt
76	Horticultural observations made in Israel in 1983	J.N. Steed
77	Sheep blowfly and flystrike in sheep: Report of a National symposium 1983	A.W. Singh C. Martin
78	A study of viral diseases affecting pigs and poultry in Singapore	P.B.D. Whyte
79	A soil conservation study tour – Darling Downs, Queensland and northern NSW	F.W. Armstrong D.J. Maschmedt
80	Optimal location, number and size of grain handling facilities in South Australia: (3) Estimation of short-run and long-run cost functions	P.D. Kerin
81	The feasibility of centralised marketing Murray Bridge glasshouse tomatoes and Continental cucumbers	J. L. King
82	Irrigated field crop gross margins for the Murray Lands area of South Australia	M.A. Krause J.N. Hannay D.L. Zimmerman
83	Vegetable production costs and returns Northern Adelaide Plains	B.W. Philp J.L. King G.S. Ronan
84	Citrus study tour 1984: 1984 International Citrus Congress and citrus producing areas of the USA	P.T. Gallasch
85	Alternative pasture legumes for southern Australia	R.W. Ellis A.D. Craig R.S. Martyn
86	A guide to sheep lice control	C.D. Tuckwell
87	Beef cattle production at Minnipa Research Centre 1969 to 1980	B.L. Ashton
88	Planning for growth in horticultural exports. Proceedings of a workshop held with the Horticultural Industry on 28 August 1985	I.R. Lewis
89	A literature review of grain handling systems.	P.D. Kerin
90	Gross margin budget guide book for Upper Eyre Peninsula.	A.J. Presser
91	Vegetable production costs and returns Adelaide Hills	G.S. Ronan J.L. King G.J. Lomman
92	Gross margins for agricultural enterprises for Yorke Peninsula and the Mid North	R.G. Edwards
93	Biennial report to pig producers 1986	The Northfield Pig Research Unit
94	Irrigated and dryland cropping margins for the Milang and Langhorne Creek area of South Australia	J.L. King
95	Livestock gross margins for Milang and Langhorne Creek, South Australia	J.L. King N.S.J. Ellis R.D. Williams
96	Development of techniques for screening barley for resistance to leaf scald disease *(Rhynchosporium secalis)*	J.A. Davidson
97	Herbicides and their fate in the environment – a review (1983)	K. Thoma R.E.R. Hartley
98	Report of the Central Veterinary Laboratories including the South East Regional Veterinary Laboratory July 1982 – 1985	Central Veterinary Laboratories, Department of Agriculture
99	A pilot study of a pig health scheme 1986	A Pointon
100	Vine clonal selection trials 1958-85 Nuriootpa Research and Advisory Centre	M.G. McCarthy
101	The cashmere industry in South Australia	N.S.J. Ellis A. Singh
102	Dairy Research Report 1986	Northfield Research Centre, Animal Research Branch
103	Gross margins for the southern mallee area of South Australia	G.D. Giles T.M Yeatman
104	Division of Plant Services Annual Report to June 1985	Officers of Plant Services Division
105	Aspects of Danish research in cereal diseases	M. Hirsch
106	Agricultural co-operatives in Australia. Report of the Working Party on Agricultural Co-operatives	The Working Party on Agricultural Co-operatives
107	Herbicides applied in low volumes by a bluff plate sprayer	M. Fulton
108	Soil and plant testing tour in USA	D. Reuter
109	Gross margins South East Region 1987	P.J. Mowatt
110	Herbicides screening group 1986 report	G.J Mitchell M.A. Maslen P.A Carter
111	Argentine ant	P E Madge G Caon
112	Treatment of dryland salinity in Western Australia – study tour	I D. Jolly B W. Hughes D.G McCarthy
113	Northern South Australia Cattle Industry Survey 1986	A.L. Gibson
114	Broccoli cultivar trials 1983/84	B.W. Philp I.S. Rogers G.J. Lomman
115	European earwig, a historical review	P.E. Madge G Gaon
116	Testing of chinese cabbage, summer cauliflower and Brussels sprouts cultivars	G J. Lomman I S Rogers B.W. Philp
117	Report of the Central Veterinary Laboratories including the South East Regional Veterinary Laboratory 1985 – 1986	Central Veterinary Laboratories
118	A spatial economic analysis of wool centralisation arrangements	B. Mayers
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