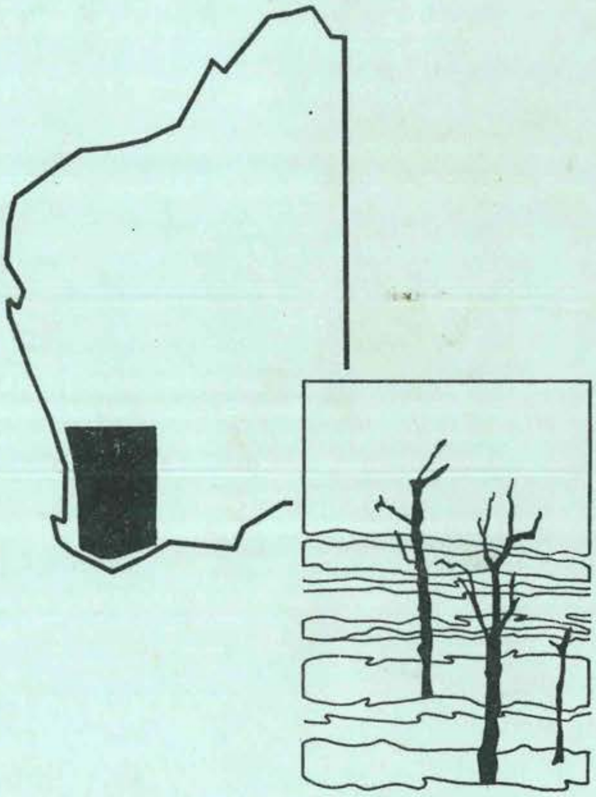
CLEARING AND STREAM SALINITY

IN THE

SOUTH WEST

OF

WESTERN AUSTRALIA



PUBLIC WORKS DEPARTMENT, WESTERN AUSTRALIA
JULY, 1979

DOCUMENT No. MDS 1/79

DOCUMENT No. MDS 1/79

CLEARING AND STREAM SALINITY

in the

SOUTH WEST

of

WESTERN AUSTRALIA

Prepared by

PUBLIC WORKS DEPARTMENT WESTERN AUSTRALIA

PLANNING, DESIGN & INVESTIGATION BRANCH

JULY 1979

CONTENTS

CONTENTS (Cont.)

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

The salination of streams and of land caused by release of salts naturally stored in the soil profile is now accepted as one of the major water supply and land use planning problems of the South West of Western Australia. The process which results from clearing deep rooted natural vegetation is not unique to the area. It is known to occur elsewhere in Australia, in the United States and in Canada. Here however, it presents a more severe problem than is known to be experienced anywhere in the world.

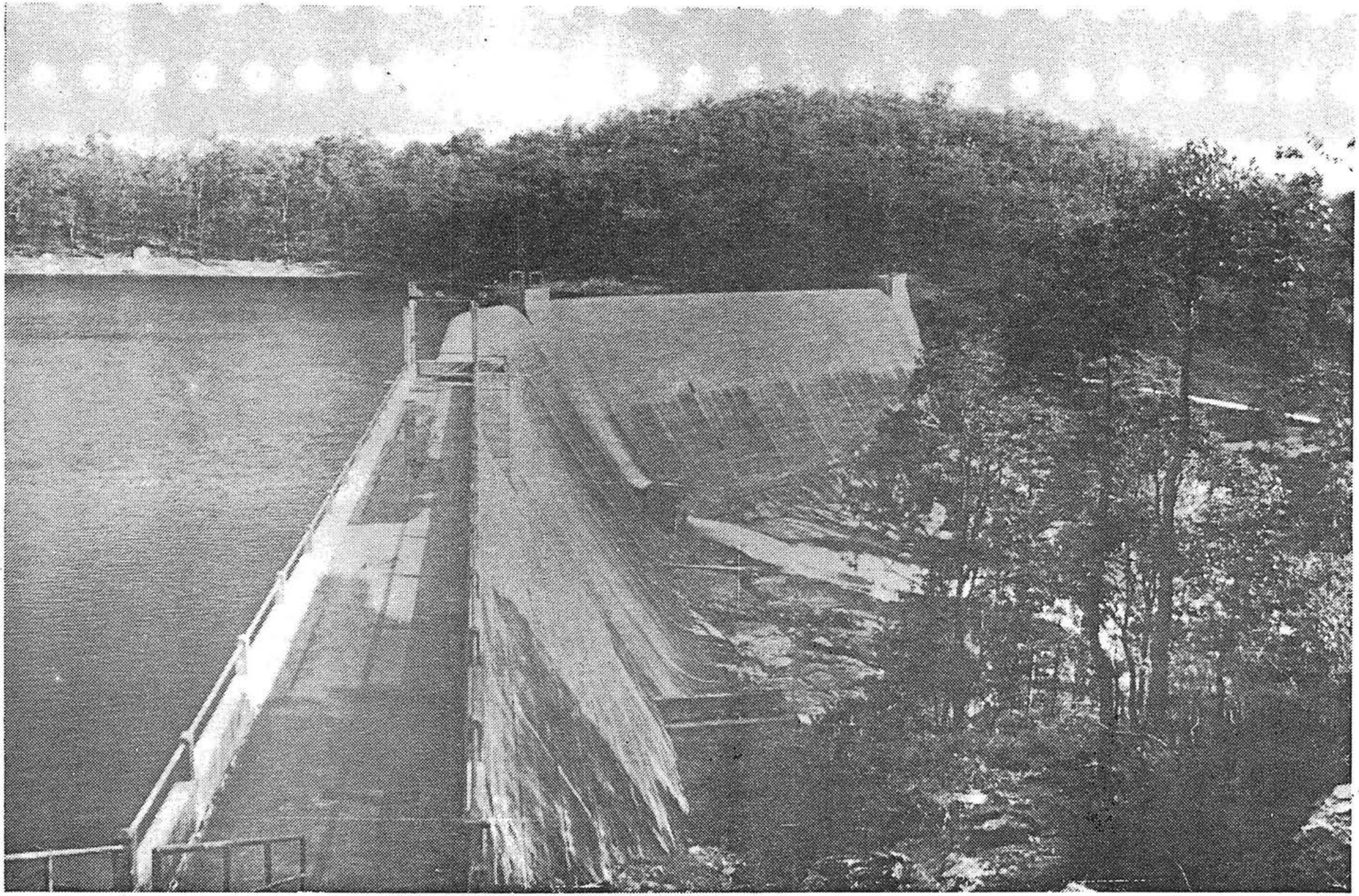
The two main effects of salt leaching are deterioration in water quality of streams and rivers, and the loss of agricultural land.

In its latest (1974) saltland survey the W.A. Department of Agricultural found that there are 167 294 hectares of land previously used for crops or pasture that have been lost to salt seeps. This compares with approximately 75 000 hectares in 1955, an increase of 4 800 hectares/year over the period. The 1974 figure represents 1.17 percent of all cleared land and there are three shires in which it is over 3.0 percent.

Although this loss of land is of considerable concern, the deterioration in the quality of the limited water resources is even more serious. It is now estimated that roughly 50 percent of the usable surface water resources of the South West have suffered significant adverse effects from salinity. The dominant cause of this has been agricultural clearing in salt sensitive zones of river catchments.

Salination of land and of water resources are both symptoms of the same disturbance of the natural water balance. However it is most important in any discussion of salinity, to maintain a clear distinction between management of salt affected land, and control of stream salinity. This distinction is necessary because a particular control measure may be beneficial in treating one symptom, but have no benefit whatsoever in treatment of the other.

This report is primarily concerned with the problem of protecting the quality of the State's water resources, which is one of the prime responsibilities of the Public Works Department. It outlines the extent of the problem and what has been, and is being done, to safeguard the fresh water resources in the best long term interests of the whole State.



RELEASE OF SALINE WATER FROM WELLINGTON DAM

FURTHER READING

(1) WOOD W.E. Increase in salt in soils and streams following destruction of the native vegetation. Journal of the Royal Society of Western Australia 10(7):35-47 (1924).

(2) DEPARTMENT OF AGRICULTURE OF WESTERN AUSTRALIA Salt encroachment - the 1974 saltland survey. Bulletin 3999 (1976)

(3) PECK A.J. Salinization of Non-Irrigated Soils and Associated Streams: A Review. Aust. J. Soil Res. 16, 157-68 (1978)

2.0 WATER QUALITY

2.1 Salinity Classifications

Varying amounts of commonly occurring salts are always found dissolved in natural waters, and salinity is a general term referring to measures of salts concentrations.

When dissolved in water, salts separate into electrically charged molecules called ions. The principal ions normally present in natural waters are sodium, calcium, magnesium, potassium, chloride, bicarbonate and sulphate.

The summation of the concentrations of all dissolved salts is known as the Total Soluble Salts (TSS) concentration and is measured as the total mass of salts in milligrams per litre of water (mg/l). A similar and more common measure, which for all practical purposes is the same, is known as the Total Dissolved Solids (TDS) concentration. The old Imperial units of grains per gallon (gpg) are still used to a small extent. A salinity of 70 gpg TDS is the approximate equivalent of 1000 mg/l TDS. However, the old Imperial units simply create unnecessary confusion now that the community has standardized on metric units.

A broad system of water quality classification based on palatability is as follows:

Fresh	0 - 500 mg/l TDS
Marginal	500 - 1000 mg/l TDS
Brackish	1000 - 3000 mg/l TDS
Saline	over 3000 mg/l TDS

The quality of water flowing from a completely undisturbed catchment in the South West of Western Australia would be fresh, in the region of 150 to 200 mg/l TDS.

In the South West, the proportions of the various ions in rainfall, in groundwater and in surface waters are fairly consistent. The average proportions are shown in Table 1 below.

TABLE 1

APPROXIMATE PROPORTIONS OF THE MAJOR IONS IN SOUTH WEST RIVERS

AS PERCENTAGE OF TOTAL SALTS

Chloride	54%
Sodium	25%
Bicarbonate	7%
Magnesium	5%
Sulphate	4%
Calcium	3%
Others	2%

The two specific ions which most affect water quality in the South West are chloride and sodium. The other ions are in relatively low concentrations and provided that salinity is within Total Dissolved Solids criteria they will be well below their appropriate concentration limits. There are no problems with toxic ions such as lead or arsenic.

2.2 Standards for Domestic Use

2.2.1 Total Dissolved Solids

The undesirable consequences of excessive TDS concentrations in domestic water are unpalatable taste, possible gastro-intestinal irritation and corrosion in water appliances. For total salinity, the World Health Organisation has set 500 mg/l TDS as the highest desirable level and 1500 mg/l TDS as the maximum permissible level for domestic purposes.

In the South West the desirable limit is below the practical minimum for some water supplies. Approximately 73% of towns are supplied water at less than 500 mg/l TDS and all of the remainder at between 500 and 1000 mg/l TDS. However, over the recent dry period, levels did go above 1000 mg/l TDS, for a few towns on the Great Southern, though supplies were still well below the 1500 mg/l TDS maximum permissible.

2.2.2 Sodium

Sodium ion is always present in natural waters, but in other parts of the world the total salts concentrations in rivers usually include lower proportions of sodium than are encountered in the South West. Sodium salts are particularly soluble and costly to remove.

Neither highest desirable or maximum permissible sodium concentrations have been set in world standards for drinking water. However the matter has received recent consideration because of an association between high sodium diets and hypertension.

The habitual sodium intake in food for most Australians is between 3000 and 4500 milligrams and a significant proportion of the population may find it beneficial to reduce this usage. However by comparison with the use in food, a daily consumption of 2 litres of 1000 mg/l TDS drinking and cooking water in the South West would give an added intake of 500 milligrams of sodium in the daily diet.

An average person's daily intake of sodium is mostly from food rather than water and is largely discretionary. Consequently, it is more feasible for such a person to control sodium intake by selection of food and by care with seasoning than it is for the community to undertake costly desalination to reduce the sodium content of public water supplies.

A very small proportion of the community with particular kidney or heart ailments are prescribed highly restricted sodium diets, and such patients may be required to specially procure low sodium water for drinking purposes. This would be obtained from rain water or a small deionizing unit at relatively low cost.

Although sodium is universally present in South West rivers, and further sodium increases for some rivers are unavoidable, it is the objective of water authorities to limit such increases. This has been one of the reasons for the introduction of clearing controls on salt susceptible catchments which have value as a water resource.

2.2.3 Chloride

Chloride is the dominant dissolved constituent in local waters. Its principal effect on water quality is to cause a salty taste and increase corrosion. The World Health Organisation has recommended a maximum permissible chloride concentration of 600 mg/l for domestic supplies and this would occur in South West water of approximately 1100 mg/l TDS.

2.3 Industrial Requirements

The limiting concentration of dissolved solids that can be tolerated by industrial users varies widely. Dissolved solids can cause foaming in boilers and interference with the clearness, colour and taste of many manufactured products. High salt contents also tend to accelerate corrosion. Typical limiting concentrations for various industrial uses are brewing 500-1000 mg/l TDS; canning and freezing 850 mg/l TDS: confectionary manufacture 50-100 mg/l TDS and paper manufacture 80-500 mg/l TDS. The supply of feed water for industrial boilers is often a problem, requirements can be as low as 50 mg/l TDS.

Generally, industrial users receive water from the same source of supply as domestic users, because separate supplies are not normally economic except for users of large volumes located in sparsely populated areas. If industrial water is required to be of better quality than a scheme can provide, a special treatment plant must be installed. If the water quality requirements of a particular industry are such that the reticulated supply to the region is not of sufficiently high quality, and there are no fresh local streams which could be developed, costs are increased to such an extent that the area becomes less attractive for the location of industry.

2.4 Agricultural Use

Agricultural use of water may be divided into two aspects, namely stock consumption and irrigation.

Animals have shown themselves to be fairly tolerant to high levels of dissolved solids in their drinking water. However the limits are known to depend on a variety of factors including the animals diet, age, physiological condition, the season, climate, how suddenly the water with high salinity level is introduced, and for what period it is used.

The upper limits of salinity in water for livestock in Western Australia are:-

Poultry	-	3000 mg/l TDS	
Pigs	-	4500 " "	
Horses	-	6500 " "	
Dairy cattle	-	7000 " "	
Beef cattle	-	10 000 " "	
Lambs	-	10 000 " "	
Sheep	-	18 500 " "	(for short periods)

(From:- Waters for agricultural purposes in Western Australia
J. Dept. Agric. W.A. 4th Series 3:623-6)

Plants are generally far less tolerant of high salinity levels than animals. Tolerance levels vary widely, and depend on a variety of factors in addition to those inherent in the plant species itself. These factors include the properties of the soil, the provision of soil drains, frequency and method of watering and whether salt build ups are regularly flushed out by fresher water (e.g. winter rains).

CATTLE GRAZING ON IRRIGATED PASTURE

TABLE 2

RELATIVE TOLERANCE OF CROP PLANTS TO SALT CONTENT OF IRRIGATION WATER

	High Tolerance	Medium Tolerance	Low Tolerance
1. Fruit	Date Palm	Olive	Citrus
		Grape	Apple
			Pear
			Plum
			Peach
			Strawberry
2. Vegetables	Asparagus	Tomato	Radish
	Spinach	Cabbage	Celery
		Lettuce	Green Beans
		Potato	
		Carrot	
		Onion	
		Cucumber	
3. Forage Crops	Salt grass	Strawberry Clover	White Clover
	Bermuda grass	Lucerne	Ladino Clover
		Rye (hay)	
		Wheat (hay)	
4. Field Crops	Barley (grain)	Rye (grain)	Field beans
	Sugar Beet	Wheat (grain)	
		Rice	
		Soy Bean	
		Sunflower	

(Source: Quality Aspects of Farm Water Supplies. Published at the request of the Australian Water Resources Council by the Department of National Development, Canberra 1969)

Some indication of the relative tolerance of crop plants to the salt content of irrigation water is given in Table 2. Water at 200 mg/l TDS or less would have little or no effect on any species, while water with a salinity of 1500 mg/l or more would be likely to have a considerable effect resulting in loss of yield for most species even those with a high tolerance.

FURTHER READING

(1) WORLD HEALTH ORGANIZATION

International Standards for Drinking Water, 3rd Edition, Geneva, Switzerland (1971).

(2) DEPARTMENT OF NATIONAL DEVELOPMENT, CANBERRA
Quality Aspects of Farm Water Supplies. Report by Victorian Irrigation Research and Advisory Services Committee. (1969).

(3) NATIONAL ACADEMY OF SCIENCES, WASHINGTON D.C.
Drinking Water and Health
Report of the Safe Drinking Water Committee (1977)

(4) NATIONAL ACADEMY OF SCIENCES, WASHINGTON D.C.
Water Quality Criteria 1972.
Report of the Committee on Water Quality Criteria.

(5) PUBLIC WORKS DEPARTMENT OF WESTERN AUSTRALIA
Salinity and Water Quality. Pamphlet. Sept. 1979
(in print).

3.0 THE CAUSE OF STREAM SALINITY

It is scientifically established that the cause of stream salinity and the development of salt land patches in the South West of Western Australia is the leaching of stored salts by increased groundwater movement after removal of native vegetation.

3.1 The Process

Salt is being continuously transported inland from the Indian and Southern Oceans and falls on to the land in rainfall and as dust. The quantity of salt precipitated declines with distance from the coast. For example, Perth (6 kilometres from the ocean) receives 225 kilograms per hectare per annum; York (95 kilometres) and Merredin (225 kilometres) receive 25 and 8 kilograms per hectare per annum respectively.

Most of the rain falling on the land is transferred back to the atmosphere through evaporation and by the vegetation through evapo-transpiration. This process leaves behind the salt in the soil and on vegetation surfaces and concentrated in the remaining water it enters the streams and rivers by surface run-off and underground seepage. The salts left deposited on the surfaces are washed off by the subsequent falls of rain.

For an undisturbed area there is a balanced, or near balanced condition, in which incoming and outgoing salt (saltfall and saltflow) are roughly equal. Over thousands of years, where there has been some excess of saltfall over saltflow, a gradual accumulation of salts has occurred in the soil. The amount of salts stored in the soil depends on the various physical properties of the soil and the degree of leaching which has occurred naturally. Frequently there is a pronounced concentration 4 to 12 metres below the surface and above the saturated zone.

Though salt precipitation declines with distance from the coast, soil salt storage increases. At a distance of 100 km or more inland it is generally very high, as much as 1000 tonnes of salt per hectare. Close to the Darling Scarp, where the soils are well leached, storage is variable but generally low and in the region of 20 tonnes per hectare.

If the natural balance is upset by the removal of the indigenous deep rooted vegetation with its high year round evapo-transpiration rate, and is replaced

A TYPICAL SALT SEEP AREA

by grasses or annual crops with shallow root systems and a much lower water use, particularly in summer, the balanced salt condition is affected. With lower vegetative use, greater quantities of water infiltrate the soil mantle raise the groundwater table and thereby initiate a gradual release of the accumulated salts by seepage and capillary action (Fig. 1).

3.2 Variation in Salinity Potential

The soil salt storage and hence the potential for leaching salts into rivers and streams in the South West of Western Australia varies widely.

The South West can conveniently be divided into four regions (Fig. 2) of differing salt leaching potential, namely:

(i) Coastal Region

The coastal plain to the west of the Darling Scarp includes the Donnybrook Sunklands, plus the strip of coastal dunes and swampy coastal plain about 15 km wide along the south coast. The soils in this region are mainly free draining sands which contain little or no salts in storage, and do not generally pose any threat to water quality if cleared.

(ii) High Rainfall Region

The high rainfall mainly forested area extends from the Darling Scarp inland to about the 1100 mm rainfall isohyet. The soil salt storage and groundwater salinities in this region are low, and in most areas, after clearing, increases in stream salinity will be small.

(iii) Intermediate Region

The intermediate region inland from the high rainfall region lies roughly between the 1100 and 900 mm rainfall isohyets. It is an area of transition between regions of low and high susceptibility to salt leaching. Soil salt storage and groundwater salinities in this region are highly variable. Clearing anywhere within this region needs to be considered very carefully as there is considerable potential for affecting stream water quality.

(iv) Low Rainfall Region

In this region which extends inland from the 900 mm rainfall isohyet, the ground salt storage and groundwater salinities are high. Clearing almost anywhere within this region will inevitably result in salt being leached in large quantities and affect both the land and the surface waters of the region.

3.3 Research

A very wide ranging programme of research and investigation into the causal mechanisms of salinity and possible control measures has developed in Western Australia. This programme involves State Government Departments including the Forests Department, the Public Works Department and the Department of Agriculture. It also involves research organisations such as CSIRO and the University of Western Australia. Informal peer group communications between research groups have maintained an effective flow of information between projects and in consequence Western Australia is a major national and international centre of dryland salinity research.

A table listing current research into the salinity problem has been included as an Appendix to this report. The table has two parts A and B. Part A covers research relating to agricultural clearing and its effects on stream salinities. Part B covers other related research.

Research into the various diverse aspects of salinity are closely interrelated. These include: the effects of jarrah dieback, of various forestry practices, of mining, of parkland and strip clearing and reforestation; the performance of indigenous species and exotics in preventing salt leaching and in rehabilitation measures. Results obtained in one area are normally of relevance and value in a number of others.

Reforestation research is being carried out by CSIRO, Forests Department and the Public Works Department at a number of different sites in different rainfall zones of the Darling Range. Various planting arrangements covering between 20% and 100% of cleared areas are being studied to assess their effectiveness in lowering groundwater levels and thereby their effectiveness in reducing saline groundwater discharge to the surface stream system. Comparisons are being made between tree survival, groundwater level reduction and transpiration characteristics and growth rates of different tree species. Associated farming practices such as cutting hay between rows of young trees and grazing stock between more mature trees are also being evaluated. These studies are currently considered to provide the most likely long term solution to reducing stream salinities but because groundwater movement and tree growth rate are both relatively slow it will be some years before conclusive results can be drawn.

An important research study in progress is the joint CSIRO/Public Works Department project with five large scale experimental catchments in high and low rainfall areas of Wellington Dam Catchment. The purpose of this project is to study the effect of different degrees of clearing on the hydrologic cycle and measure the effect on stream salinity.

The Public Works Department, in collaboration with Mr H.S. Whittington of Brookton, is undertaking a trial at Batalling Creek on the Wellington Dam catchment to study the effectiveness of interceptor banks in controlling stream salinity. The trial was only started in July 1977 and is still in its early stages. However a first progress report has recently been issued (May 1979).

Two vital areas of research currently in progress are concerned with the effects of bauxite mining and of the woodchipping industry on water quality. Research in these areas is co-ordinated by State Government Inter-departmental Steering Committees. The effects of bauxite mining is studied in eight separate research projects and woodchipping in four more.

The eight research projects established to study the effects of bauxite mining on water resources include mathematical modelling (2), groundwater monitoring (2), mine site rehabilitation, a paired catchment study, streamflow salinity sampling and jarrah dieback studies. The results from all this research are published regularly and an overall report by the Steering Committee is published periodically, the latest being dated September 1978.

The four research projects concerned with woodchipping consist of the identification of areas vulnerable to salinity increase, monitoirng of groundwater, monitoring of stream water quality and a paired catchment study. Results of these are also published regularly and the most recent full report of the Steering Committee was published in April 1978.

FURTHER READING

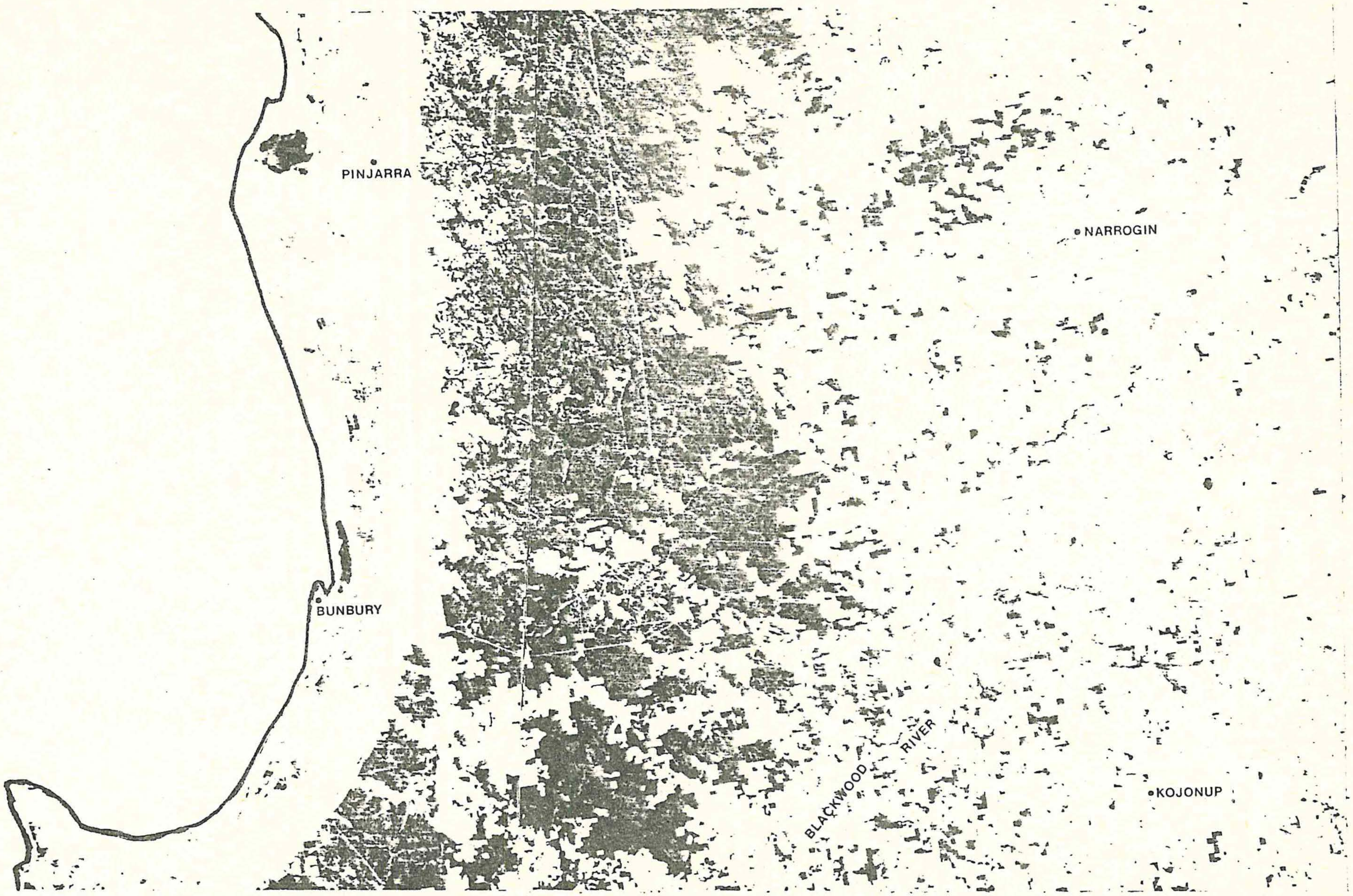
(1) HINGSTON F.J. and GALAITIS V. The geographic variation of salt precipitated over Western Australia. Aust. J. Soil. Res. 14, 319-35 (1976)

(2) DIMMOCK G.M., BETTENAY E. and MULCAHY M.J. Salt Content of lateritic profiles in the Darling Range, Western Australia. Aust J. Soil Res. 12, 63-9 (1974)

(3) DEPARTMENT OF CONSERVATION AND ENVIRONMENT OF WESTERN AUSTRALIA Land Management and Water Quality. A seminar on current research into the effects of land use on stream salinity and turbidity in South Western Australia. Cottesloe Civic Centre. Sept. 1976.

(4) PUBLIC WORKS DEPARTMENT OF WESTERN AUSTRALIA Investigation of the Whittington Interceptor System of Salinity Control - Progress Report May 1979. Water Resources Information Note.

(5) PUBLIC WORKS DEPARTMENT OF WESTERN AUSTRALIA Salinity and the Water Balance. Pamphlet Sept 1979 (in print).



SATELLITE IMAGE SHOWING FORESTED AREAS AND CLEARED AGRICULTURAL LAND

4.0 SURFACE WATER RESOURCES OF THE SOUTH WEST

The South West of Western Australia is mainly dependent upon the modest water resources of rivers and streams draining from the south western corner of the Western Plateau. It is estimated that surface water comprises 77% of the total water assessed as capable of diversion for public use. The source of the remaining 23% is the underground water of the coastal plain.

There is little prospect of supplementation from elsewhere. The South West is surrounded by agricultural and semi-arid, pastoral and mining areas to which it exports water through the Goldfields and Agricultural Area Water Supply Scheme and the Great Southern Towns Water Supply Scheme. Pumping water to the South West from the remote Kimberleys is never likely to an acceptable economic possibility. Order of magnitude estimates have shown that such a scheme would be at least 10 times the cost of desalination of sea water.

As a consequence of the growing level of demand for water and this isolation of the South West, it is important that the limited resources of the region be protected. The total mean annual discharge of all rivers of the South West amounts to 6100 x $10^6 m^3$. However only 2610 x $10^6 m^3$/annum of this total are divertible for water supply purposes and only 47% of these are fresher than 500 mg/l TDS.

Approximately 34%, or 890 x $10^6 m^3$/annum, of the divertible resources have already been degraded by clearing to salinities in excess of 1000 mg/l TDS. Considering the resources which remain fresher than 1000 mg/lTDS, only about 1250 x $10^6 m^3$/annum, or 48% of the total divertible resources are in shorter rivers wholly protected by forests. Some 530 x $10^6 m^3$/annum, or 20% of divertible resources are in an intermediate group of rivers. These intermediate rivers are a group almost entirely fresher than 1000 mg/l TDS, and are so situated that their quality would decline seriously if private land was mostly cleared.

The significance of the quality deterioration in South West rivers can be seen in perspective when it is appreciated that already some 25% of the divertible resources have been developed for use.

In general the quality of an individual river or stream depends on the location of its catchment area in relation to the regions of susceptibility (as shown in Figures 2 and 3) and the incidence of clearing in the salt susceptible low rainfall and intermediate regions. The distribution of State Forest in relation to these regions of susceptibility is of great significance to protection of the stream water quality. State Forest extends inland from the Darling Scarp to about the 800 mm or 700 mm rainfall isohyet.

Table 3 illustrates the association between rainfall, clearing and salinity for 20 major rivers of the South West which together comprise 59% of gross surface resources and about 73% of divertible surface resources. The surface resources excluded from Table 3 are mainly smaller streams draining from the high rainfall region and the coastal plain and in such cases would be fresh irrespective of clearing. The rivers of Table 3 have been divided into three categories.

Group 1 contains those shorter rivers which are afforded the protection of being mostly in State Forest with only limited portions, if any, in agricultural (largely cleared) areas in the less than 900 mm (low rainfall) region. The 9 rivers tabulated in this group are fresh and mainly below 250 mg/l TDS.

Group 3 on the other hand contains the rivers whose catchments extend well into the low rainfall region where considerable portions of their catchments have been largely cleared for agricultural purposes. The 6 rivers in this group are brackish to saline.

Group 2 are rivers which are intermediate in their penetration of inland areas and have suffered some salinity rise due to partial clearing. These rivers have not been lost as potable water resources, but if clearing of all private land was completed, then their quality would be seriously degraded to salinity levels which are marginal or unacceptable for public water supply. There are five rivers in this group with a total mean annual flow of $720 \times 10^6 m^3$ which represents 12% of the gross surface water resources and 20% of the divertible resources of the South West. Because their salinity situation is precarious, these rivers have been the main focus of recent initiatives to prevent salinity increase by the introduction of controls over catchment clearing.

TABLE 3

MAJOR RIVERS OF THE SOUTH WEST

		Catchment area above damsite		Furthest extent inland		Mean Annual Flow	Mean Annual Salinity Level
		km^2	%Cleared	km	Rainfall mm	$m^3 x 10^6$	mg/l TDS
1.	Brunswick	213	25	40	1 200	78	230
	Margaret	443	30	45	1 100	135	200
	Harvey	380	-	45	950	113	200
	Shannon	337	-	45	900	94	215
	Preston	603	40	60	900	97	250
	Donnelly	805	18	75	800	154	230
	Deep	1 250	15	85	700	172	200
	Serpentine	663	-	70	700	81	200
	Canning	754	-	70	700	65	400
2.	Denmark	650	16	55	750	44	570
	Collie	2 830	23	100	600	185	750
	Warren	3 890	33	140	550	365	725
	Kent	1 650	33	90	550	84	1 100
	Helena	1 470	2½	85	550	72	360
3.	Hay	1 400	70	65	600	71	2 000
	Kalgan	3 000	60	90	500	130	2 500
	Murray	6 840	70	170	450	351	1 800
	Frankland	5 800	60	150	400	183	1 700
	Blackwood	19 300	85	280	400	620	1 150
	Swan/Avon	119 000	75	500	250	418	5 000

FURTHER READING

(1) PUBLIC WORKS DEPARTMENT OF WESTERN AUSTRALIA.
The Usable Water Resources of Western Australia.
Interim Report, June 1977.

(2) PUBLIC WORKS DEPARTMENT OF WESTERN AUSTRALIA
Water Resources in System 6. May 1977

(3) SADLER B.S. Projected Future Balances of Water Resources and Demands. In Proceedings of A Seminar on Irrigated Agriculture on the Coastal Plain. Extension Service University of Western Australia. July 1977.

(4) PECK A.J. and HURLE D.H. Chloride Balance of Some Farmed and Forested Catchment in South Western Australia. Water Resources Research, Vol. 9, No. 3, June 1973.

(5) HAVEL J.J. The effects of water supply for the city of Perth, Western Australia, on other forms of land use. Landscape Planning 2: 75-132 (1975).

(6) FORESTS DEPARTMENT OF WESTERN AUSTRALIA
Managing Jarrah Forest Catchments
Forest Focus No. 19 November 1977.

(7) PUBLIC WORKS DEPARTMENT OF WESTERN AUSTRALIA.
The Salinity Problem of South West Rivers. Pamphlet Sept. 1979 (in print).

(8) PUBLIC WORKS DEPARTMENT OF WESTERN AUSTRALIA.
Water Use in Western Australia. Pamphlet Sept. 1979 (in print).

(9) PUBLIC WORKS DEPARTMENT OF WESTERN AUSTRALIA.
The Water Resources of the World and Western Australia.
Pamphlet Sept. 1979. (in print).

5.0 MEASUREMENT AND PREDICTION OF STREAM SALINITY

5.1 Data Collection

The measurement and assessment of the quantity and quality of surface water resources involves sophisticated systems of data acquisition and handling. Major variations occur in both the quantity and quality of streamflow through the year and between years. Drought periods or wet periods may extend over a number of years and during flood events rapid changes may occur within hours. Continuous monitoring of river flows in conjunction with frequent water sampling are therefore necessary over many years, before the characteristics of the flows down a river can be reliably assessed.

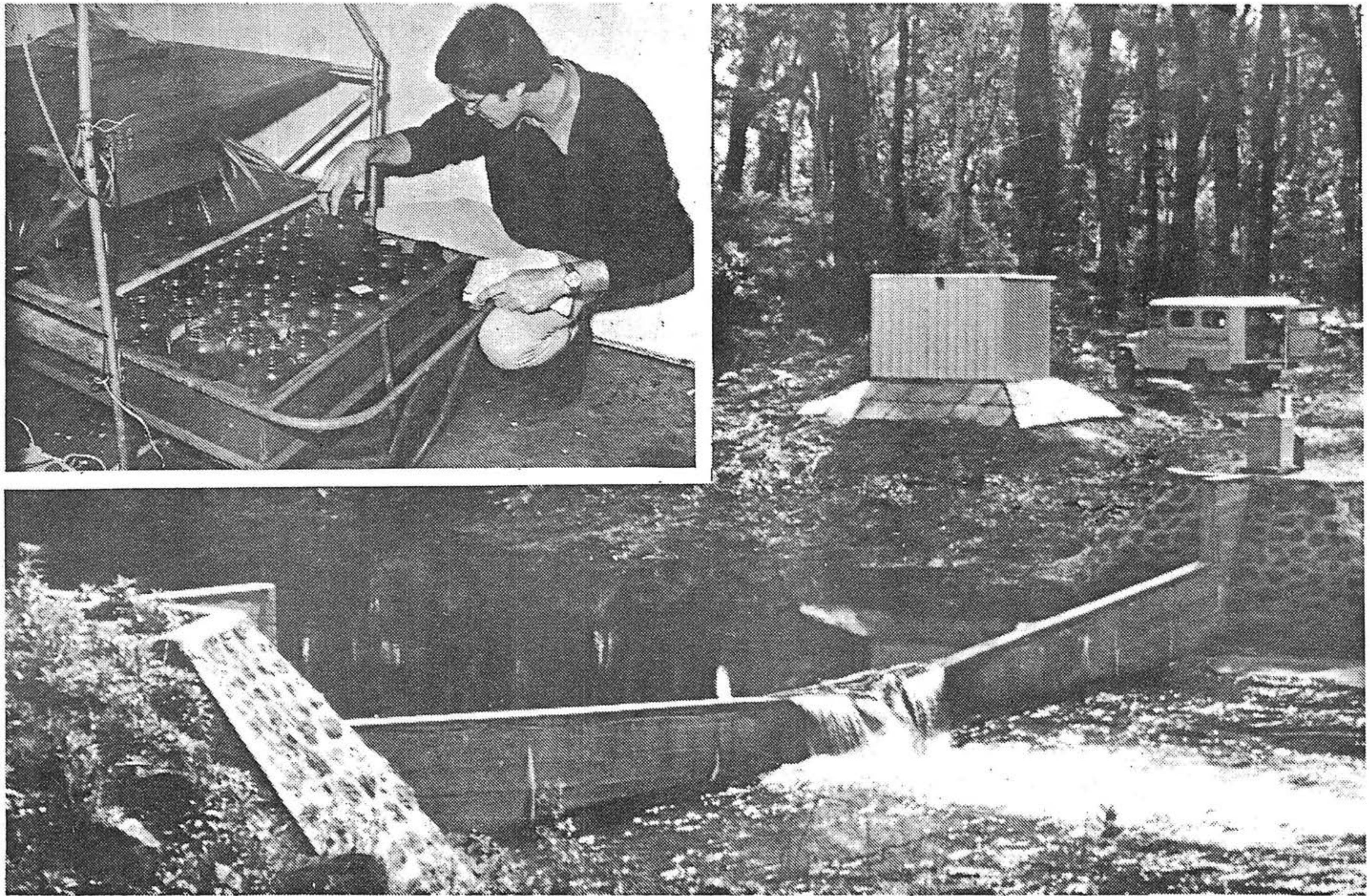
The Public Works Department has developed and operates an efficient system of water resources data collection which includes a computerised system of data storage and analysis. Currently some 300 gauging stations are operated throughout the State and several million items of rainfall, streamflow and water quality information have been collected and stored for water resources assessment.

The collection and analysis of these data over a long period of time has provided a reliable understanding of the effect of land clearing on stream salinity throughout the South West Region.

5.2 The Basis for Stream Salinity Assessment

Long term water quality data have formed the basis for observing the trends of increasing salinity in many of the south west rivers following the clearing of land for agriculture. Gauging stations which measure the quantity and quality of river flow clearly demonstrate the time trends of salinity increase and the changing salinity pattern as the rivers flow from the low rainfall zones through the high rainfall zone to the coast. The portions of these rivers which drain the inland agricultural areas have an average salinity in excess of 3000 mg/l TDS. As these rivers traverse through the higher rainfall regions closer to the coast their salinities decrease as a result of the fresher inflow from the forested catchments.

The streamflow records are complemented by an integrated programme of research projects which investigate and evaluate particular aspects of stream salinity in more detail. For example regional studies have been made of rainwater chemistry, soil salt storage and groundwater characteristics. In addition intensive studies have been made on small research catchments established to



A GAUGING INSTALLATION MEASURING RIVER FLOW AND SALINITY

The pumping sampler (insert) was developed by the PWD to automatically collect salinity samples.

study the effects of clearing and the comparison of groundwater levels between cleared and uncleared areas.

The data derived from long term records and research studies have demonstrated the following basic points which are relevant to assessment of the salinity hazard:

(i) Prior to clearing catchments show an approximate balance between the salts deposited on the landscape each year by rain or dust and the salts washed from the landscape each year by streamflow.

(ii) Following clearing in the low rainfall agricultural areas over twenty times the yearly input of salts can be discharged down the river system.

(iii) In the high rainfall region of the Darling Range the salts discharged by streamflow following clearing are only two or three times the yearly input and, the salinities generally remain below 200 mg/l TDS.

5.3 Stream Salinity Predictions

It has been clearly evidenced by measurement and research that the primary cause of the increase in stream salinity following clearing is an increase of groundwater flow which transports some of the salts stored in the soil to the surface stream system. The amount of additional salts leached from the landscape and therefore the increase in stream salinity depends on the areas cleared, on the quantity of additional water discharging from the groundwater system and, most importantly, on the quantities of salts stored in the landscape. For example, when salt storage is low, as in the high rainfall coastal margin of the Darling Range, the increased groundwater flow following clearing only carries small quantities of additional salts to the stream and therefore stream salinities are not significantly increased. In contrast, where salt storage is high the salinity of discharging groundwater following clearing can be extremely high and stream salinities can increase dramatically.

Groundwater salinity and soil salt storage are low in areas with average annual rainfall in excess of 1100 mm, but rapidly increase in areas of lower rainfall further inland. In areas with annual rainfall of between 800 and 900 mm salt storages are generally more than 15 times higher than salt storage in areas with rainfall in excess of 1100 mm. In rainfall areas between 600 and 700 mm salt storages can be over 50 times those in the high rainfall areas. Estimates of the additional groundwater flow following clearing have been based on observed rates of groundwater rise and calculation of catchment salt and water balances before and after clearing. The salinity of the additional groundwater flow has been based on drilling programmes which determine both the total salt storage and groundwater salinity. These have been complemented by data on base flow salinities in cleared areas. Using these data an averaged pattern of the additional salts and groundwater discharged per unit area of clearing for different rainfall zones of the Darling Range has been determined (Fig. 5). When considered with the information available on uncleared areas of private land, the rise in stream salinity as a result of clearing can be predicted.

This approach has been used to provide an estimate of the long term average salinity likely to develop as a result of further agricultural clearing. As noted earlier salinities vary dramatically around the average from year to year. In the case of the Collie River detailed studies of the variations in stream salinity have been carried out which have led to improved methods of operating Wellington Reservoir to minimise reservoir salinities.

FURTHER READING

(1) PUBLIC WORKS DEPARTMENT OF WESTERN AUSTRALIA
Streamflow Records of Western Australia to 1975.

(2) PECK A.J. Estimating the Effect of Land Use Change on Stream Salinity. Aust. J. Soil Res. 1975.

(3) PUBLIC WORKS DEPARTMENT OF WESTERN AUSTRALIA
Overview of the Computer System for Processing Water Resources Information
Water Resources Technical Report No. 82 Sept. 1978.

(4) PUBLIC WORKS DEPARTMENT OF WESTERN AUSTRALIA
Measurement of the Surface Water Resources of Western Australia. Pamphlet Sept. 1979 (in print).

6.0 THE COLLIE RIVER

The Collie River is one of the major water resources of the South West. Wellington Dam, constructed some 30 km inland, develops a yield of 102 million cubic metres per annum (Fig. 6).

The water from Wellington Reservoir represents about 25% of the total which is currently being provided for public water supply and irrigation purposes throughout the whole of the South West. This includes:- the Perth metropolitan supply; the irrigation schemes; the Goldfields and Agricultural Areas Water Supply Scheme, the Great Southern Towns Water Supply Scheme, as well as supplies for major regional towns such as Mandurah, Bunbury and Manjimup.

The Collie River has potential for further development to an estimated 150 million cubic metres per annum. At this full stage of development, the Collie River resource represents approximately 10% of the divertible fresh water supply potential of the entire South West.

The two main present users of water from Wellington Reservoir are the Great Southern Towns Water Supply and the Collie Irrigation District.

The Great Southern Towns Water Supply (G.S.T.W.S.) reticulates water for domestic, industrial and agricultural purposes to more than 30 inland towns and 600 000 hectares of farmland. Present annual consumption is approximately 8 million cubic metres.

The Collie Irrigation District is located on the coastal plain to the west. There are presently more than 6 000 hectares of irrigated land mostly used to grow pasture for dairy cattle, plus some land used to grow fodder crops, fruit and vegetables. The water allocation from Wellington Reservoir is 68 million cubic metres per annum.

The catchment extends from the high rainfall region through the intermediate region and with a large portion in the low rainfall region. Fortunately a large portion of this catchment is State Forest.

Most clearing of the Collie River catchment has taken place in relatively recent times. Of the total catchment area of 2 830 square kilometres above Wellington Dam, only 250 square kilometres (or 9%) had been cleared prior to 1960. An accelerated rate of clearing in the late 1950's and early 1960's gave rise to some concern and led, in 1961 to a ban on any further alienation of Crown Land within the catchment area. However, by this time approximately 1 000 square kilometres of 35% or the total area, had been alienated, and clearing was being undertaken at a sharply increased rate. By 1976 an area of 636 square kilometres or 22½% of the catchment had been cleared (Fig. 7).

It has been estimated that if the remaining 374 square kilometres of uncleared alienated land were to be cleared, the mean annual salinity level of the water flowing into Wellington Reservoir would rise from approximately 750 mg/l TDS to as high as 1700 mg/l TDS. It has also been estimated that, because of the delayed effect, even without any further clearing the level will continue to rise for about the next 20 years to somewhere in the region of 1100 mg/l TDS (Fig. 7). The water supplied from Wellington Dam over the last 2 dry years has been in the range of 840 - 880 mg/l TDS for water supply (from an upper level offtake) and slightly above 900 mg/l TDS for irrigation purposes (from the low level offtake).

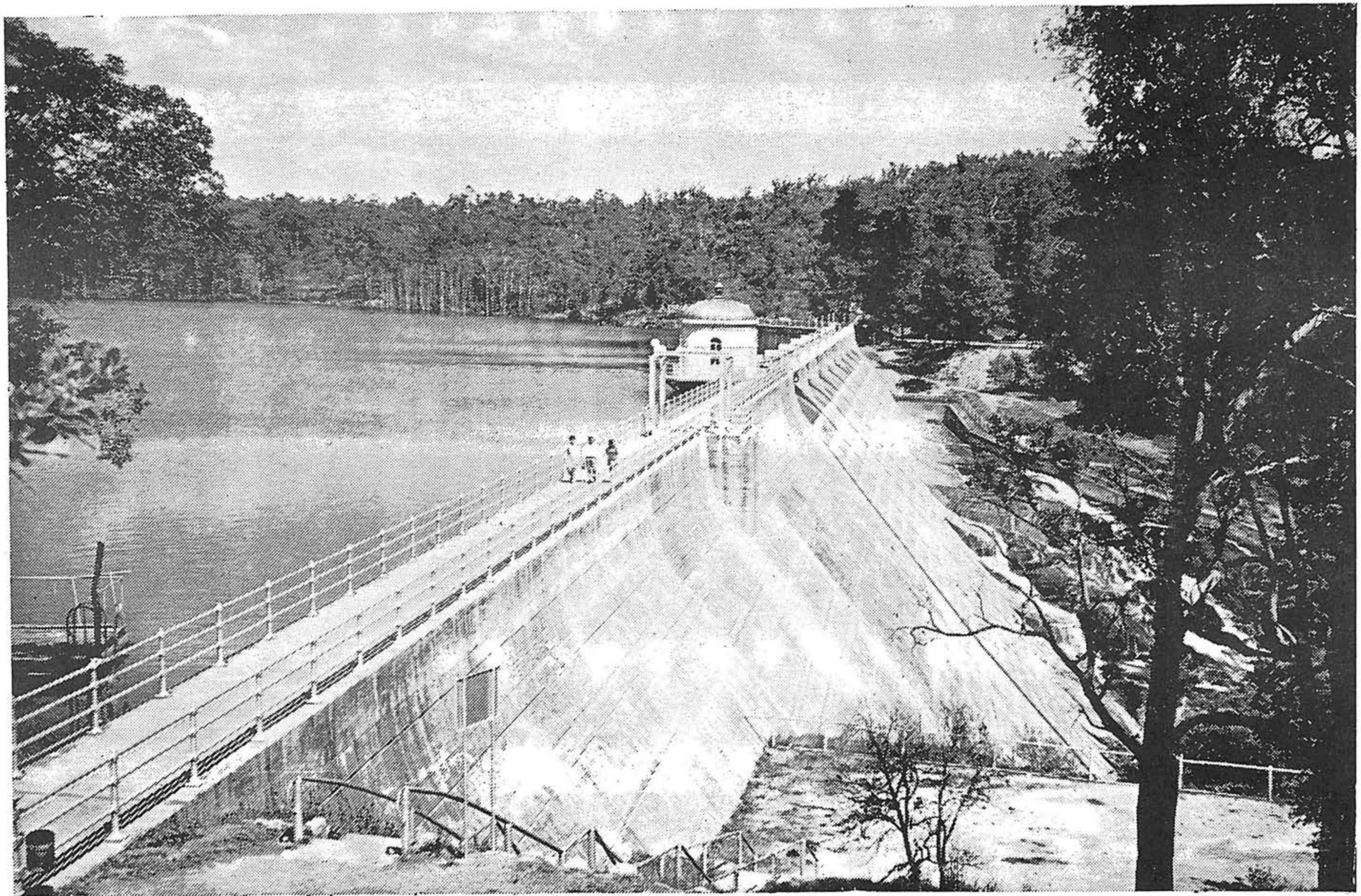
7.0 THE HELENA RIVER

The Helena River with a mean annual flow of 72 million cubic metres constitutes a fairly large resource. The river has been developed by means of Mundaring Weir and the Lower Helena Pipehead Dam which have been integrated with the Metropolitan Region storages to provide a yield of 29.5 million cubic metres per annum. The Mundaring System supplies water to the Goldfields and Agricultural Areas. The construction of another dam on the Upper Helena, would increase the yield of this river to approximately 50 million cubic metres per annum.

The Mundaring Weir catchment is located almost entirely in the low rainfall and intermediate regions (Fig. 8). A comparatively small portion of the catchment 75 square km (5%) of the total catchment area of 1470 square kilometres has been alienated and the remainder is State Forest. However, of the area alienated roughly half (38.6 square kilometres) remains uncleared.

The current mean annual salinity level of the run-off from the catchment area above Mundaring Weir is 360 mg/l TDS. Predictions are that if the remainder of the alienated land (38.6 km^2) were cleared salinity would rise to somewhere in the region of 700 mg/l TDS (Fig. 9). This is a large increase for a comparatively small (2½%) portion of the catchment.

Very little clearing has taken place on the Mundaring Weir catchment in recent years. However, the alienated uncleared areas remain a potential threat as it would obviously be most undesirable for such an increase in salinity level to occur and for this important resource to deteriorate. Also there is a widespread incidence of jarrah dieback disease and it is not known to what extent this might eventually affect salinity levels. Commencing in 1956, 12 600 hectares of private land have been progressively acquired by the Public Works Department on the Mundaring Weir Catchment for salinity control purposes.



MUNDARING RESERVOIR. THE SOURCE SUPPLYING THE GOLDFIELDS AND AGRICULTURAL WATER SUPPLY SCHEME

8.0 THE DENMARK RIVER

There is an existing pipehead dam on the Denmark River which provides the water supply to the town of Denmark. However this dam utilizes only a small portion of the mean annual flow of the Denmark which is over 44 million cubic metres.

The potential yield of the Denmark River is approximately 30 x $10^6 m^3$. While it is small compared with say the Warren, because of its location it is of importance to Albany and the lower Great Southern Water Supply. To achieve the yield the Denmark River could be developed at its present site or at alternative sites further upstream (Fig. 10).

The catchment area upstream of the pipehead dam is 650 square kilometres. Of this area approximately 150 square kilometres (23%) is alienated, and of this approximately 116 square kilometres have been cleared. Most of the alienated land is in the northern and north-eastern portion of the catchment, plus a small area immediately upstream of the existing dam.

There has been no further release of land on the catchment since 1956. However, clearing of alienated land has continued, but at a fairly slow rate. There remains 34 square kilometres of uncleared alienated land within the Denmark River catchment area.

Records from the P.W.D. gauging station No. 603 136 indicate that the present mean annual salinity level of the Denmark River is approximately 570 mg/l TDS. In comparison, gauging station No. 603 173, which is 25 km upstream, has a salinity level which is approximately 50% higher than the lower station. The recorded mean annual flow at the upstream station is 10.0 x $10^6 m^3$, from a catchment area of 285 km^2 which is at present approximately 28% cleared.

It is predicted that if all the uncleared land were to be cleared, the mean annual salinity level of the Denmark River would rise to 850 mg/l TDS. (Fig. 11). Without further clearing it is predicted that the salinity will rise to 640 mg/l TDS as a result of clearing recently carried out.

9.0 THE WARREN RIVER

The Warren River with a mean annual flow of 365 million cubic metres is the largest single source of potable water in the entire South West, and it could be developed to supply two and a quarter times as much water as at present supplied from Wellington Dam. Potential dam sites have been recognised on the Upper Wilgarup River, on the Upper Lefroy Brook, on Dombakup Brook and on the main Warren River to the South of Barker Road about 17 km upstream from the coast (Fig. 12).

The rainfall over the Warren River catchment varies between 550 mm at the upstream end in the Kojonup District to approximately 1400 mm in the vicinity of the main dam site. There has been an embargo on any further release of Crown land in the Warren River catchment area since 1977.

The current position of the Warren River with regard to salinity is very precarious. The mean annual salinity level has been rising steadily over the past 30 years according to the records of P.W.D. stream gauging station No. 607 220 which is located near the dam site, (as shown in Figure 13) and is at present 725 mg/l TDS.

The catchment area above the main river dam site is 3885 square kilometres; of this 1788 square kilometres (46%) is alienated and 1250 square kilometres (32%) has been cleared. Thus there is a further 538 square kilometres of uncleared alienated land, and it is predicted that salinity in the Warren River would rise to a mean annual level of 1400 mg/l TDS if all the alienated land was cleared.

A total of 216 square kilometres of the Warren River catchment was cleared between 1969 and 1977, representing an average rate of 27 square kilometres per year. It is predicted that inevitably the mean annual salinity level will continue to rise to approximately 1000 mg/l TDS as a result of clearing already completed.

10.0 THE KENT RIVER

The Kent River has a mean annual flow of over 84 million cubic metres and is a large resource which would have a good development potential. There are two recognized dam sites, one approximately 7 kilometres upstream, the other approximately 6 kilometres downstream of the junction between the Kent and Styx Rivers (Fig. 14).

In the catchment area upstream of gauging station No. 604 010 (1650 square km) approximately 1000 square kilometres (60%) is alienated. This is mostly in the northern area, which has low average rainfall. There has been no alienation of land in the Kent River catchment area since 1961. Of the area alienated only approximately 550 square kilometres (55%) has been cleared i.e. approximately 33% of the catchment. Thus there remains approximately 450 square kilometres of uncleared alienated land. Aerial photographs show that clearing has taken place at a rate of approximately 12 square kilometres per year over the last decade.

Future salinity levels for the Kent River are difficult to predict. The present estimated mean annual level of 1 100 mg/l weighted average TDS has the river just entering the brackish category and any further clearing of alienated land will cause the situation to further deteriorate. It is predicted that if the remaining alienated land was cleared, the salinity level would rise to somewhere in the vicinity of 2 500 mg/l TDS.

The Kent River is strategically located in relation to Albany and the lower Great Southern Water supplies and protection of its quality is essential so that blending with the Denmark River in the future remains feasible.

11.0 ALTERNATIVE SALINITY CONTROL MEASURES

Although often described in simple terms the salinity problem and solutions to the problem are very complex. A combination of a number of actions will be necessary to successfully manage the salinity problem in the South-west rivers. These actions may be classified as follows:-

(i) Prevention of further salinity rise;

(ii) Restoration of rivers to lower salinities;

(iii) Adaptation to the increased river salinities.

In practice any one or a combination of these actions could be appropriate.

11.1 Prevention

The only certain method presently available of preventing an increase in stream salinity is to avoid any permanent clearing of native vegetation from sections of a catchment where there is a high salt storage in the soil. Had this practice been followed in earlier years of the State's development there would now have been greater reserves of fresh water available. However, complete prevention would have led to curtailment of the agricultural industry on which the region's development was largely based.

Preventive measures currently feasible for control of further salinity increase in rivers are:

(i) Imposing constraints on the further alienation of forested Crown land.

(ii) Control of further clearing on Crown and alienated land.

The first of these measures above would not achieve sufficient control to prevent serious salinity increases in rivers of Group 2. Table 4 summarises the predicted effects on these rivers if Crown land is protected from further clearing and clearing allowed to continue on private land.

TABLE 4

RIVERS IN THE INTERMEDIATE GROUP

River	Land Uses in Catchment			Av. Salinity Total Dissolved Solids	
	Forest %	Private Land %			
		Uncleared	Cleared	Present	Future if all Private Land Cleared
Denmark	79	5	16	570	850
Collie	65	12	23	750	1700
Warren	54	14	32	725	1400
Kent	40	27	33	1100	2500
Helena	95	2.5	2.5	360	700

Clearing control for prevention of salinity rise does not mean a permanent ban on all further clearing. However it does mean that as far as possible extensive clearing within critical catchments would be limited to areas with little or no salt susceptibility at least until such time as alternative preventive measures can be found and proven.

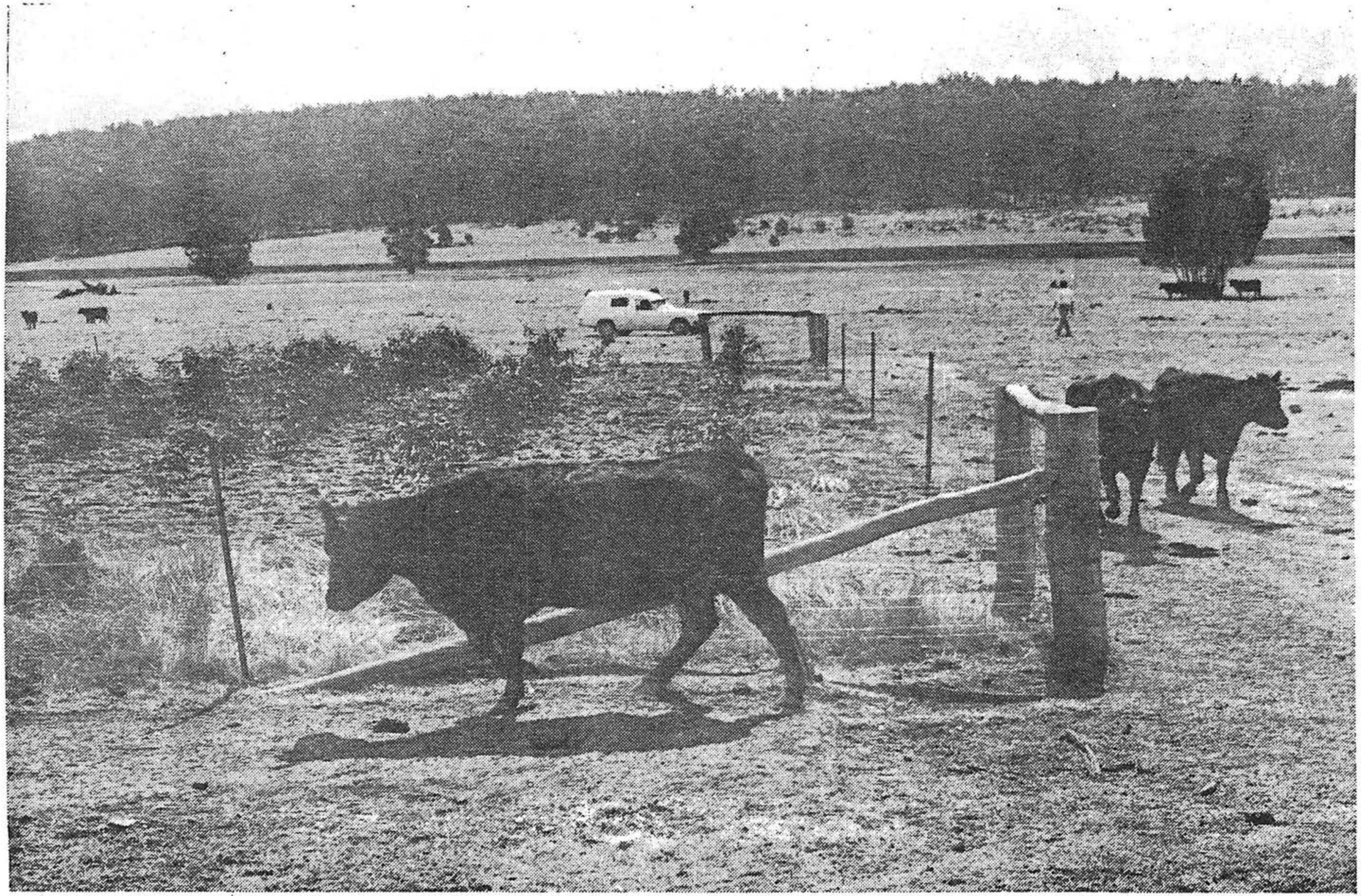
11.2 Restoration

All forms of restorative measures are designed to reduce the release of salts into streams affected by clearing, and involve catchment management practices which try to readjust the sub-surface water balance.

On present knowledge the form of restoration most likely to prove successful, is some form of reforestation. Reforestation may not achieve complete reversal of salinity but the benefit will be substantial. Also reforestation is a slow process and it will be many years before benefits will be fully observable.

The extent to which it may be necessary to reforest land that has been cleared in order to reverse the salt leaching process is not known with any degree of certainty. Various estimates have put the figure at somewhere between 10% and 40% or even higher. Possible styles of planting include parkland, block and strip. Planting in wide strips on the low slopes parallel to water courses is likely to be a basic first step with additional block planting at intake areas on the upper slopes a possibility. A variety of tree species are being considered for reforestation. The planting of commercially productive tree species will be investigated and hopefully some can be used.

Research into many aspects of reforestation is currently in progress. The results of such research will complement the experience to be gained from the large scale pilot scheme being planned for the Wellington Dam catchment (see Section 12.0 below).



WELLINGTON DAM CATCHMENT REFORESTATION

Other restorative measures involving modified farming practices and Whittington interceptor drains have been suggested and are being studied. None of these measures have developed sufficiently to justify their use for controlling stream salinity at present.

11.3 Adaptation

Prevention and restoration of the catchment situations which cause river salinity, will not completely control the problem in South West rivers. Therefore as the need for further water continues to increase, means must be sought for adapting water supply systems to the best use of what resources are available.

Adaptation to increased river salinity could mean acceptance of some deterioration in supply quality. Adaptation also could involve engineering measures which in most cases will be costly and which are likely to involve a partial loss of the water resource. Complete abandonment of the resource is the last resort in adaptation, but is all that may be feasible for certain very brackish rivers.

A range of engineering measures intended to adapt to river salinity are possible. These measures include reservoir management by the release of the more saline layers that form in the reservoir as it is filled. Also, diversion of saline headwaters, blending of fresh and brackish waters and desalination have been considered.

Diversion of the saline headwaters of the Collie River has been given preliminary consideration and was indicated as a costly solution. A number of engineering and environmental difficulties were also indicated. Broadly speaking diversion of the entire headwaters of a river would be costly and wasteful of resources whereas diversion of small flows, although cheaper, appears likely to have limited benefit. Small diversions are more likely to be supplementary to clearing control rather than providing an alternative. When considering diversion schemes one of the environmental questions which arise is the acceptability of using another river as a salt drain. Further investigations are necessary to determine the engineering feasibility of diversions and confirm or disprove their presently indicated costs. Such investigations are being planned and will give consideration to the Collie, Warren and Kent rivers. Hydrologically the schemes would be quite complex and the investigations are expected to require some years to reach a conclusive assessment.

Desalination to restore the quality of a large volume of water is a very costly process, both in purely economic terms and in energy requirement. Other disadvantages are that it entails some loss of resource (approximately 15%) through blowdown and this in turn presents problems of disposal, both economic and environmental. Economically, desalination is one of the last resort measures.

At the present time, reservoir management and blending are being carried out with some small benefits and other engineering measures are possibilities for the future.

In irrigation some adaptation to the effect of increased salinity levels is possible by the use of larger volumes of water, by more frequent applications and by the selection of only the more porous soils for irrigation purposes. In some cases the installation of sub-surface drains could be advantageous though this is very costly and only likely to be economic in the production of very high value crops. The choice of more salt tolerant species is another possible measure.

Adaptation in domestic use is limited to the passive acceptance of lower standards in terms of taste, and in the small but not negligible costs inherent in the accelerated deterioration of pipes, tanks and domestic appliances.

12.0 ACTION TAKEN

The salinity problem is a very serious one and one that will certainly have a far reaching effect on the future of the State. The problem has been recognized since early this century when, following a programme of ringbarking on the Mundaring Weir catchment in an attempt to increase the water yield after two consecutive dry years in 1902-3, an increase in salinity was reported. However, up until the early 1960's the clearing of land for the development of the State's agricultural industry was considered of primary importance. Only in recent years has the balance shifted and the protection of what remains of the region's limited water resources has become of primary concern.

In addition to the establishment of research and monitoring programmes the following significant actions with respect to the management of the salinity problem have been taken:

(i) In 1961 a ban was placed on further alienation of Crown Land in the Collie, Denmark and Kent River catchments.

(ii) Between 1956 and 1973 the Public Works Department acquired 12 600 hectares of alienated land on the Mundaring Weir catchment for salinity control purposes. This land is being progressively replanted by the Forests Department.

(iii) In 1976, the Public Works Department acquired Stene's farm on the upper Collie Catchment. This is a 4500 hectare property, of which 1500 hectares had been cleared. Trials are being undertaken on the cleared section of this property to study reforestation and agro-forestry techniques and their effectiveness for controlling salinity.

(iv) As a result of a research study carried out by the University of W.A. with assistance from the Public Works Department and the Australian Water Resources Council, the stratification phenomena of Wellington Reservoir have been analysed. Making use of the results of these investigations the Public Works Department initiated a programme of releasing the more saline water at times prior to the irrigation season when the reservoir is suitably stratified. This programme has been operating since

TAKING SALINITY MEASUREMENTS ON WELLINGTON RESERVOIR the winter of 1976 and has had a small but positive effect in reducing the build up of salinity in the reservoir. The overall reduction in salinity is about 10%, though to achieve this a 20% loss of yield has been the necessary cost.

(v) In 1976 legislation was enacted to introduce clearing control over the Wellington Dam Catchment Area. Details of the legislation are given in section 13.0.

(vi) In 1978 the control over the release of Crown Land was extended to include all river basins of the South West Region, from the Collie River through to the Denmark River.

(vii) In 1978 legislation was enacted to extend clearing control to four more catchments in the South West: Mundaring Weir Catchment Area; Denmark River Catchment Area, and the Warren and Kent River Water Reserves.

(viii) A programme of reforestation of the Wellington Dam Catchment area is being planned and financial assistance from the Commonwealth Government is being sought. It is proposed that planting will be carried out over a 10 year or longer period and the planting rate will be built up to approximately 2000 ha per year after the first 3 or 4 years. Planting will be undertaken on land acquired through the clearing control compensation process, and on additional land purchased on the open market. Planting under this programme commenced in 1979.

(ix) All Government Departments and Instrumentalities are aware of the effects of clearing in salt sensitive zones and make every endeavour to minimize all clearing activities. Their activities are subject to the provision of the Country Areas Water Supply Act. When clearing is necessary for essential services such as power lines, all licenses are issued on the basis of an equivalent area of cleared land being acquired and reforested.

FURTHER READING

(1) PUBLIC WORKS DEPARTMENT OF WESTERN AUSTRALIA
Collie River Salinity Control, April 1979.

(2) IMBERGER J., PATTERSON J., HEBBERT R. and LOH I.
Simulation of the Salinity Structure in a Reservoir of Medium Size. A.S.C.E., Hydraulics Division. Vol. 104, No. HT5 Proc. Paper 13773, May, 1978 pp 725 - 743.

(3) LOH I.C. and HEWER R.A. Salinity and flow simulation of a catchment reservoir system. Institution of Engineers, Australia. National Conference Publication No. 77/5, pp 192-3.

(4) FORESTS DEPARTMENT OF WESTERN AUSTRALIA
South West Agro-Forestry.
Forest Focus No. 20, April 1978.

13.0 CLEARING CONTROL LEGISLATION

13.1 Summary of Statutory Provisions

In 1976, in view of the continued clearing on the Wellington Dam catchment, the predicted resulting increase in salinity and the lack of any suitable alternative course of action, the Government introduced legislation to control clearing by means of an amendment to the Country Areas Water Supply Act. The amending Act (No. 81 of 1976) was passed by Parliament without opposition, and became law at proclamation on November 15 of that year.

Subsequently in 1978, because of the serious salinity position of the Helena, Denmark, Warren and Kent Rivers (as outlined in Sections 7.0 to 10.0) and the importance of these water resources for the State's future development, the Government acted on the recommendations of the Western Australian Water Resources Council and introduced a further amendment to the Country Areas Water Supply Act. This amendment, simply extended to these four rivers the same clearing control provisions as the 1976 Amendment had introduced for the Wellington Dam Catchment Area. The Amendment (No. 95 of 1978) was passed by Parliament without opposition and became law at proclamation on December 15, 1978.

In summary the legislation provides that:-

(i) A person who causes or permits the indigenous undergrowth, trees or bush on land within the boundaries of a declared Catchment Area or Water Reserve to be removed, destroyed or damaged (so as to eventually be destroyed) commits an offence, unless the clearing is under, and in accordance with the conditions of a clearing licence.

(ii) Any person guilty of an offence is liable to a fine not exceeding one thousand dollars and is required to reforest the land.

(iii) Application for a clearing licence is made to the Under Secretary of the Public Works Department.

(iv) The Under Secretary may refuse any application to grant, renew or transfer a clearing licence, and is required to do so where the clearing would result in less than one tenth part of the land in question being left under indigenous vegetation.

(v) Any person who is aggrieved because a licence to clear was not granted or who has had a licence revoked or suspended or has had any unacceptable conditions imposed in relation to a licence, has the right of appeal to the Minister.

(vi) Where an application for a clearing licence is refused or is granted subject to conditions that are unacceptable to the applicant, the applicant may claim compensation for injurious affection.

(vii) A claim for compensation under the Act may extend, not only to the land which was the subject of the application for a clearing licence, but also to any other land in the same occupation or ownership which is shown to have been rendered unproductive, or uneconomic, or to have been otherwise injuriously affected, by the operation of the Act, and whether or not that land is situated within the catchment area.

(viii) If the Public Works Department and the owner fail to agree as to whether any land, or any estate has been injuriously affected or as to the amount of compensation, the dispute shall be determined by arbitration under and in accordance with the Arbitration Act, 1895, unless the parties agree on some other method of determination.

13.2 Payment of Compensation

Compensation is made in one of the following forms, the choice being mainly dependent upon the wishes of the owner:

(i) A lump sum cash payment.

(ii) The exchange of the uncleared area of land for a cleared area of land of comparable value to the compensation considered due.

(iii) The purchase of the uncleared area of land by the Public Works Department.

(iv) The purchase of the entire holding by the Public Works Department.

13.3 Zones and Guidelines

For the purposes of better management of the catchments they have been divided into four separate zones having decreasing stringency of controls. The zones correspond to areas of diminishing salt hazard which can be closely related to the rainfall isohyets, but their positioning has accepted higher risks in the intermediate regions (see Section 3.2) of the three southern catchments than for the Collie (Wellington Dam) and Helena (Mundaring Weir) catchments.

These zones and the clearing policies within them may be altered at any time when investigative results indicate desirable refinements. The zones are shown for each Catchment Area and Water Reserve in Figures 6, 8, 10, 12 and 14.

ZONE A Zone A comprises the inland portions of the catchments located in the low rainfall region. The salinity hazard is uniformly high throughout this zone and it therefore requires maximum protection. No broad scale clearing for farm development purposes will be licenced within this zone.

ZONE B Zone B comprises the inland half of the intermediate region in southern catchments but has been located more to the western side of the intermediate region of the Mundaring Weir and Wellington Dam catchments. The control in this zone has been made slightly less restrictive than in Zone A. Licences to clear up to 10 ha (cumulative from December 15, 1978) will be granted and applications for up to a further 10 ha will be favourably considered depending on the location of the property.

ZONE C Zone C comprises the other half of the intermediate region in southern catchments and somewhat further to the West in the Wellington Dam catchment. This zone is less susceptible to to salinity but is not entirely free of risk. Licences will be granted to clear up to 25 ha (cumulative). Applications for larger amounts will normally be given favourable consideration after various aspects associated with the particular property have been assessed.

ZONE D Zone D comprises the portion of the catchment in the high rainfall region with little or no susceptibility to salt leaching. Zone D in the Wellington Dam catchment comprises the area of the Collie Coal Basin. The area of deep sandy soil is known to have little or no salts in storage, and is not a salinity risk.

Licences for clearing will normally be granted in Zone D, subject only to the statutory limitation that 10% of the holding remains uncleared.

The zoning as briefly outlined above was introduced in March 1979 following two years of experience in developing effective working arrangements for the Wellington Dam Catchment Area. The catchments of the Warren River and Collie River contain sections in all four zones. The Kent River and Denmark River catchments include areas in Zones A, B and C, but in both cases there is no alienated land in Zone B. The Mundaring Weir catchment area contains only Zones A and B. Essential items of clearing such as for fencing, fire breaks, dam construction etc. will be licenced in all zones.

FURTHER READING

(1) Country Areas Water Supply Act Amendment Act No. 81 of 1976.

(2) Country Areas Water Supply Act Amendment Act No. 95 of 1978.

(3) Country Areas Water Supply Act - Regulations.

(4) PUBLIC WORKS DEPARTMENT OF WESTERN AUSTRALIA
Country Areas Water Supply Act 1947-1978. Guidelines for the granting of licences to clear indigenous vegetation. March 1979.

14.0 SUMMARY

Agricultural development on river catchments and the conservation of fresh water resources are conflicting objectives in the medium and low rainfall areas of the South West. For many decades the community has accepted that severe deterioration in the quality of some of the major rivers of the South West was the price that had to be paid for the development of the agricultural industry on which the State's economy had largely depended.

However, approximately 36% of the surface water of the South West is now so affected by salinity that it can no longer be considered useful for domestic, industrial or agricultural purposes. Therefore, while the agricultural industry is of vital importance to the State, it has obviously become necessary to protect those remaining water resources which are still of value.

In the case of the short rivers it has been sufficient to strictly control any further alienation of Crown Land. If all the remaining uncleared alienated land in the catchments of these rivers were to be cleared it would have a minor deleterious effect on salinity levels, but would not be sufficient to raise them above 500 mg/l TDS on a mean annual basis.

With the longer rivers, such as the Avon, Blackwood, Hay and Frankland, a large percentage of each catchment has been alienated, and most of it is cleared so that salinity levels are already very high, being in brackish or saline categories. Since clearing control would only have a very limited beneficial effect, its introduction has not been considered to be justified.

In the case of the five intermediate length rivers namely the Collie, Helena, Denmark, Warren and Kent, it was necessary to introduce control of clearing over all land within the catchment areas of these rivers. The first three listed in this group are already being utilized for water supply purposes, and all five are regarded as being of great importance to the State's development in the long term.

Unfortunately some farmers have been seriously affected, particularly those whose properties were not in an advanced stage of development when the clearing controls were introduced. While it has been possible to compensate financially for injurious affection, it is not practical to offset all the social inconveniences. However, the payment of compensation at least spreads the financial burden of protecting the State's water resources over the whole community.

There is little prospect of any early relaxation being made on clearing controls. Research and large scale trials (such as reforestation on the Wellington Dam catchment) will determine how and to what extent trees in the landscape are necessary to control salinity. Studies on other methods of salinity control will also contribute. The other methods include reservoir management, the Whittington interceptor drain system and engineering solutions such as saline diversion. These studies will also determine to what extent an area of indigenous vegetation can be cleared without causing excessive salination of water supplies.

The basic causes of the salinity problem are well understood. However the processes are highly complex and research and detailed investigation will be required for a long time to develop new and more refined management techniques.

The extent to which stream salinity can be controlled is of very great importance to the future of the State. Important steps have now been taken to conserve what remains of the limited surface water resources of the South West.

APPENDIX

CURRENT RESEARCH INTO THE SALINITY PROBLEM

A. RESEARCH RELATING TO AGRICULTURAL CLEARING AND ITS EFFECTS ON STREAM SALINITIES

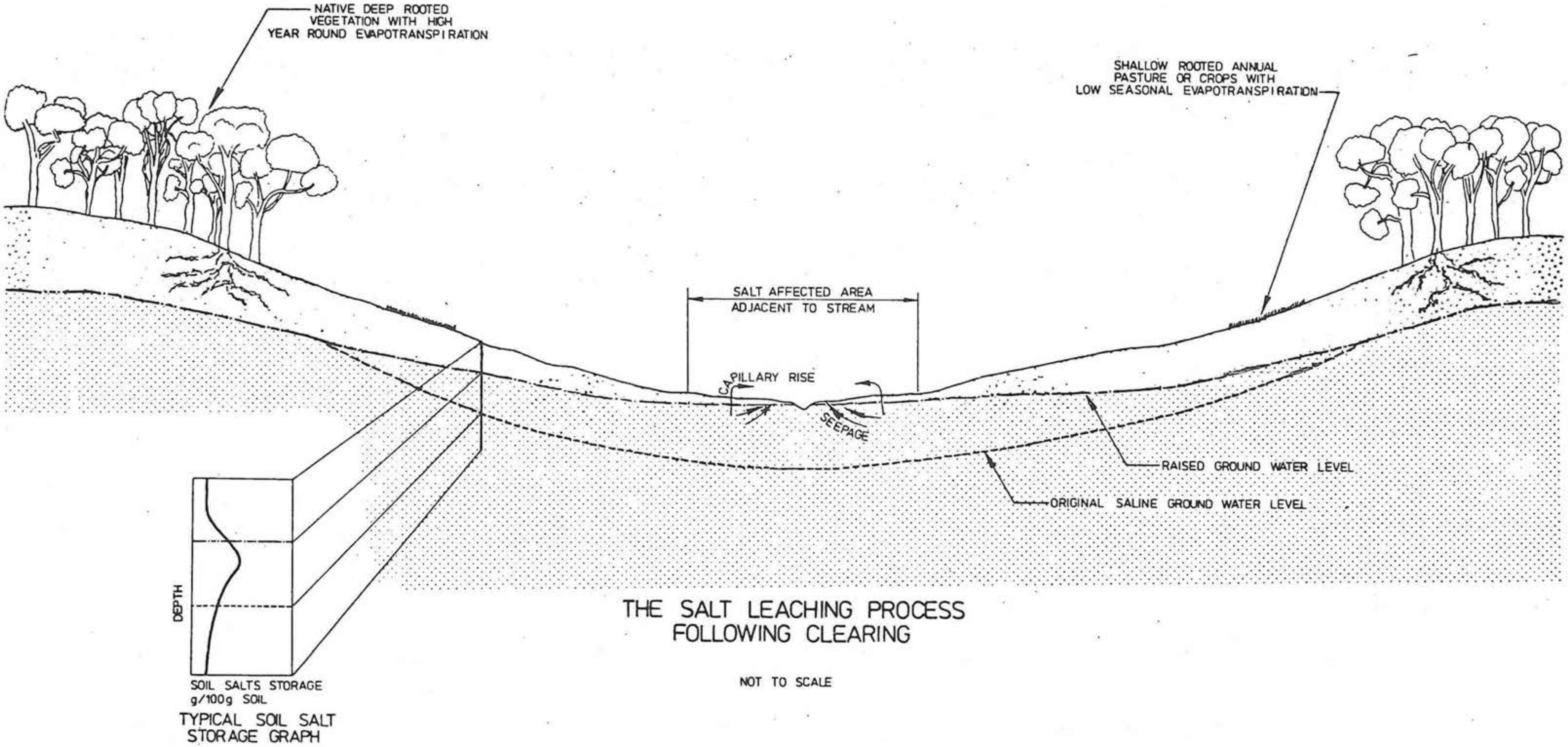
	Primary Authorities Involved	Assisting Authorities
1. HYDROLOGICAL RESEARCH INTO THE PROCESSES CAUSING THE PROBLEM		
1.1 Bakers Hill Experimental Catchments. A paired catchment study involving stream gauging and groundwater monitoring.	CSIRO	PWD
1.2 Collie Experimental Catchments. A detailed study involving 5 catchments in which complete salt and water balance calculations are being carried out and some clearing strategies are being investigated. Salt budgets of specific trees are being investigated in conjunction with the various clearing strategies.	CSIRO/PWD	Forests Agriculture Mines
2. RESEARCH RELATED TO REHABILITATION OF SALT AFFECTED STREAMS		
2.1 Agro-Forestry Trials. Mundaring Catchment Productivity trials of combined agricultural and forestry operations in the same area of land. Groundwater monitoring of areas reforested upslope from salt affected land.	CSIRO/Forests	PWD
2.2 Stene's Farm - Partial Reforestation. Trial reforestation of cleared areas which already have a salinity problem using different tree species. Groundwater monitoring and measurement of the salt affected area. Transpiration measurement of wandoo regrowth and adjacent pasture.	PWD/Forests	Mines CSIRO Agriculture

	Primary Authorities Involved	Assisting Authorities
2.3 Murray River Reforestation Trials. Reforestation trials upslope from salt seeps in 3 rainfall zones of the Murray River catchment. The growth rates and water use of different tree species and groundwater levels are under detailed measurement.	CSIRO	-
2.4 Bakers Hill - Agro-Forestry Trials. Productivity trials of agricultural and forestry practices. Tree survival and growth rates on salt affected land.	CSIRO	-
2.5 Surface Drainage Trial. The value of a system of interceptor drains desiged by Mr H.S. Whittington for improving the salinity of streams draining agricultural land is being studied on the Collie catchment.	PWD	Agriculture
2.6 Species Screening Trial. Screening of different species with a high tolerance to saline water.	CSIRO	-
2.7 Agricultural Treatments. A series of projects primarily directed to salt affected land rather than stream water quality, usually involving planting of salt tolerant grasses, shrubs or trees.	Agriculture	-

B. RESEARCH RELATING TO THE SALINATION OF STREAMS OTHER THAN THAT DIRECTLY ASSOCIATED WITH AGRICULTURAL CLEARING

		Primary Authorities Involved	Assisting Authorities
1.	EFFECTS OF BAUXITE MINING ON WATER QUALITY		
1.1	Hunt Steering Committee Research. A total of eight projects designed to research in detail the effects of actual mining and rehabilitation on water supplies.	MWB, Forests Mines, PWD, Agriculture Environment University of W.A., CSIRO, D.I.D.	
1.2	Del Park Research Catchment. A catchment study of both the surface and groundwater changes caused by Bauxite mining.	CSIRO	PWD.
2.	EFFECTS OF THE WOODCHIPPING INDUSTRY ON WATER QUALITY		
2.1	Four projects designed to monitor and study the effects of cutting and rehabilitation by the woodchip industry, on water supplies.	PWD, Forests Mines Agriculture Environment MWB, DID CSIRO.	PWD
3.	EFFECTS OF FOREST MANAGEMENT ON WATER QUALITY		
3.1	Mundaring Catchment Experiments involving stream sampling and small research catchments to study the effects of heavy logging operations in salt sensitive areas.	Forests	PWD

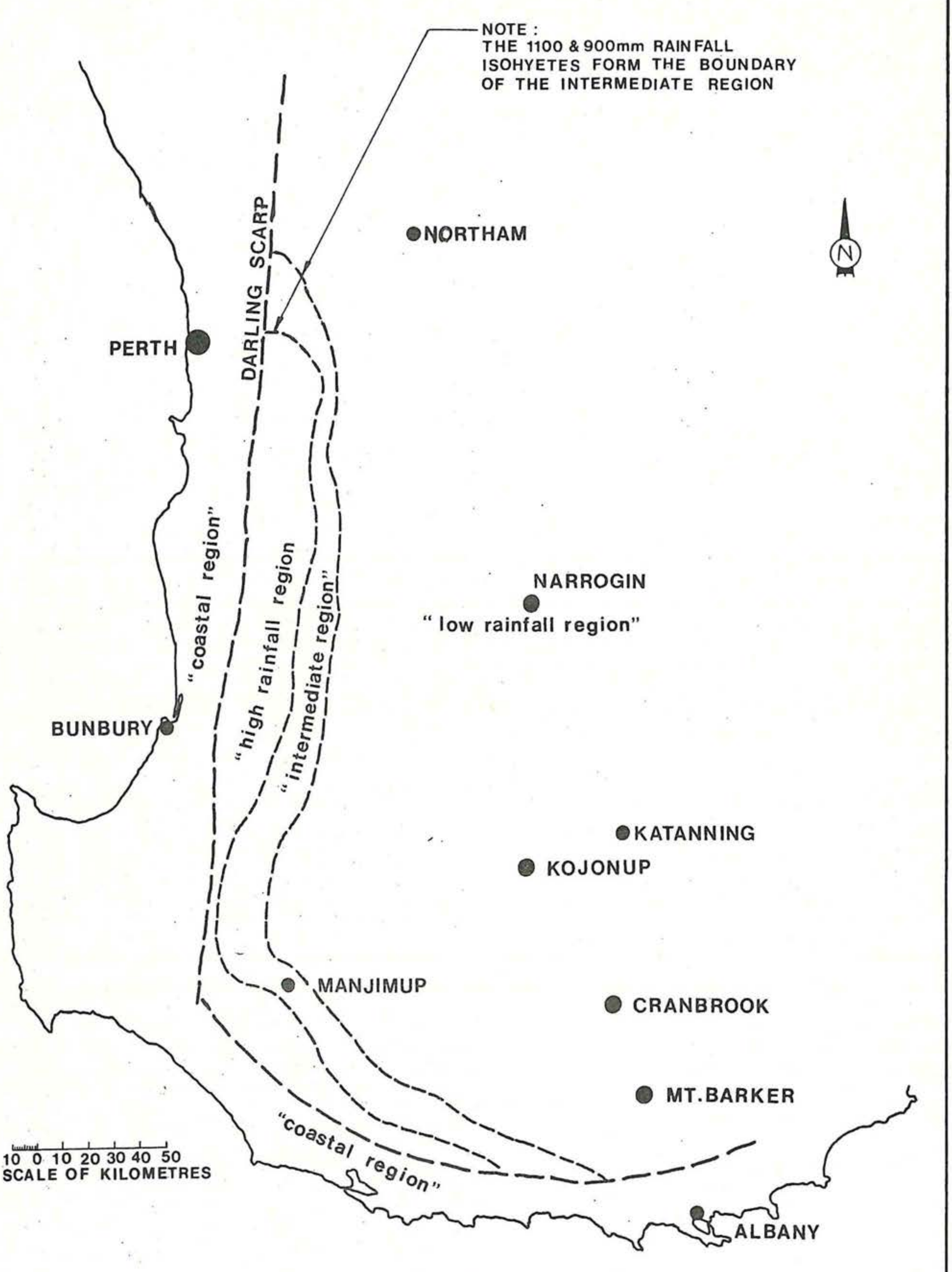
		Primary Authorities Involved	Assisting Authorities
3.2	Murray Catchment. Studies involving the effects of different forest thinning operations on the yield and salinity of streams.	Forests	PWD
3.3	Sunklands. The effect of conversion of native forest to pines on flow and salinity in the Donnybrook Sunklands.	Forests	
4.	IMPORTANT RELATED STUDIES		
4.1	Studies of the Salt Content in Soil Profiles.	Forestry CSIRO PWD	Mines
4.2	Evpo-transpiration Studies	CSIRO	
4.3	Salt Content in Rainfall	CSIRO	
4.4	Salinity and Temperature Stratification of Reservoirs	University of W.A.	PWD



THE SALT LEACHING PROCESS FOLLOWING CLEARING

NOT TO SCALE

FIGURE 1



AREAS OF SALINITY POTENTIAL IN THE SOUTH WEST

FIGURE 2

RIVER CATCHMENTS IN THE SOUTH WEST

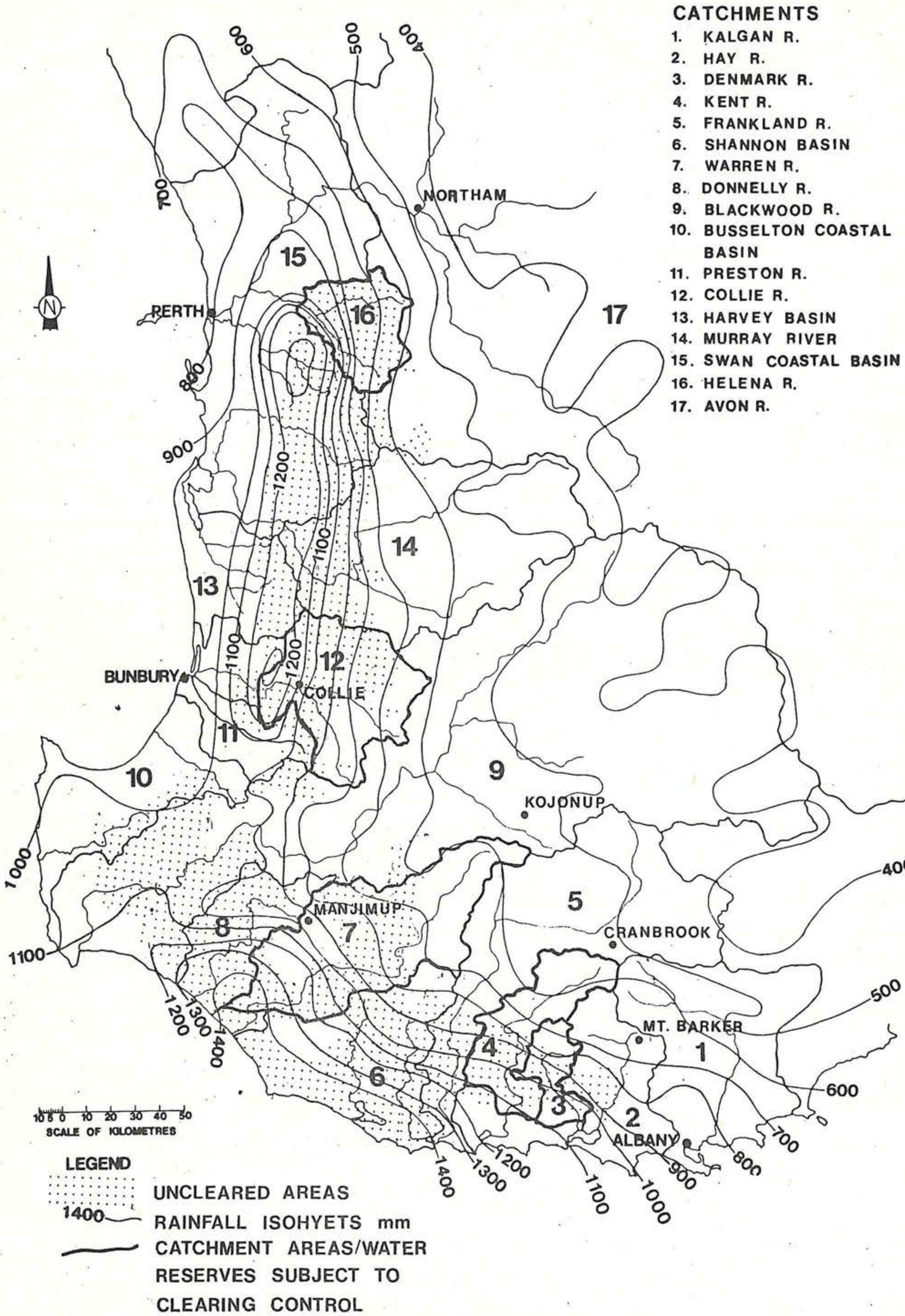


FIGURE 3

DIVERTIBLE SURFACE RESOURCES

(2610 MILLION CUBIC METRES PER YEAR)

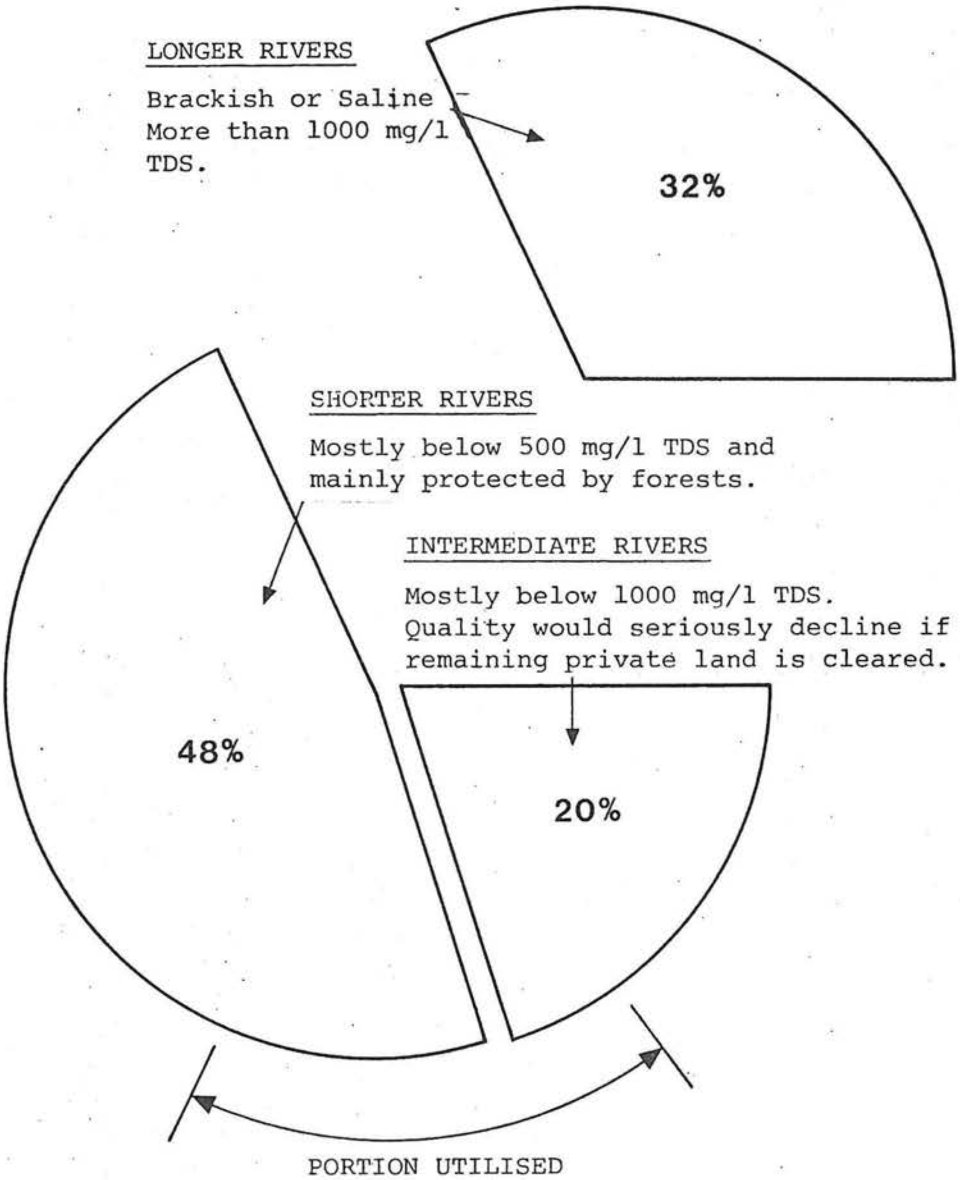


FIGURE 4

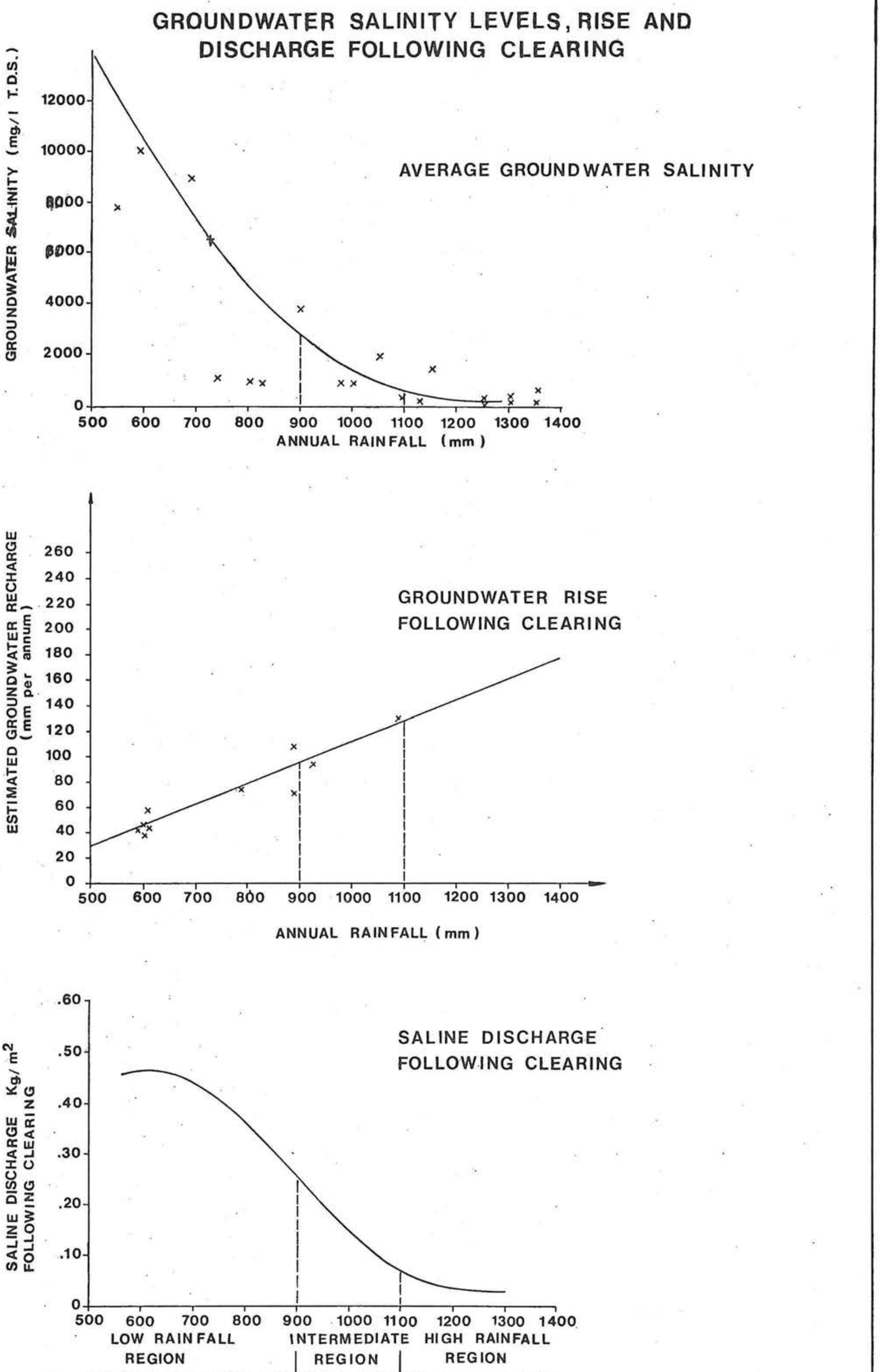

GROUNDWATER SALINITY LEVELS, RISE AND DISCHARGE FOLLOWING CLEARING
AVERAGE GROUNDWATER SALINITY
GROUNDWATER SALINITY (mg/l T.D.S.)
12000
10000
8000
6000
4000
2000
0
500 600 700 800 900 1000 1100 1200 1300 1400
ANNUAL RAINFALL (mm)
GROUNDWATER RISE FOLLOWING CLEARING
ESTIMATED GROUNDWATER RECHARGE (mm per annum)
260 240 220 200 180 160 140 120 100 80 60 40 20 0
500 600 700 800 900 1000 1100 1200 1300 1400
ANNUAL RAINFALL (mm)
SALINE DISCHARGE FOLLOWING CLEARING
SALINE DISCHARGE Kg/m2 FOLLOWING CLEARING
.60 .50 .40 .30 .20 .10 0
500 600 700 800 900 1000 1100 1200 1300 1400
LOW RAINFALL REGION
INTERMEDIATE REGION
HIGH RAINFALL REGION
ANNUAL RAINFALL (mm)

FIGURE 5

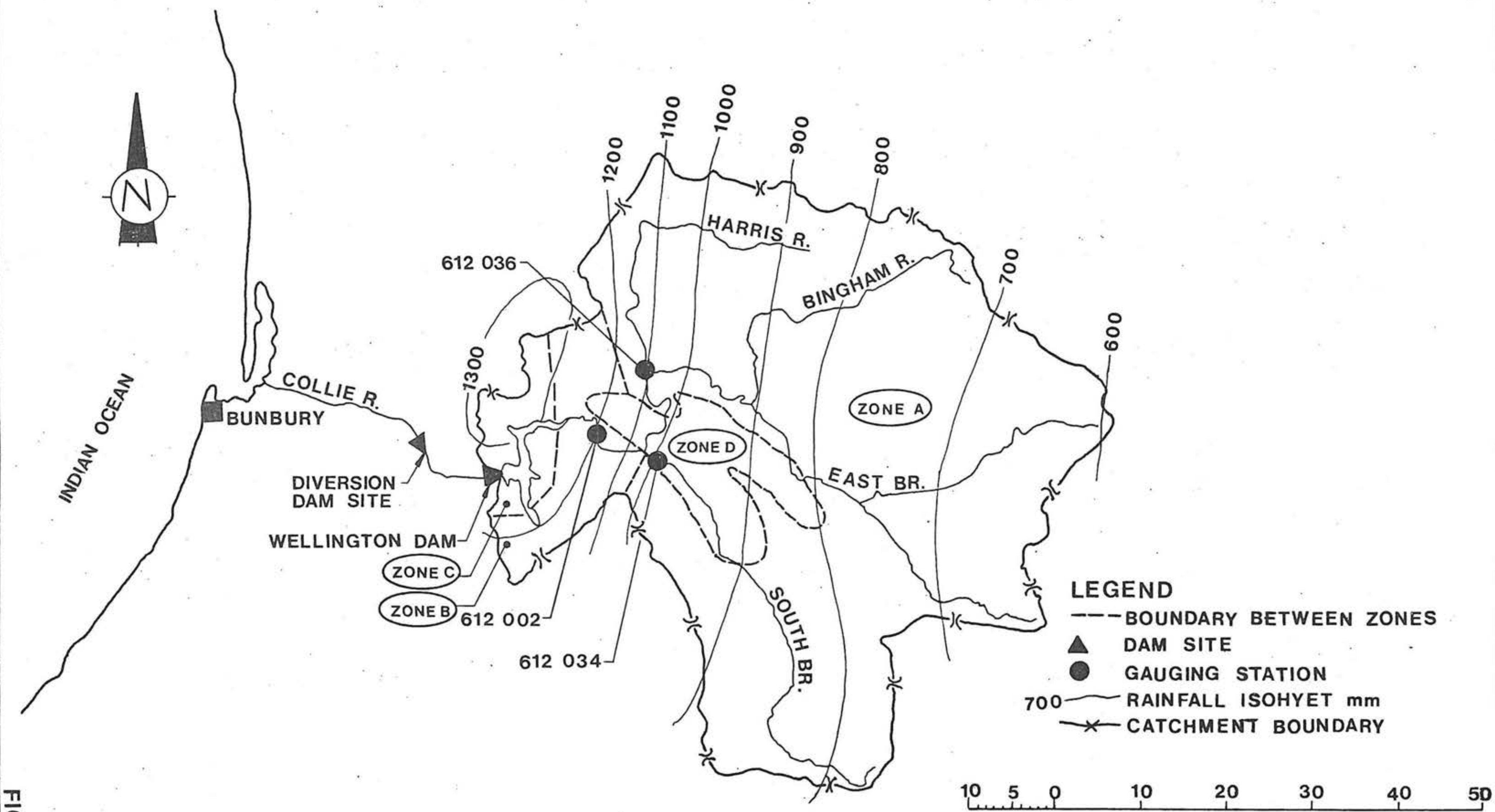
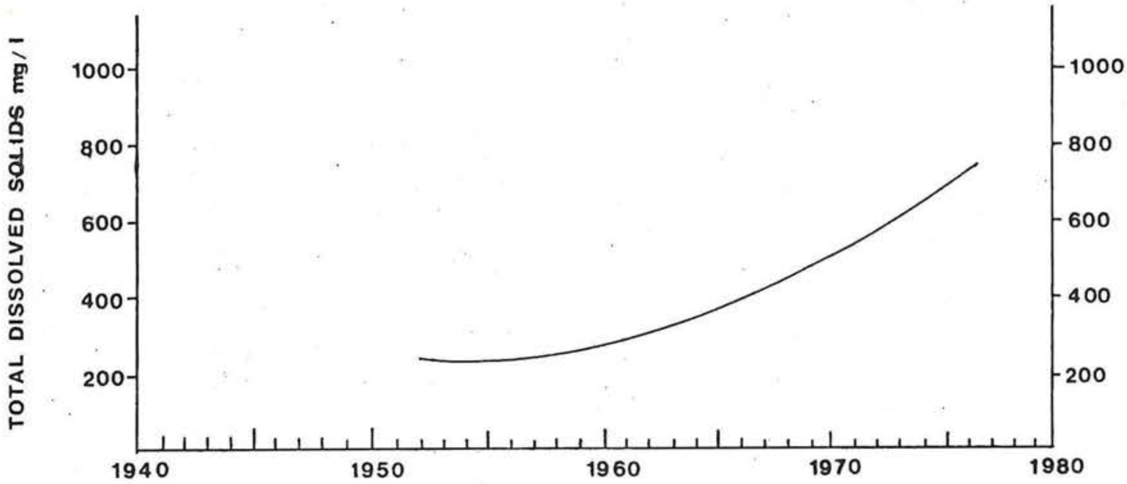


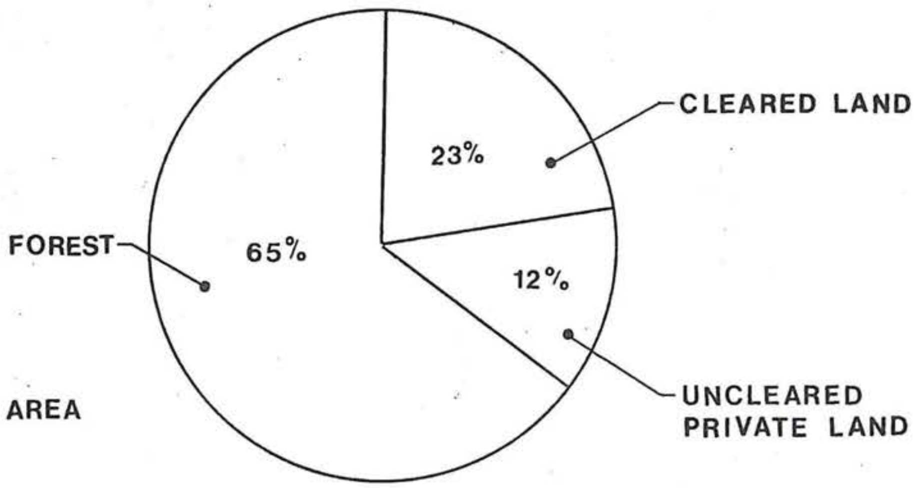
FIGURE 6

WELLINGTON DAM CATCHMENT AREA

WELLINGTON RESERVOIR

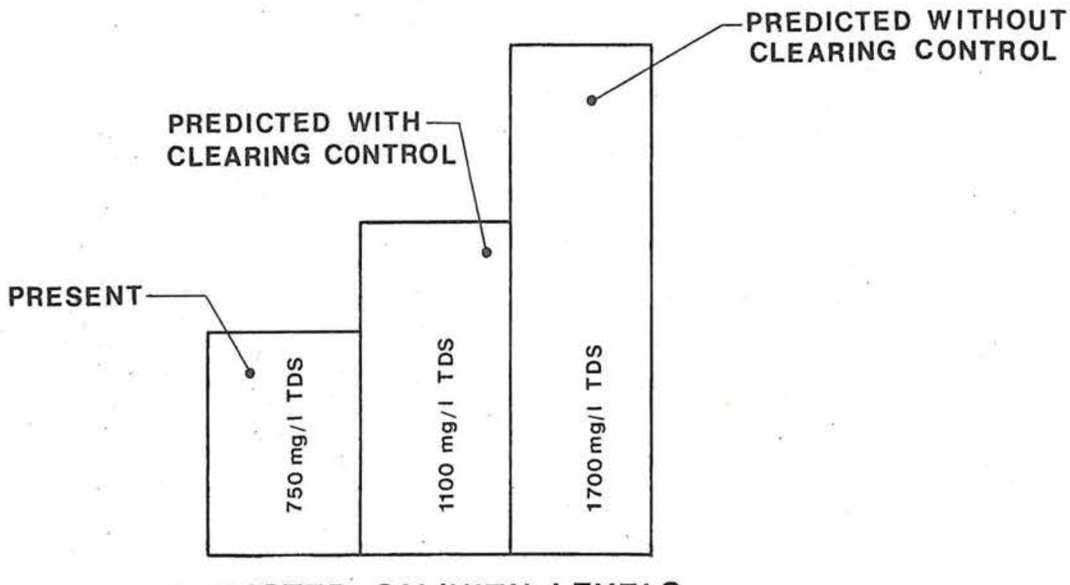


RESERVOIR SALINITY
ESTIMATED TREND OF MEAN ANNUAL LEVEL



CATCHMENT AREA
2830 Km^2

CATCHMENT CLEARING



PREDICTED SALINITY LEVELS

FIGURE 7

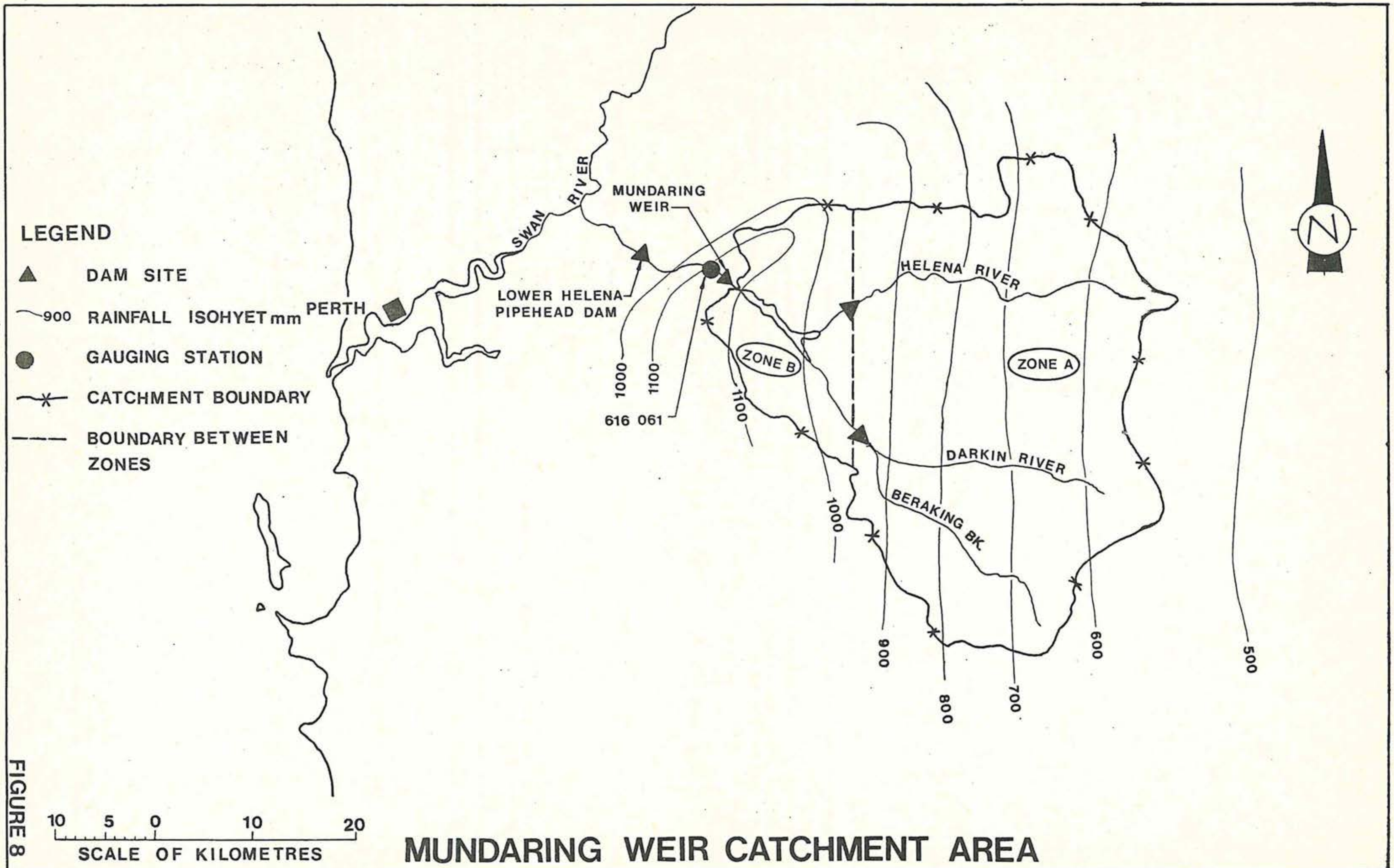


FIGURE 8

MUNDARING WEIR CATCHMENT AREA

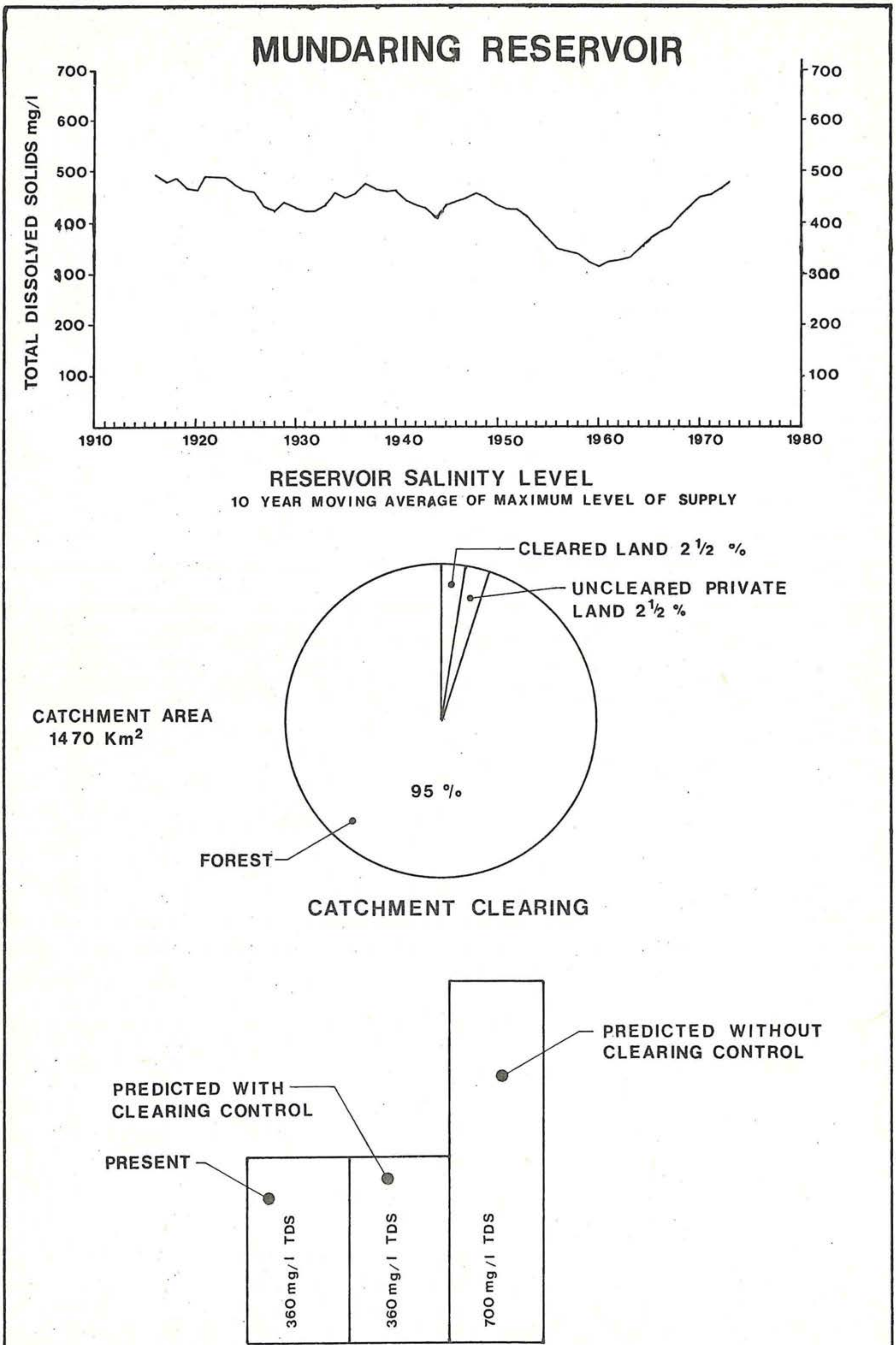
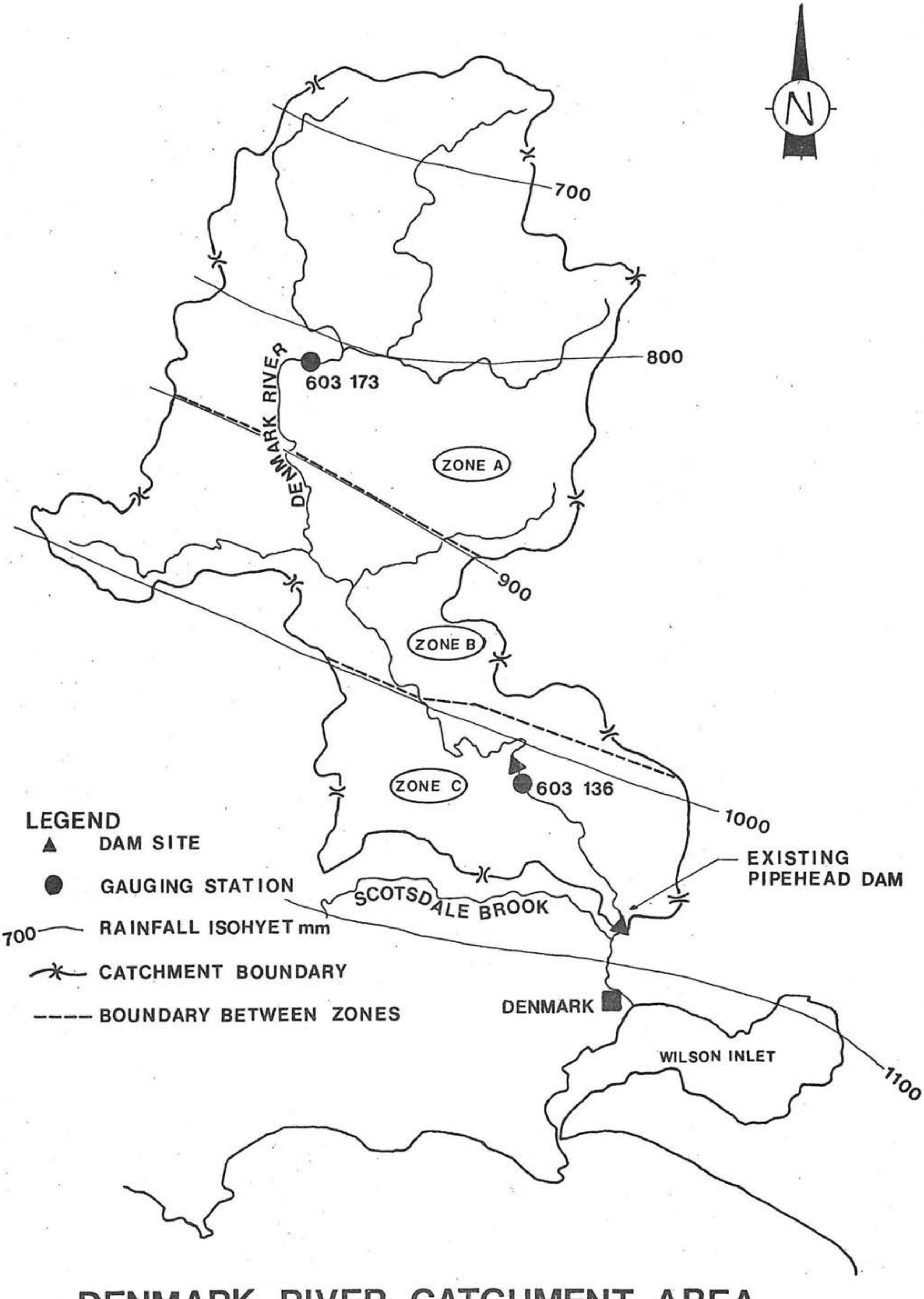

MUNDARING RESERVOIR
TOTAL DISSOLVED SOLIDS mg/l
700
600
500
400
300
200
100
1910
1920
1930
1940
1950
1960
1970
1980
RESERVOIR SALINITY LEVEL
10 YEAR MOVING AVERAGE OF MAXIMUM LEVEL OF SUPPLY
CLEARED LAND 2 1/2 %
UNCLEARED PRIVATE LAND 2 1/2 %
CATCHMENT AREA 1470 Km²
95 %
FOREST
CATCHMENT CLEARING
PREDICTED WITHOUT CLEARING CONTROL
PREDICTED WITH CLEARING CONTROL
PRESENT
360 mg/l TDS
360 mg/l TDS
700 mg/l TDS
PREDICTED SALINITY LEVELS

FIGURE 9



DENMARK RIVER CATCHMENT AREA

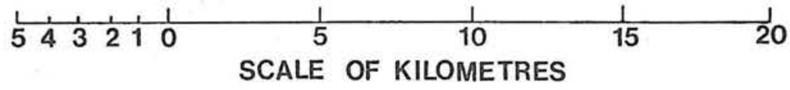
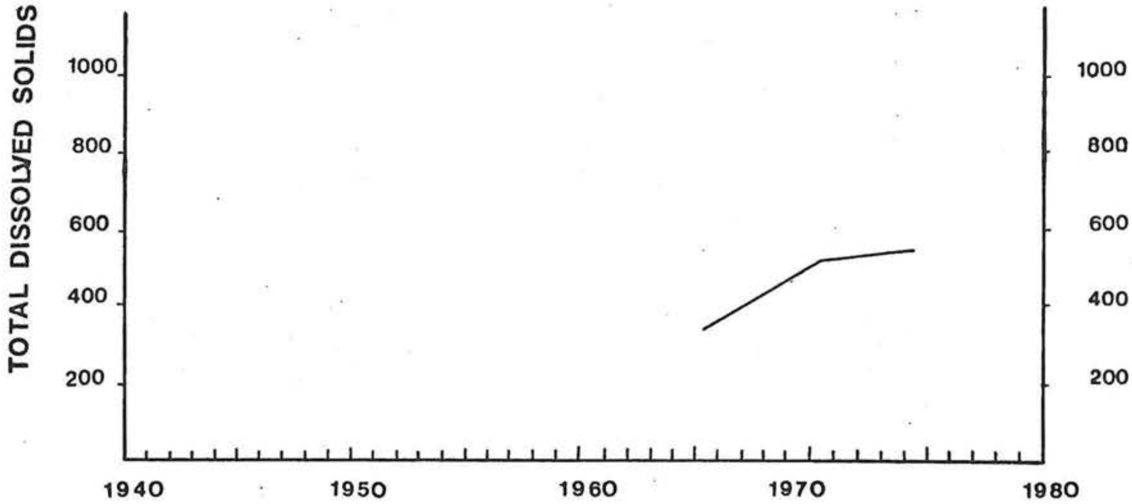
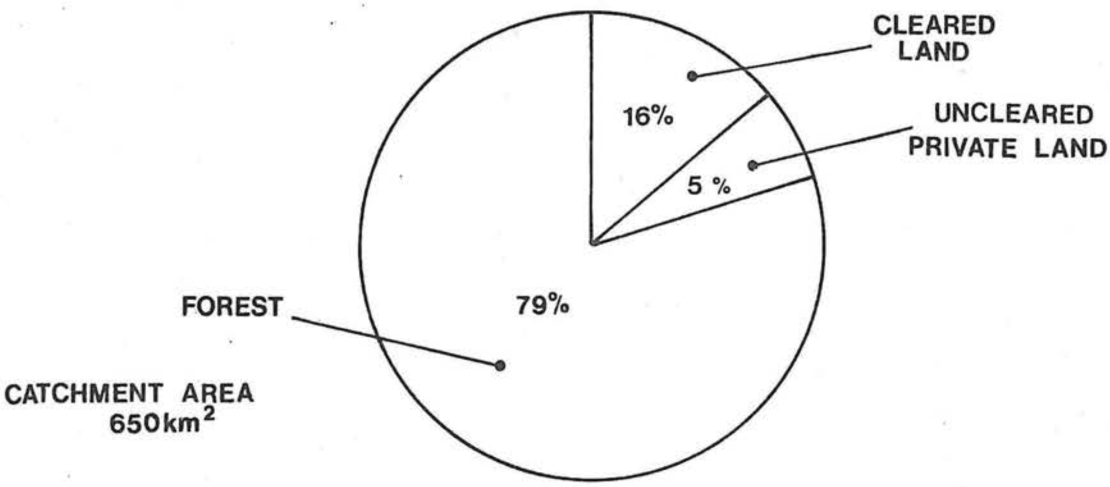


FIGURE 10

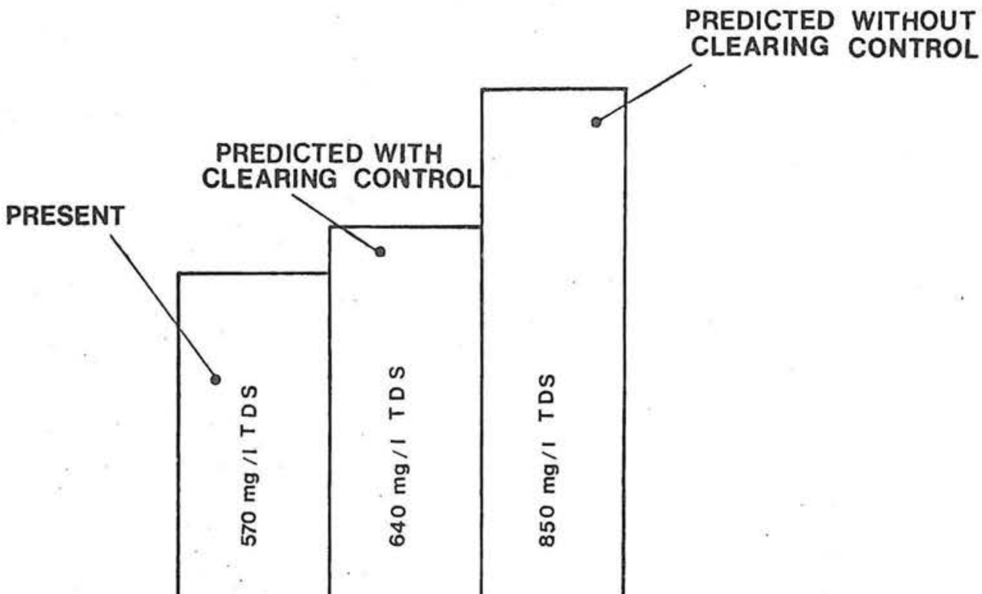
DENMARK RIVER



RECORDED SALINITY LEVELS
10 YEAR MOVING AVERAGE OF ANNUAL WEIGHTED MEAN



CATCHMENT CLEARING



PREDICTED SALINITY LEVELS

FIGURE 11

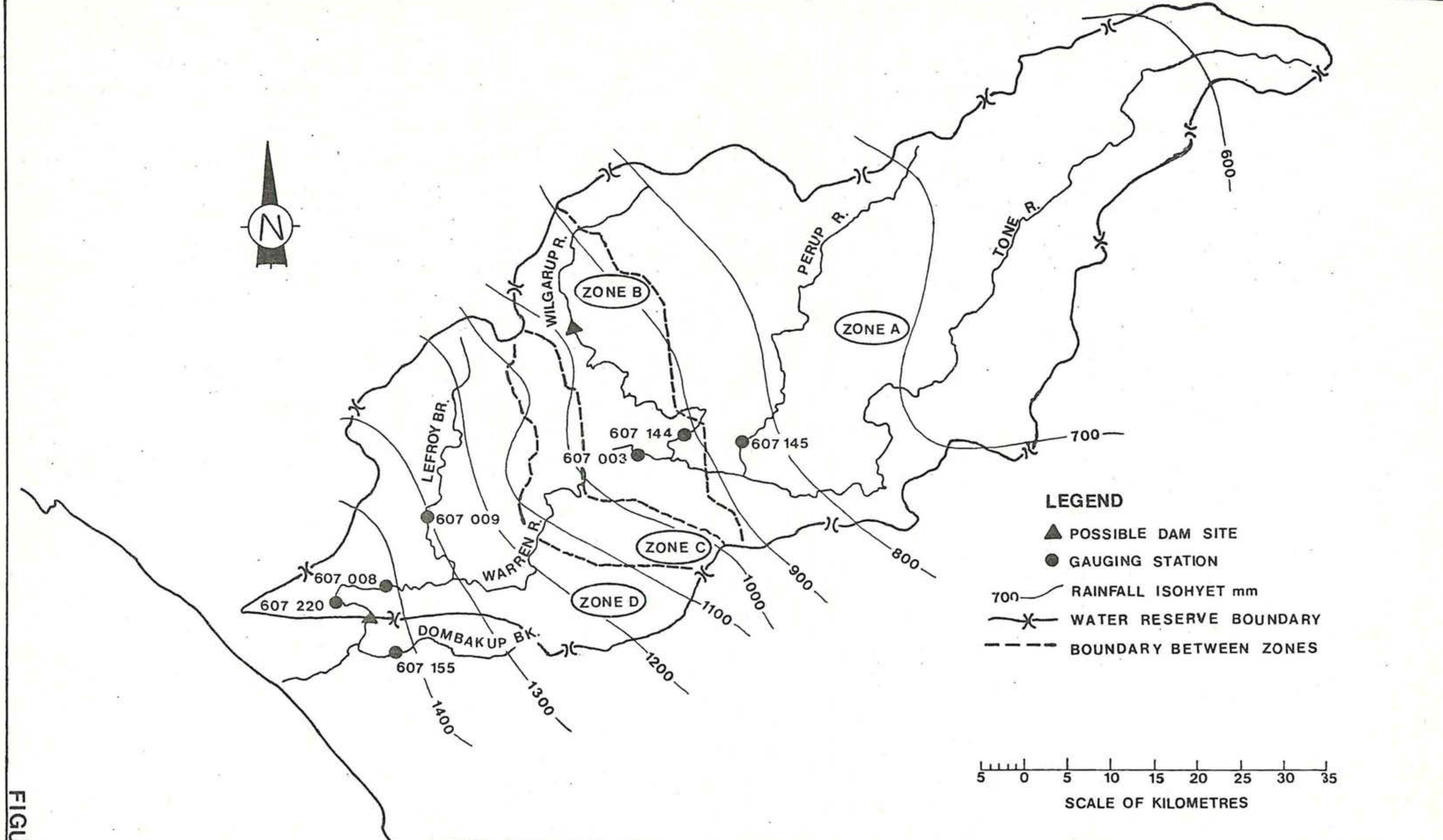
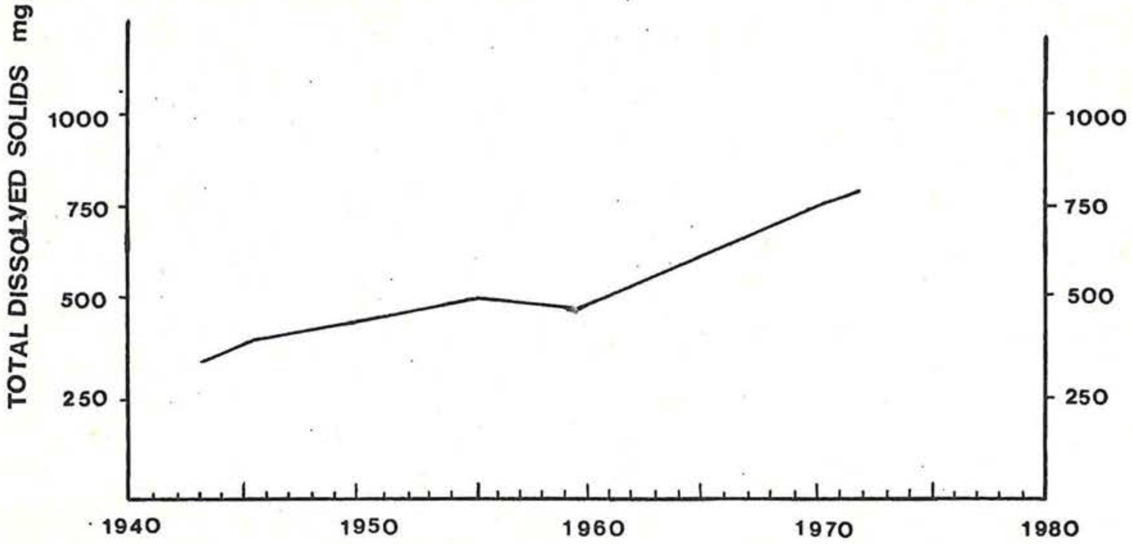


FIGURE 12

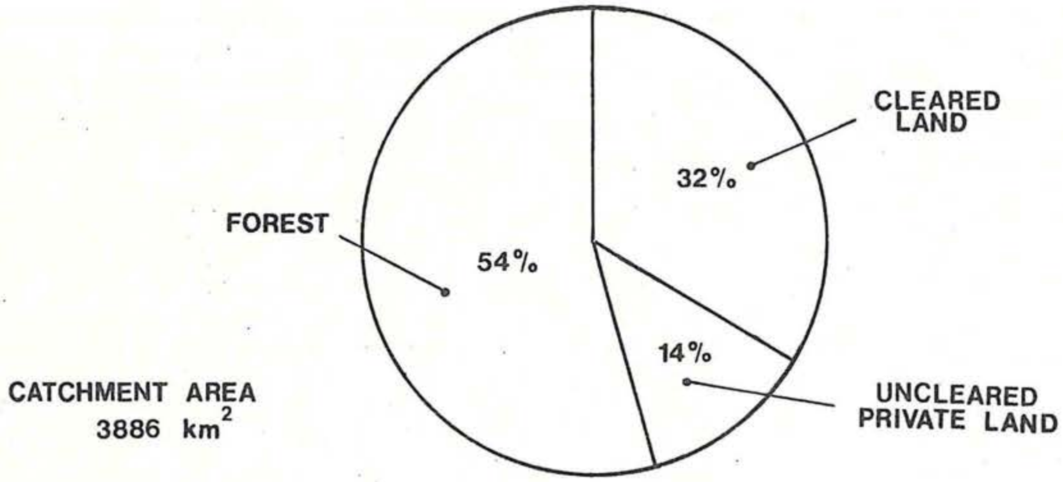
WARREN RIVER WATER RESERVE

WARREN RIVER

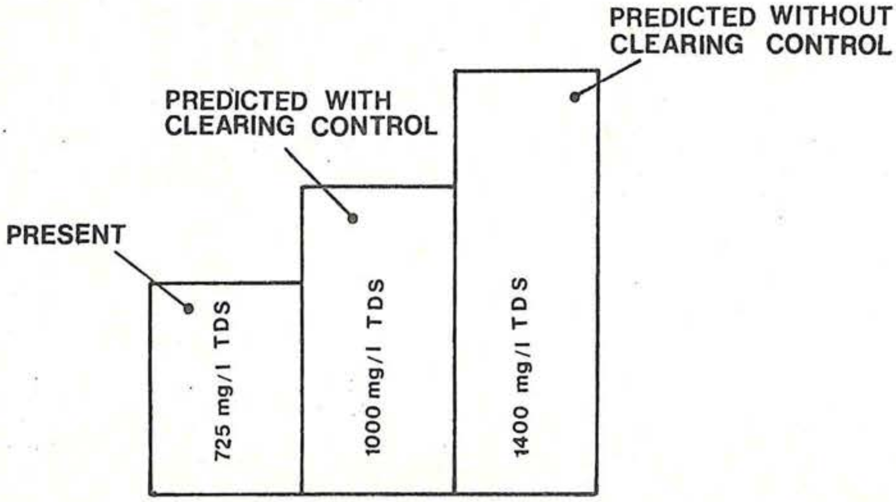


RECORDED SALINITY LEVELS

10 YEAR MOVING AVERAGE OF ANNUAL WEIGHTED MEAN

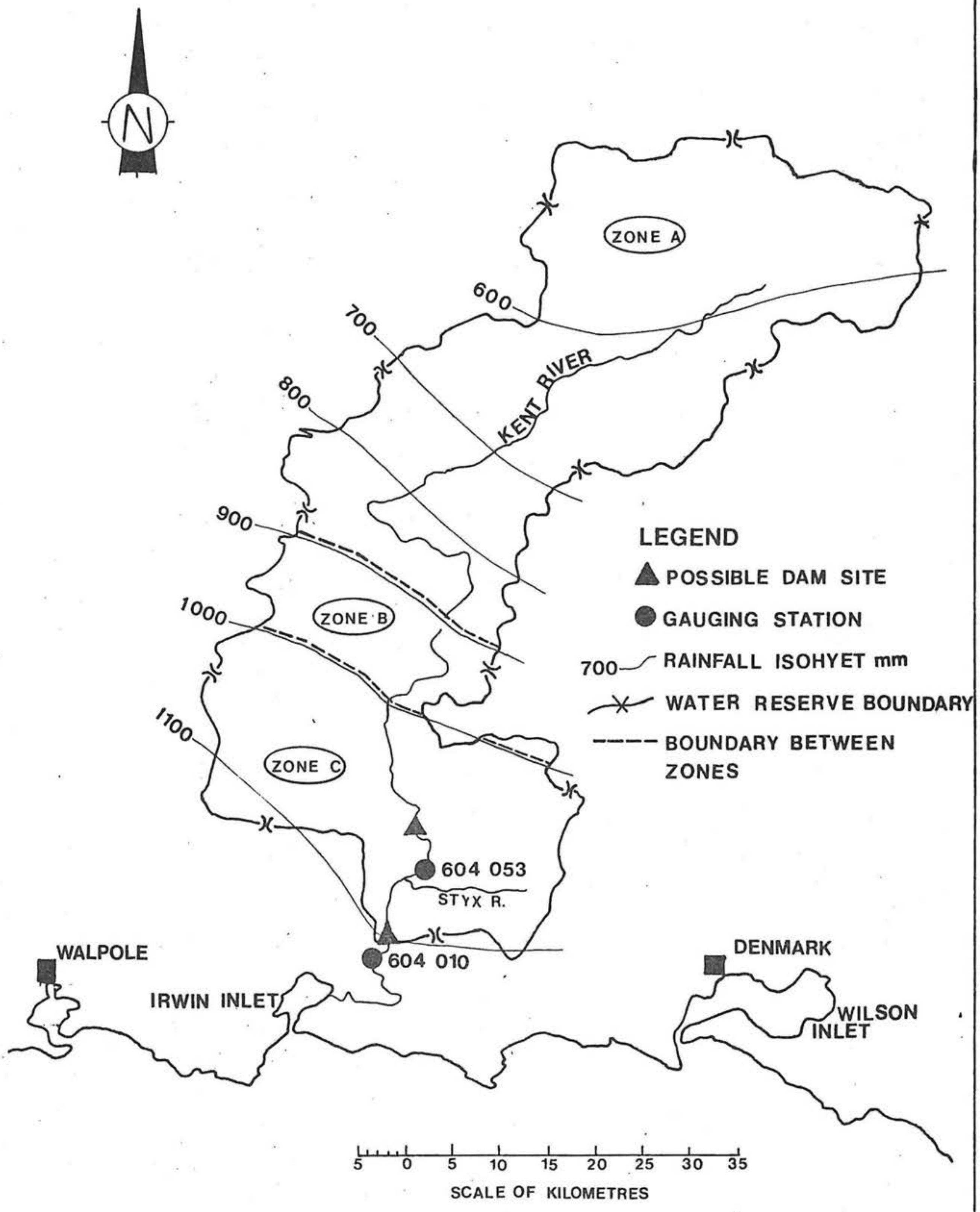


CATCHMENT CLEARING



PREDICTED SALINITY LEVELS

FIGURE 13



KENT RIVER WATER RESERVE

FIGURE 14

KENT RIVER

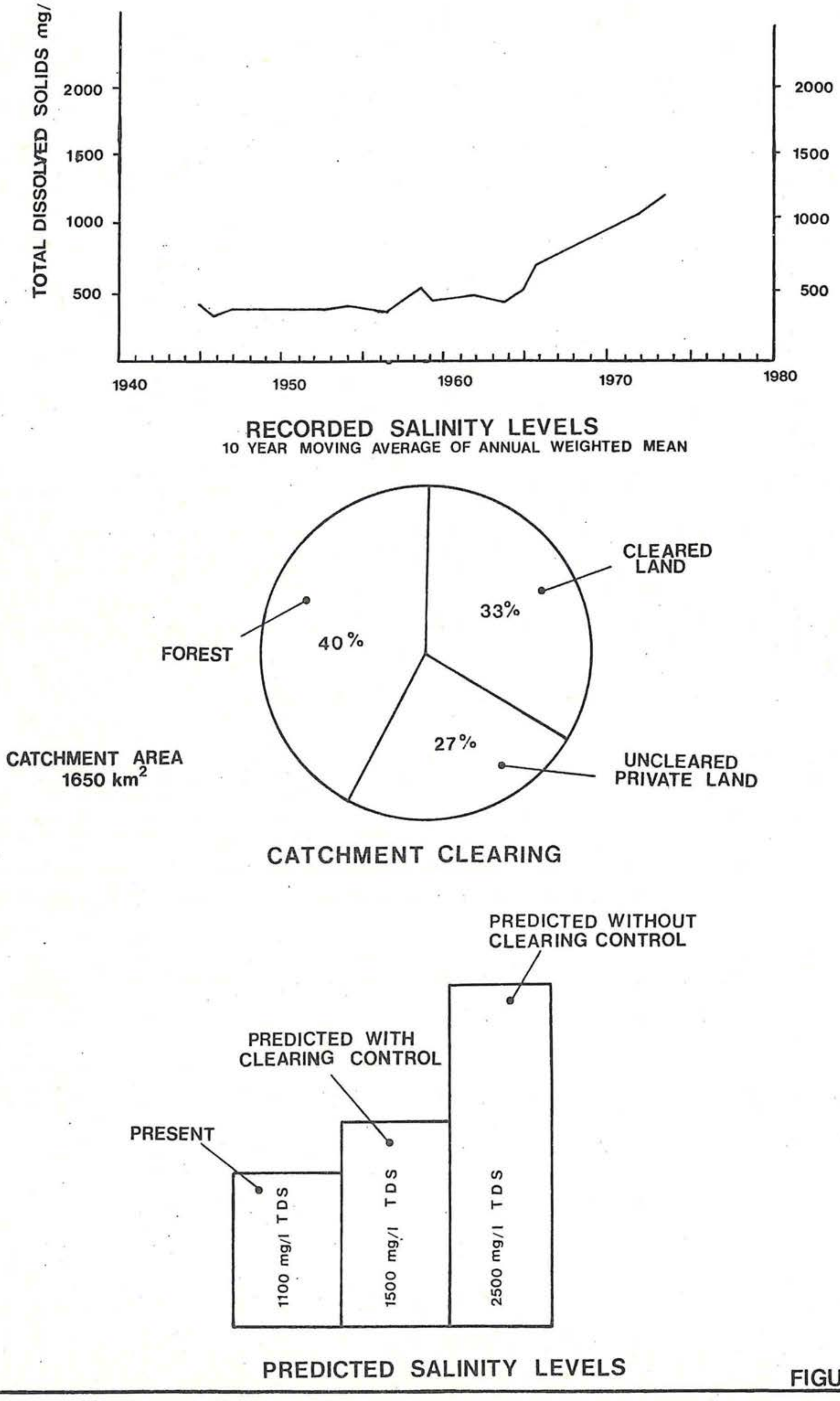


FIGURE 15