Water Authority
of Western Australia

WATER RESOURCES DIRECTORATE

Potential Thinning Of Darling Range Catchments

Report No. WH 29

February 1987

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Hydrology Branch

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WATER AUTHORITY OF WESTERN AUSTRALIA

POTENTIAL THINNING OF DARLING RANGE CATCHMENTS

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FIGURES

SUMMARY

The harnessing of additional water resources for the Perth Metropolitan Area is becoming increasingly expensive as all the relatively low cost sources of potable water have already been developed. It is therefore very appealing to increase the yield of developed resources. One way of achieving this could be to thin the forest to increase streamflow. As the water resource implications of thinning have not been previously addressed by the Water Authority this report aims to provide an estimate of areas available for thinning and possible water yield increments which may result from the Northern Jarrah Forest catchment areas.

Each of the catchments of Mundaring, Canning, Serpentine, Wungong, North Dandalup and South Dandalup were investigated and found to have thinning potential. Area statements for each catchment are given in terms of rainfall grouping, broad forest type (pole or massed stand) and whether wood or water production is of primary concern. These catchments are believed to have a total area of 1153 km^2 suitable for water production and 644 km^2 suitable for wood production.

To quantify streamflow increases resulting from thinning a numerical computer water balance model of the Canning Catchment was used. After assuming a management scenario for water production it was found that increases of up to 70% and 80% (23 to 28 million cubic metres per annum) may be achievable.

Many limitations to these results have become obvious during the study and are:

(a) Thinnable areas need better definition.

(b) Will dieback spread make thinning impossible?

(c) Forest growth following thinning is not well understood.

(d) Understorey growth must be controlled to gain streamflow benefits.

(e) Adequacy of model representation of forest water balance processes.

(f) No investigation of the effects of upper slope clearing on lower slopes were conducted.

(g) Thinning time frames are long and may be difficult to adhere to.

(h) Salinity increase resulting from thinning has not been considered.

It is recommended that the following should be undertaken:

(a) Areas suitable for forest management be identified in more detail.

(b) Short and long term forest management policies be clearly established.

(c) Research programmes for field experimentation and numerical modelling of the silvicultural and hydrologic effects at process and implementation scales be expedited.

1. INTRODUCTION

Economically viable water resources available for use by the Perth Metropolitan area are limited and to date most of the relatively cheap sources of potable water have been harnessed. As demand increases more expensive and less environmentally appealing sources will have to be developed. One way some of this increased demand might be met is by increasing the yield from already existing sources by forest thinning. However the areas available for thinning and the potential flow increases generated are unknown and require investigation.

Restructuring of the catchments forest by thinning also has the potential to increase the quality and quantity of the timber produced. The improvements in the millable products of the forest, though depending on thinning management policy, must have economic benefit and be able to offset some of the costs of thinning.

This report aims to give 'ball park' figures of thinnable areas in the main catchments of the Northern Jarrah Forest and to give an indication of potential flow increases from thinning. It is an expansion of 2 seminars given at the Department of Conservation and Land Management (CALM), Como, by the author in October 1986. Data relating to thinnable areas were supplied by CALM and processed at the Water Authority using the IMGRID system on the Facom computer. To quantify flow increases resulting from thinning a computer based process model developed at the Authority and set up for the Canning catchment was used.

2. FOREST THINNING

2.1 Catchments Studied

The catchments investigated in this study are Mundaring, Canning, Wungong, Serpentine, North Dandalup and South Dandalup (Figure 1). They are the main water sources in the Northern Jarrah Forest and therefore the most likely areas to be thinned.

2.2 Rainfall Zones

The long term rainfall is significant to this investigation because it controls the density of the forest and the quantity of salt stored and potentially available for mobilisation. An isohyet map of the catchments is shown on Figure 2.

As thinning will reduce evapotranspiration it may cause an increase in groundwater levels leading to salt mobilisation and therefore a consideration of likely salt stores is important. Large salt storage is believed to be absent in the high rainfall zone (HRZ), variable in the intermediate rainfall zone (IRZ) and high in the low rainfall zone (LRZ). Because of the significance of rainfall all area statements have been presented in terms of rainfall grouping to allow alternative selections of thinnable areas to be made in the future.

2.3 Classified Forest

Besides salinity drawbacks it is unlikely that any significant flow or wood benefits will be gained from the LRZ and therefore only its wetter portions were considered. The areas for which CALM supplied data are shown on Figure 3. They do not correspond exactly to isohyets but represent all areas for which forest classification data are available. Because of this a large proportion of some catchments (e.g. Mundaring) have not been included in thinning area statements and have been marked unclassified (unclass) throughout this report.

2.4 Divisions of Thinnable Forest

The classified areas were further divided into the following 3 forest types:

(a) Pole stands,
(b) Massed stands, and
(c) Unthinnable stands.

A pole stand is a relatively even-aged young forest with most trees having similar dimensions. It is suited to thinning as it is relatively easy to select good quality trees for retention in a thinned forest.

A massed forest is one with a markedly uneven size distribution probably caused by a variety of tree age. Thinning of this forest would be difficult because retainable trees may not exist. It is believed that clearfelling and regeneration is the most appropriate action for this forest and this is the management policy assumed in modelling studies.

An unthinnable forest is one which has no potential for thinning and corresponds to areas like streamzones, swamps, national parks or is classed for long term isolation because of dieback.

These classes are probably not always distinct but on average are a reasonable division of forest for thinning assessment.

2.5 Thinning for Water Production

One alternative thinning management policy is to optimize water production. These policies would be concerned with streamflow generation and not the quantity, quality or economics of wood production. The forest would still be thinned to encourage quality timber growth where it was practical and would not lead to yield loss.

This option would result in the thinning of all pole and massed stands without regard to other influences e.g. what tree type was dominant or if dieback was likely to develop.

2.6 Thinning for Wood Production

If forest thinning was aimed at maximising the production of timber, and water yield benefits were viewed only as a cost reducing spinoff, a very different management policy would be implemented to that for water production. On the most productive sites in the high and intermediate rainfall zones forest thinning is economically attractive to CALM. The cost of the treatment can be justified in terms of increased timber growth in remaining stems that will ultimately provide an increased royalty of any final timber yield. Some 2000 hectares are currently thinned in the Northern Jarrah Forest and if additional capital was available up to 5000 hectares per year could be treated.

For wood production thinning only the better sites within pole and massed stands would be thinned and those selected in this study had the following characteristics:

(a) Forest type of Jarrah,

(b) System 6 geomorphological area of Dwellingup, Hester or Murray,

(c) Dieback absent, and

(d) Codominant API height class of A and A+.

3. THINNABLE AREAS

3.1 Mundaring Catchment

The Mundaring catchment as indicated in Table 1, is 74% unclassified because if has a significant area within the LRZ. Very little of the catchment is within the HRZ with most of the potentially thinnable area of 227 km^2 in the IRZ.

Only 50% (118 km^2) of the area thinnable for water production is expected to be suitable for wood production.

3.2 Canning Catchment

The Canning catchment is described in detail later in this report. However, shown on Table 2 is a breakdown of the forest into thinnable areas. Approximately 28% (207 km^2) of the catchment is suitable for water production thinning of which 114 km^2 (55%) has potential for wood production.

3.3 Wungong Catchment

An area statement for Wungong catchment, shown on Table 3, indicates all the catchment has been classified and most is in the HRZ. The majority of the catchment (54% or 71 km^2) is suited to water production thinning with much of this (51 km^2) suitable for wood production.

3.4 Serpentine Catchment

Table 4 indicates that of Serpentine's total area of 647 km^2, 23% is not classified, 31% is not suitable for thinning and the rest, 304 km^2 (47%) is potentially thinnable. Only 25% of the catchment is thinnable for wood production. Most of Serpentine's thinnable area is within the IRZ.

3.5 North Dandalup Catchment

All of the North Dandalup catchment has been classified of which 117 km^2 (79%, see Table 5) is potentially thinnable for water production. Some 50% of the catchment is suited to wood production thinning and most of this is in the HRZ.

3.6 South Dandalup Catchment

Nearly all of the South Dandalup catchment has been classified and most, 229 km^2 (74%) is suitable for water production as indicated on Table 6. The area potentially thinnable for wood production represents 40% of the catchment or 125 km^2.

3.7 Summary of Thinnable Areas

Tables 7 and 8 summarize the area information of the Northern Jarrah Forest catchments. Areas with thinning potential are indicated by rainfall groups on Table 7 and total thinnable areas are on Table 8. As indicated, approximately 56% of the water production thinning areas are also suitable for wood production thinning.

4. LAI OF THINNABLE AREAS

Having defined areas with the potential for thinning it was then necessary to confirm that these areas did have sufficient forest to warrant thinning. This was done by calculating a mean Leaf Area Index (LAI) for each rainfall group for each catchment. These data were derived from December 1980 and December 1983 Landsat satellite images (bands 5 and 7) and the results are shown on Table 9.

The table indicates that there is sufficient leaf cover in all groupings to permit a thinning programme, however the impact of thinning will vary. For example on Wungong with a LAI of 1.38 to 1.44 in the HRZ there will be significantly less yield increase than the North Dandalup HRZ where the LAI is between 1.75 and 1.79. (A description of the expected reduction in LAI due to thinning is given later in this report).

It was expected that LAI would reduce approximately 16% from 1200 mm to 900 mm rainfall but this is clearly not always the case. This indicates that the forest has already been lightly thinned over significant areas and leading to a probable yield increase from that of virgin forest. The LAI variations are believed to be primarily caused by logging, though dieback and burning are probably significant contributors.

5. POTENTIAL WATER INCREASE

5.1 Darling Range Catchment Model

The Darling Range Catchment Model (DRCM) is a computer based process model which reproduces the movement of rain (and salt) as it is cycled through a catchment. Water is lost from the modelled catchment to the atmosphere via evapotranspiration, or out of the catchment via streamflow or groundwater flow. Evapotranspiration processes are controlled by the LAI and act on various interconnecting stores. The catchment is divided into like-units referred to as subcatchments and which are connected by streamlines. DRCM was developed within the Authority and has been successfully tested on a number of catchments including the Canning.

As the model is designed to investigate management options, and because the model had been set up for the Canning, it was decided to simulate the impact of thinning on the Canning catchment.

5.2 Canning Simulations using DRCM

The streams and gauging stations of the Canning catchment are indicated on Figure 4 and its Isohyets are shown on Figure 5. Both have been presented to help familiarize the reader with the catchment.

The CALM forest classification into poles, massed, unthinnable and unclassified forest is shown on Figure 6 and quantified on Table 2. It indicates that much of the catchment is unclassified and there are significant areas which are unthinnable.

Because of the model structure the available thinning information and the isohyet locations it was decided to thin in the model only the catchment below the Scenic Drive gauging station (i.e. Canning and not South Canning on Figure 4). A breakdown of the areas modelled for thinning in Canning is shown in Table 10 and indicates an area of 147 km^2 or 20% of the entire catchment.

Before considering the models simulation of thinning, its ability to reproduce the historical streamflow must be established. The actual historical inflows to Canning Reservoir and those simulated by DRCM are plotted on Figure 7. The probability of these inflows are shown on Figure 8 and the mean actual and simulated inflows for the period 1912 - 1983 were 55.4 and 59.1 million cubic metres per annual respectively. Most of the mismatch is believed to relate to the rainfall record. Further details of the Canning modelling are found in a report titled the Flow and Salinity Study of the Canning Catchment by R. Hammond (1987).

5.3 LAI Variation to Represent Thinning

To model flow changes caused by thinning a long term thinning management policy had to be devised. This policy had to be expressed in terms of leaf area change to allow incorporation in DRCM. The policy and the LAI variation were supplied by G. Stoneman (CALM Forest Hydrology Research Officer) based on the Inglehope experimental data and is shown on Figure 9. The LAI variation shown represents 200 years of managed thinning from a clearfelling event, i.e. forty years after clearfelling the forest would be thinned and then every 30 years until 130 years had elapsed when the forest would again be clearfelled and the cycle repeated.

Having viewed data from other sources (woodchip data) it is felt that the linear regrowth curves indicated on Figure 9 are not realistic. Therefore an alternative set of curves to represent thinning management are also shown on Figure 9 though they have identical cycling.

This LAI variation had then to be converted to a realistic thinning scenario representable by the model. The thinning management policy used by the model is shown in terms of LAI on Figure 10. It shows:

(a) An assumed ground storey LAI of 0.2 that exists for the entire modelled period of 1911 to 1984 (a very conservative estimate and could be much greater).

(b) Two growth curves for the thinning of a pole forest both derived from those of Figure 9. It is assumed that all pole stands were thinned to a LAI of 0.6 (plus 0.2 for ground storey) in June 1911 of the historic rainfall sequence used in the modelling.

(c) Two growth curves for thinning massed stands, both based on Figure 9 data and assuming clearfelling in June 1911 of the rainfall sequence.

5.4 Thinning Canning for Water Production

Canning catchment flow simulations were produced for the 1911 to 1984 period assuming forest thinning for water production had occurred. The thinning management policy used is that indicated on Figure 10. The areas thinned are the pole and massed forest indicated on Figure 6. Two scenarios, to represent the alternate regrowth curves, were simulated and are presented below.

5.4.1 Modelling Results, Stoneman Regrowth LAI

The simulation of the Canning Reservoir inflows after thinning, assuming Stoneman regrowth, are presented on an annual basis in Figure 11. Also plotted on the figure are the historical synthetic inflows for comparison. On Figures 12 and 13 this data is plotted as a probability plot (Fig 12) and as an annual flow increase. The simulations suggest that thinning has resulted in an increase in flow for all years, this increase tends to be more significant in drier years and has greatest impact in the first twenty years.

5.4.2 Modelling Results, WAWA Regrowth LAI

The results of thinning Canning assuming the Water Authority estimate of regrowth LAI is shown on Figures 15, 16 and 17. As in 5.4.1 above, the data is on an annual basis with the historical simulations displayed for comparison. The plots indicate that thinning causes flow increases in all years. The increases tend to be more significant in low rainfall years and more evenly distributed over the period investigated compared with those using the Stoneman regrowth.

5.4.3 Summary of Thinning Modelling

The results of the simulations of thinning are summarised in Table 11 in terms of mean annual flows. The table clearly shows flow will increase dramatically, from 70% to 80% depending on regrowth curves. It must be remembered that these flows are for a water production thinning and probably represent the maximum gains expected from thinning. A significant result of the modelling is that management of the flow increase is possible and desirable (i.e. management would need to guarantee that flow increases were evenly distributed)

6. LIMITATIONS OF THINNING INVESTIGATIONS

There are a number of limitations to the thinning information presented herein that must be noted or require further investigation. These are:

(a) Areas described as thinnable appear to be a little coarse and probably need refinement e.g. areas of rock outcrop are considered thinnable.

(b) Dieback is very important to the well-being (or lack of it) of the forest. Knowledge is still incomplete on the impact that a thinning program would have on dieback spread.

(c) The variation (regrowth) of leaf area after thinning is not well understood. Two possible regrowth scenarios have been presented herein, producing similar results, but an alternative and less advantageous (for yield) regrowth may actually occur.

(d) Modelling results are not perfect for the historical forest and any additional errors which may be introduced by a radically different forest structure cannot be assessed. For example, interception is an important model process and may have different characteristics for a thinned forest.

(e) No investigation of upper slope clearing relative to lower slopes has been conducted. Clearing of upper slope forest could result in lower slope forest becoming greener and using water expected to contribute to streamflow.

(f) Will the streamzone become greener and use the additional water available because of thinning? This has been investigated by simulating a streamzone with a LAI of 3.0 (above a realistic level) and observing the result. A flow reduction of 3% was found indicating this to be a minor problem, as modelled. However the current modelling structure does not specifically simulate this process.

(g) Growth of the groundstorey after the upperstorey has been thinned might be a problem because it would have the capacity to use much of the water. It would therefore need to be controlled.

(h) A rigid forest thinning program may need to be adhered to over a long period of time if the flow increases are to be adequately managed. It is not known if the nature of the forest or changing management will allow this.

(i) The issue of salinity increase has not been addressed, it is not likely to be a problem in the HRZ but must be considered if thinning of the IRZ and LRZ is to occur.

7. CONCLUSIONS

The conclusions of this study of the thinning potential of the Northern Jarrah Forest are:

(a) There is an area of 1153 km^2 potentially thinnable for water production.

(b) Of the water production area 644 km^2 is potentially thinnable for wood production.

(c) There is expected to be an increase of between 23 and 28 million cubic metres of flow from the Canning catchment if the area below the Scenic Drive gauging station is thinned for water production.

(d) Current management practice (e.g. logging) has caused an unmeasured increase in flow from that which would have occured from a virgin forest.

(e) The forest regrowth response following thinning is very important and should be further investigated.

(f) Control of the ground storey expansion following thinning is important and must occur. Therefore when evaluating the cost benefits of thinning the cost of groundstorey control must be included.

These results are a preliminary assessment and although the indications of significant water yield increases are promising there are sufficient unknowns to suggest that substantially more field data and modelling is required.

8. RECOMMENDATIONS

(a) Areas suitable for forest management which may potentially impact streamwater quantity and quality be identified in more detail.

(b) Short and longer term forest management practices for these areas be clearly established.

(c) Research programmes for field experimentation and numerical modelling of the silvicultural and hydrologic effects at process and implementation scales be expedited.

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TABLE 1
MUNDARING CATCHMENT
THINNABLE AREA

THINNING TYPE		WATER PRODUCTION				TIMBER PRODUCTION			
RAIN (mm)	AREA (km^2)	POLES (km^2)	MASSED (km^2)	UNTHIN (km^2)	UNCLASS (km^2)	POLES (km^2)	MASSED (km^2)	UNTHIN (km^2)	UNCLASS (km^2)
> 1300	0	0	0	0	0	0	0	0	0
1200-1300	0	0	0	0	0	0	0	0	0
1100-1200	18	15	1	2	0	9	1	8	0
1000-1100	36	23	1	12	0	18	1	17	0
900-1000	95	50	12	33	0	39	8	48	0
800- 900	206	71	19	86	30	32	8	136	30
700- 800	410	22	13	18	357	1	1	51	357
< 700	691	0	0	0	691	0	0	0	691
TOTAL AREA (km^2)	1456	181	46	151	1078	99	19	260	1078
% TOTAL	100	12	3	10	74	7	1	18	74

TABLE 2
CANNING CATCHMENT
THINNABLE AREA

THINNING TYPE		WATER PRODUCTION				TIMBER PRODUCTION			
RAIN (mm)	AREA (km^2)	POLES (km^2)	MASSED (km^2)	UNTHIN (km^2)	UNCLASS (km^2)	POLES (km^2)	MASSED (km^2)	UNTHIN (km^2)	UNCLASS (km^2)
> 1300	0	0	0	0	0	0	0	0	0
1200-1300	23	11	3	9	0	11	3	9	0
1100-1200	42	22	6	14	0	20	6	16	0
1000-1100	36	16	4	16	0	12	3	21	3
900-1000	218	68	18	68	64	34	10	110	64
800- 900	269	42	15	29	183	10	5	71	183
700- 800	143	1	1	1	140	0	0	3	140
< 700	1	0	0	0	1	0	0	0	1
TOTAL AREA (km^2)	732	160	47	137	388	87	27	226	388
% TOTAL	100	22	6	19	53	12	4	31	53

TABLE 3
WUNGONG CATCHMENT
THINNABLE AREA

THINNING TYPE		WATER PRODUCTION				TIMBER PRODUCTION			
RAIN (mm)	AREA (km^2)	POLES (km^2)	MASSED (km^2)	UNTHIN (km^2)	UNCLASS (km^2)	POLES (km^2)	MASSED (km^2)	UNTHIN (km^2)	UNCLASS (km^2)
> 1300	9	2	0	7	0	2	0	7	0
1200-1300	84	40	13	31	0	29	11	44	0
1100-1200	26	9	4	13	0	5	3	18	0
1000-1100	12	3	0	9	0	1	0	11	0
900-1000	1	0	0	1	0	0	0	1	0
800- 900	0	0	0	0	0	0	0	0	0
700- 800	0	0	0	0	0	0	0	0	0
< 700	0	0	0	0	0	0	0	0	0
TOTAL AREA (km^2)	132	54	17	61	0	37	14	81	0
% TOTAL	100	41	13	46	0	28	11	61	0

TABLE 4
SERPENTINE CATCHMENT
THINNABLE AREA

THINNING TYPE		WATER PRODUCTION				TIMBER PRODUCTION			
RAIN (mm)	AREA (km^2)	POLES (km^2)	MASSED (km^2)	UNTHIN (km^2)	UNCLASS (km^2)	POLES (km^2)	MASSED (km^2)	UNTHIN (km^2)	UNCLASS (km^2)
> 1300	3	2	0	1	0	1	0	2	0
1200-1300	105	52	5	48	0	35	3	67	0
1100-1200	118	55	14	49	0	30	10	78	0
1000-1100	141	90	12	39	0	50	6	85	0
900-1000	131	55	5	22	49	24	2	56	49
800- 900	95	9	1	37	48	0	0	47	48
700- 800	54	0	0	2	52	0	0	2	52
< 700	0	0	0	0	0	0	0	0	0
TOTAL AREA (km^2)	647	263	37	198	149	140	21	337	149
% TOTAL	100	41	6	31	23	22	3	52	23

TABLE 5
NORTH DANDALUP CATCHMENT
THINNABLE AREA

THINNING TYPE		WATER PRODUCTION				TIMBER PRODUCTION			
RAIN (mm)	AREA (km^2)	POLES (km^2)	MASSED (km^2)	UNTHIN (km^2)	UNCLASS (km^2)	POLES (km^2)	MASSED (km^2)	UNTHIN (km^2)	UNCLASS (km^2)
> 1300	54	40	2	12	0	28	1	25	0
1200-1300	71	50	6	15	0	31	4	36	0
1100-1200	23	15	5	3	0	8	3	12	0
1000-1100	0	0	0	0	0	0	0	0	0
900-1000	0	0	0	0	0	0	0	0	0
800- 900	0	0	0	0	0	0	0	0	0
700- 800	0	0	0	0	0	0	0	0	0
< 700	0	0	0	0	0	0	0	0	0
TOTAL AREA (km^2)	148	105	13	30	0	67	8	73	0
% TOTAL	100	71	9	21	0	45	5	50	0

TABLE 6
SOUTH DANDALUP CATCHMENT
THINNABLE AREA

THINNING TYPE		WATER PRODUCTION				TIMBER PRODUCTION			
RAIN (mm)	AREA (km^2)	POLES (km^2)	MASSED (km^2)	UNTHIN (km^2)	UNCLASS (km^2)	POLES (km^2)	MASSED (km^2)	UNTHIN (km^2)	UNCLASS (km^2)
> 1300	21	9	4	8	0	7	3	11	0
1200-1300	49	32	4	13	0	22	3	.24	0
1100-1200	54	41	5	8	0	21	4	29	0
1000-1100	69	56	5	8	0	35	3	31	0
900-1000	57	46	3	8	0	21	1	35	0
800- 900	44	23	1	20	0	4	1	39	0
700- 800	16	0	0	15	1	0	0	15	1
< 700	0	0	0	0	0	0	0	0	0
TOTAL AREA (km^2)	310	207	22	78	1	110	15	184	1
% TOTAL	100	67	7	25	0	35	5	59	0

TABLE 7
SUMMARY OF THINNABLE AREAS

THINNING TYPE		WATER PRODUCTION				TIMBER PRODUCTION			
RAIN (mm)	AREA (km^2)	POLES (km^2)	MASSED (km^2)	UNTHIN (km^2)	UNCLASS (km^2)	POLES (km^2)	MASSED (km^2)	UNTHIN (km^2)	UNCLASS (km^2)
> 1300	87	53	6	28	0	38	4	45	0
1200-1300	332	185	31	113	3	128	24	177	3
1100-1200	281	157	35	88	1	93	27	160	1
1000-1100	294	188	22	84	0	116	13	165	0
900-1000	502	219	38	132	113	118	21	250	113
800- 900	614	145	36	172	261	46	14	293	261
700- 800	623	23	14	36	550	1	1	71	550
< 700	692	0	0	0	692	0	0	0	692
TOTAL AREA (km^2)	3425	970	182	653	1620	540	104	1161	1620
% TOTAL	100	28	5	19	47	16	3	34	47

TABLE 8
TOTAL AREA OF CATCHMENTS THINNABLE

CATCHMENT	WATER PRODUCTION km^2	WOOD PRODUCTION km^2
MUNDARING	227	118
CANNING	207	114
WUNGONG	71	51
SERPTENTINE	300	161
NORTH DANDALUP	118	75
SOUTH DANDALUP	229	125
TOTAL	1 153	644

TABLE 9
LAI FOR RAINFALL ZONES IN CATCHMENTS

RAINFALL (mm)	MUNDARING	CANNING	WUNGONG	SERPENTINE	NORTH DANDALUP	SOUTH DANDALUP
> 1300	-	-	1.38	2.02	1.75	1.60
1200 - 1300	-	1.42	1.44	1.71	1.79	1.70
1100 - 1200	1.82	1.62	1.79	1.79	1.43	1.73
1000 - 1100	1.68	1.62	1.73	1.73	-	1.92
900 - 1000	1.61	1.67	1.70	1.82	-	2.05
800 - 900	1.45	1.55	-	1.80	-	1.91
700 - 800	1.56	1.79	-	1.63	-	1.92
< 700	1.34	1.66	-	-	-	-

TABLE 10
AREA OF CANNING THINNED
IN MODEL FOR WATER PRODUCTION

RAIN (mm)	AREA (km^2)	POLES (km^2)	MASSED (km^2)	UNTHIN (km^2)	NOT MODELLED (km^2)
> 1300	0	0	0	0	0
1200-1300	23	11	3	9	0
1100-1200	42	22	6	14	0
1000-1100	36	16	4	16	0
900-1000	218	32	10	32	144
800- 900	269	32	11	22	204
700- 800	143	0	0	0	143
< 700	1	0	0	0	1
TOTAL AREA (km^2)	732	113	34	93	492
% TOTAL	100	15	5	13	67

TABLE 11

RESULTS OF THINNING MODELLING

(1911 - 1984)

CATCHMENT	AREA	MEAN HISTORICAL FLOW		MEAN THINNED FLOW (STONEMAN LAI)		MEAN THINNED FLOW (WAWA LAI)	
	km^2	10^6 m^3	mm	10^6 m^3	mm	10^6 m^3	mm
ENTIRE CANNING	724	59.1	81.6	87.8	121.3	82.9	114.5
SOUTH CANNING	494	25.7	52.0	25.7	52.0	25.7	52.0
THINNED CANNING	230	33.4	145.2	62.1	270.0	57.2	248.7

7238R

FIGURE 1

WATER AUTHORITY OF WESTERN AUSTRALIA

POTENTIAL THINNING OF DARLING RANGE CATCHMENTS

GENERAL LOCALITY PLAN

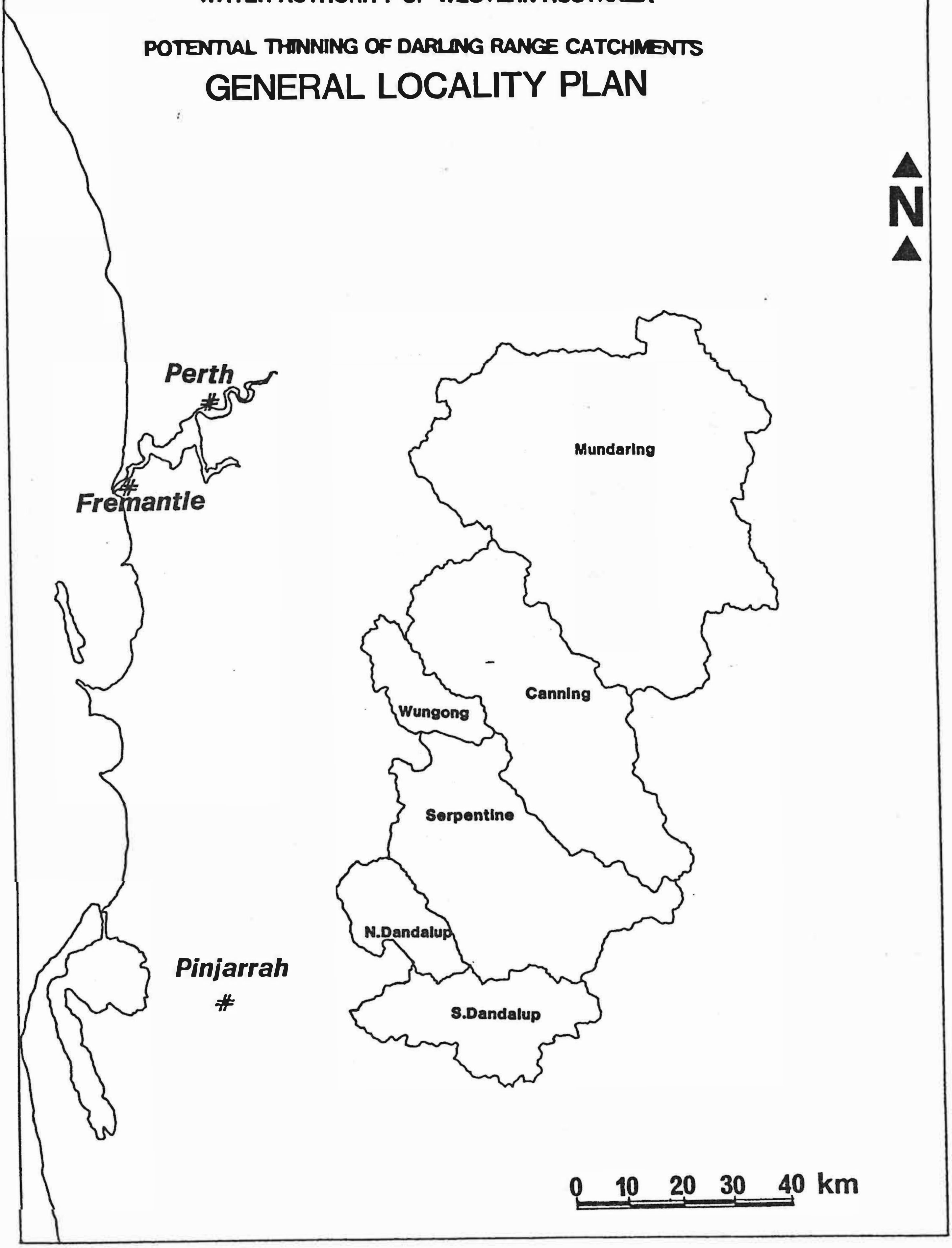


FIGURE2

WATER AUTHORITY OF WESTERN AUSTRALIA

POTENTIAL THINNING OF DARLING RANGE CATCHMENTS

ISOHYETS

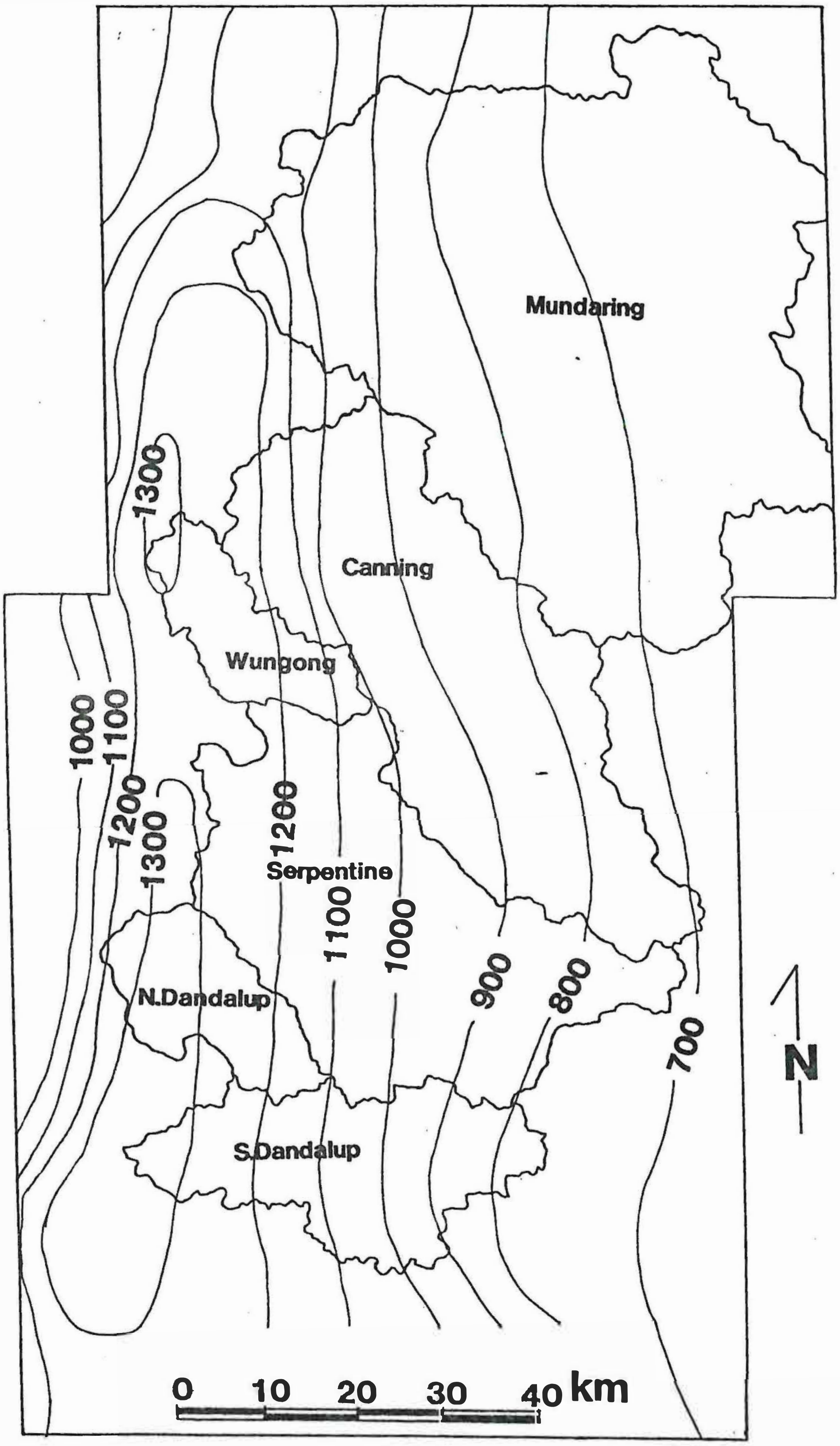
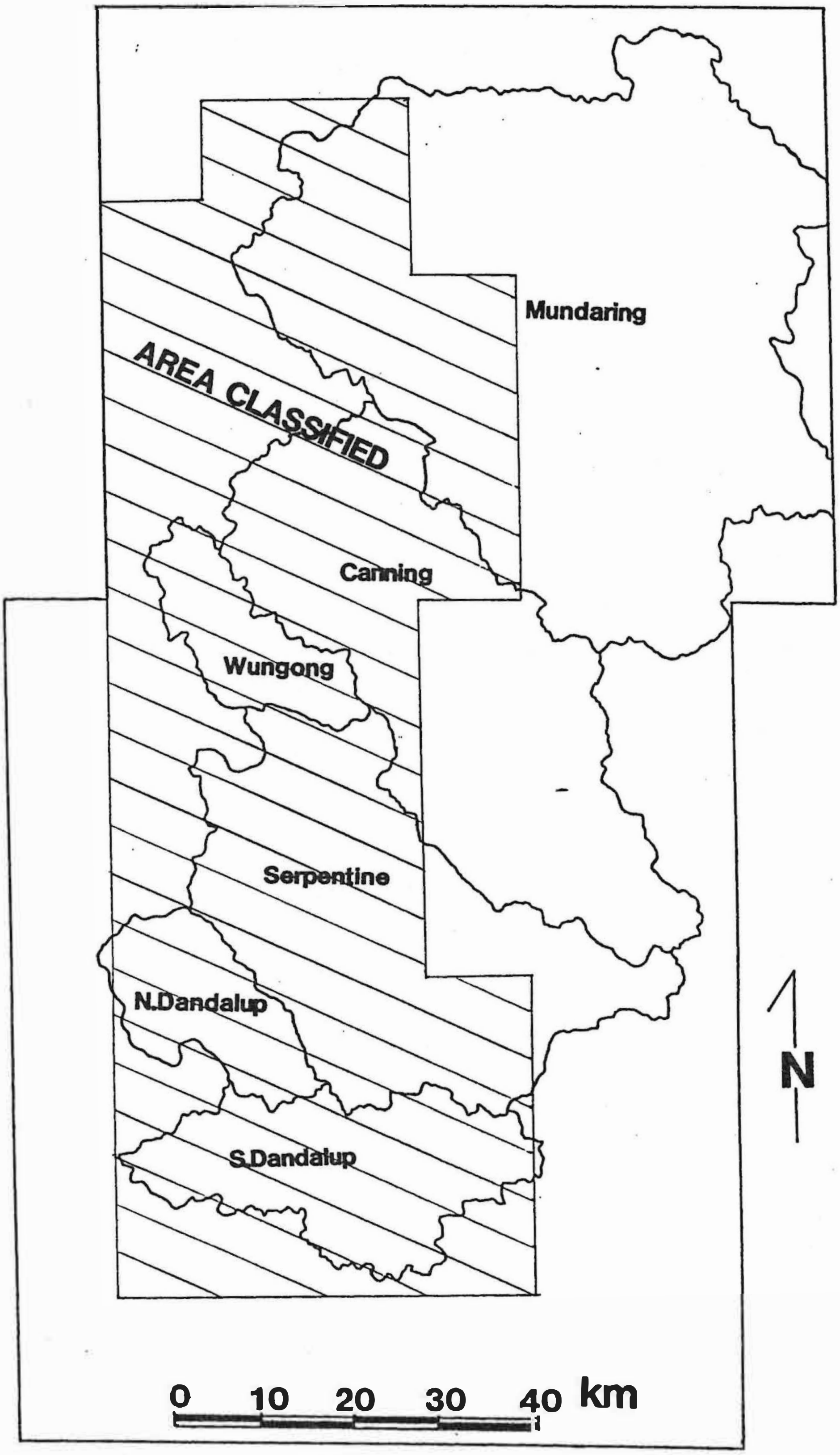


FIGURE3

WATER AUTHORITY OF WESTERN AUSTRALIA

POTENTIAL THINNING OF DARLING RANGE CATCHMENTS

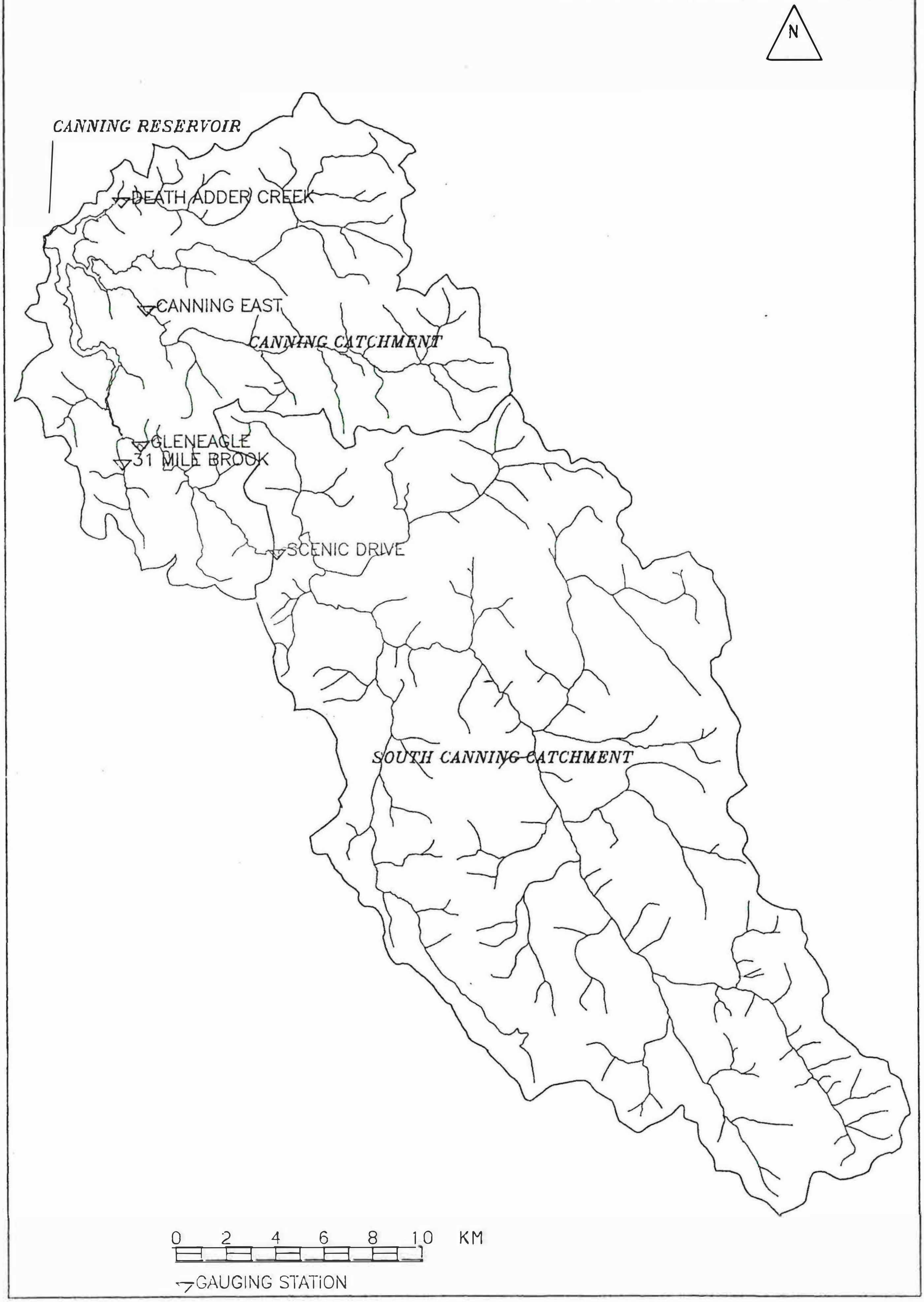
THINNING AREAS INVESTIGATED



WATER AUTHORITY OF WESTERN AUSTRALIA
POTENTIAL THINNING OF DARLING RANGE CATCHMENTS

FIGURE 4

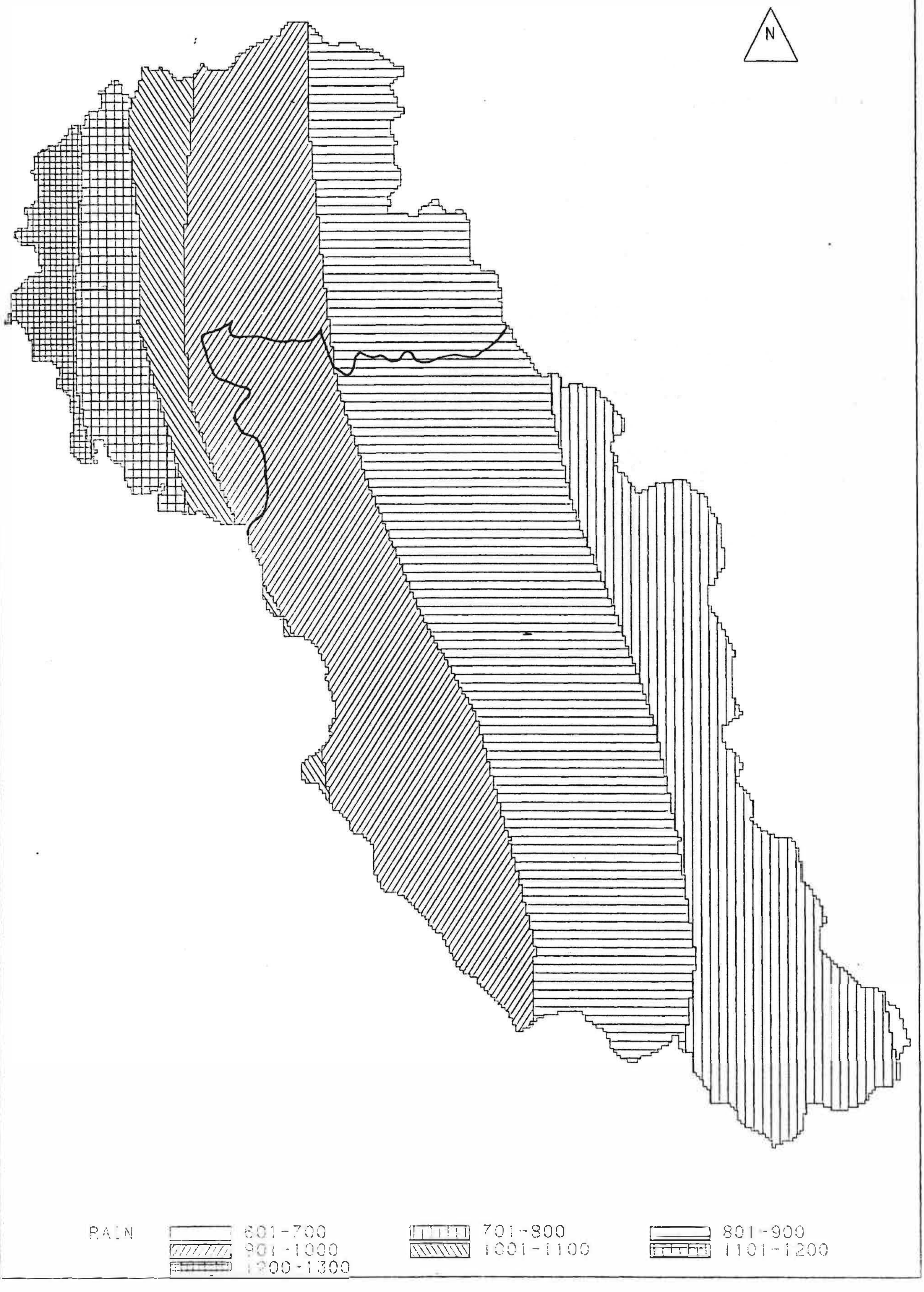
STREAMS AND GAUGING STATIONS



WATER AUTHORITY OF WESTERN AUSTRALIA
POTENTIAL THINNING OF DARLING RANGE CATCHMENTS

FIGURE 5

CANNING ISOHYETS



WATER AUTHORITY OF WESTERN AUSTRALIA

POTENTIAL THINNING OF DARLING RANGE CATCHMENTS

FIGURE 6

CANNING THINNABLE AREAS

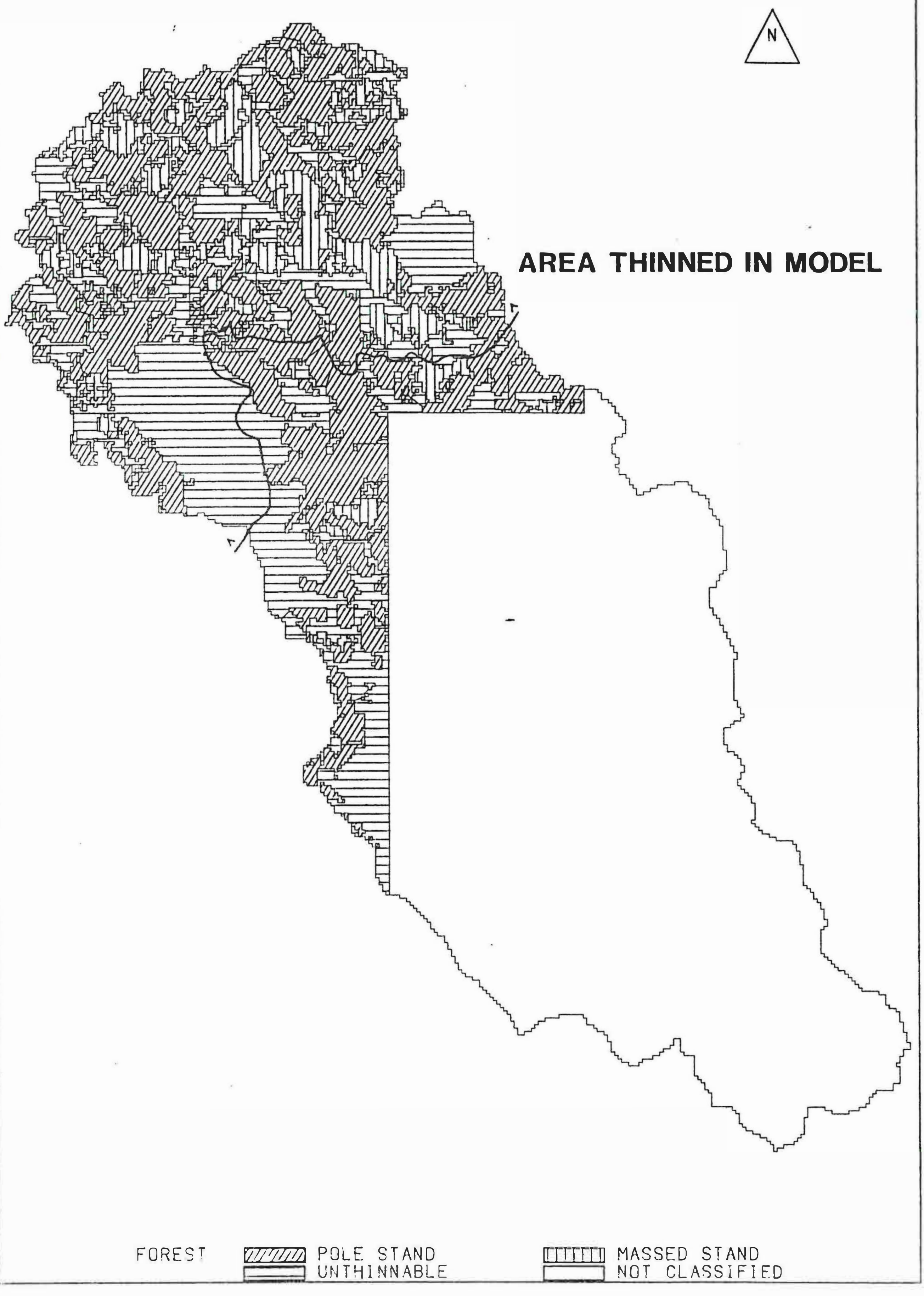
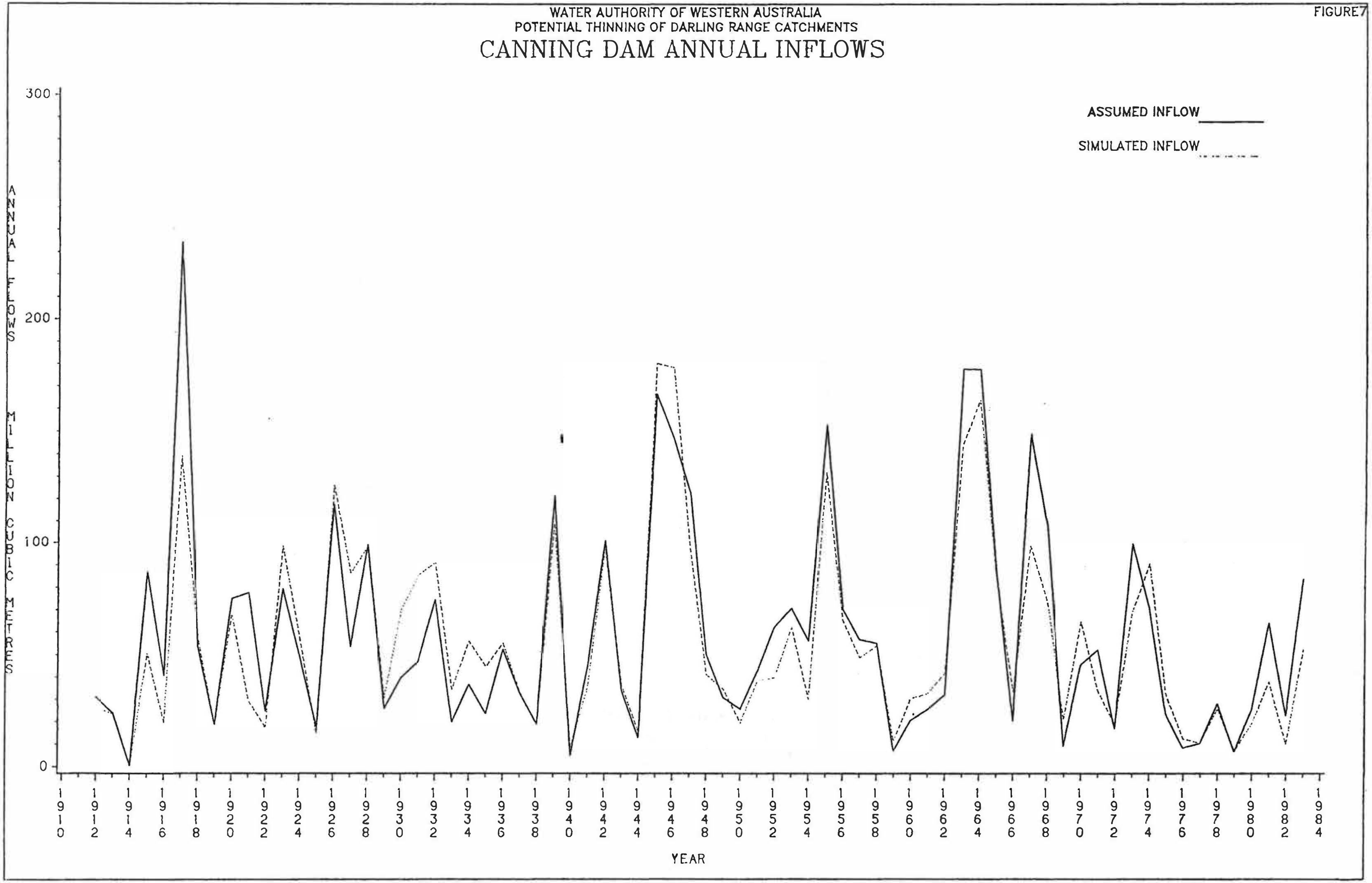
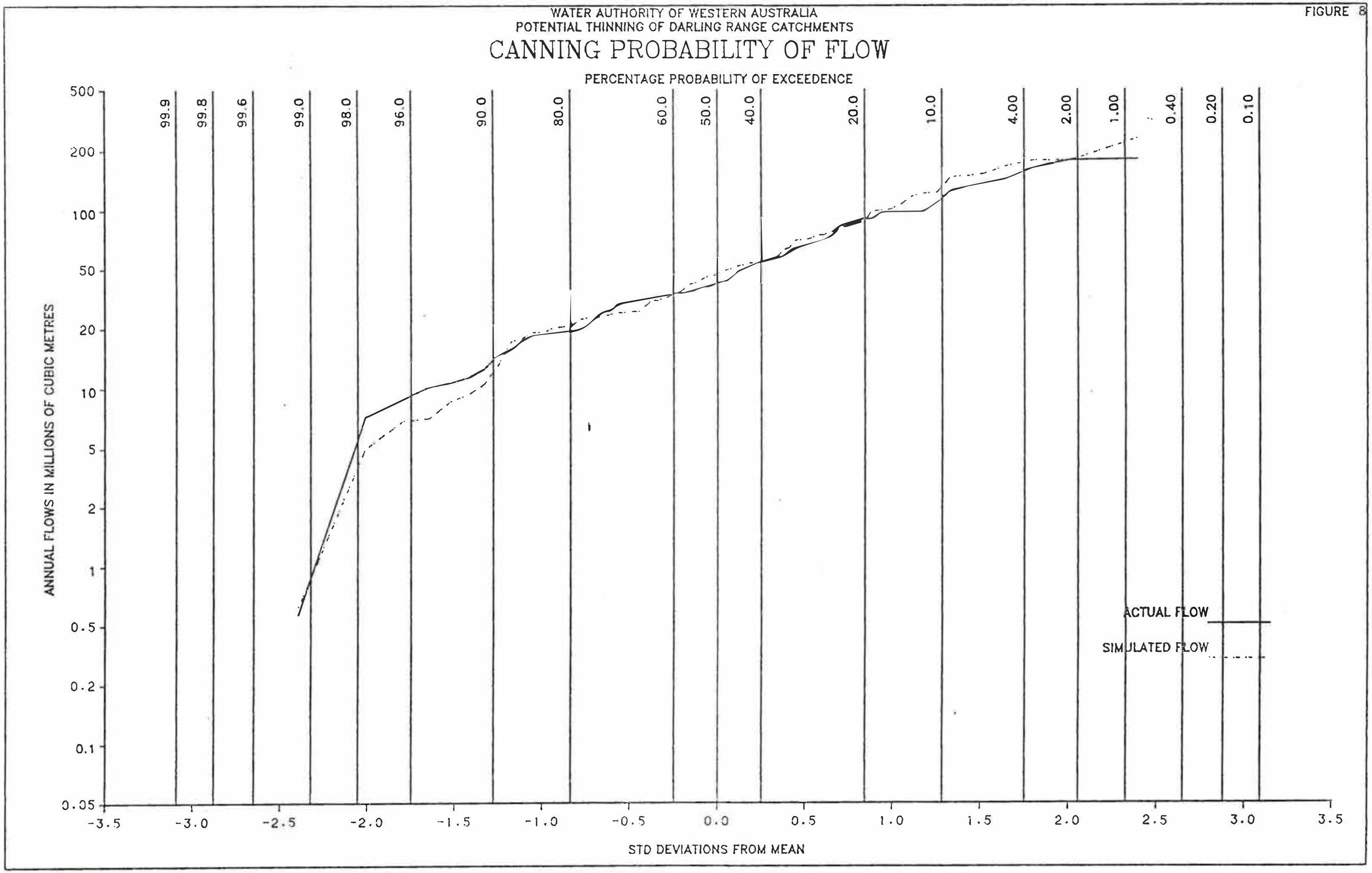


FIGURE7

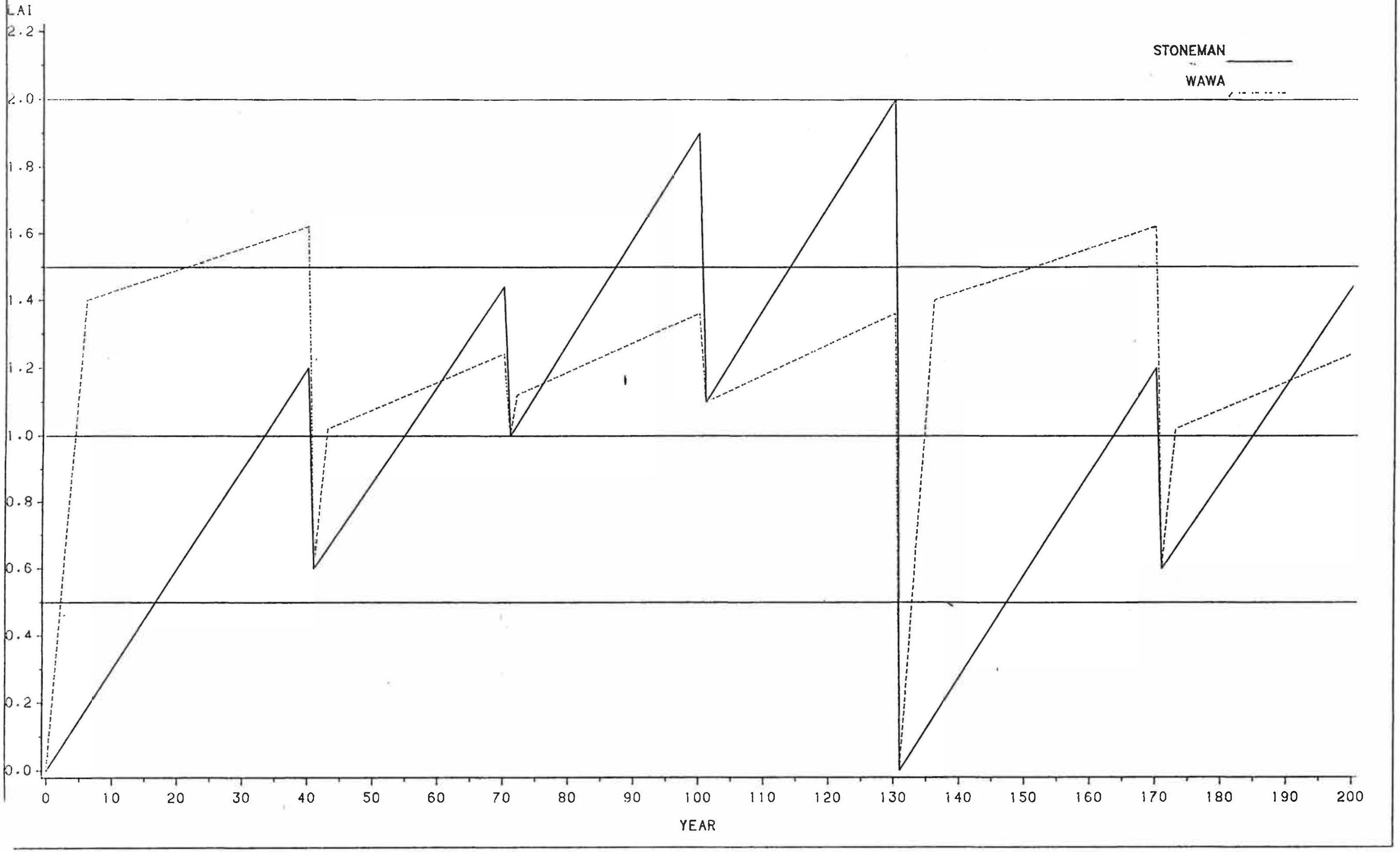

WATER AUTHORITY OF WESTERN AUSTRALIA
POTENTIAL THINNING OF DARLING RANGE CATCHMENTS
CANNING DAM ANNUAL INFLOWS
ASSUMED INFLOW
SIMULATED INFLOW
ANNUAL FLOWS MILLION CUBIC METRES
300
200
100
0
1910
1912
1914
1916
1918
1920
1922
1924
1926
1928
1930
1932
1934
1936
1938
1940
1942
1944
1946
1948
1950
1952
1954
1956
1958
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
YEAR



WATER AUTHORITY OF WESTERN AUSTRALIA
POTENTIAL THINNING OF DARLING RANGE CATCHMENTS
CANNING PROBABILITY OF FLOW
FIGURE 8
PERCENTAGE PROBABILITY OF EXCEEDENCE
99.9
99.8
99.6
99.0
98.0
96.0
90.0
80.0
60.0
50.0
40.0
20.0
10.0
4.00
2.00
1.00
0.40
0.20
0.10
ANNUAL FLOWS IN MILLIONS OF CUBIC METRES
500
200
100
50
20
10
5
2
1
0.5
0.2
0.1
0.05
-3.5
-3.0
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
STD DEVIATIONS FROM MEAN
ACTUAL FLOW
SIMULATED FLOW

WATER AUTHORITY OF WESTERN AUSTRALIA
POTENTIAL THINNING OF DARLING RANGE CATCHMENTS

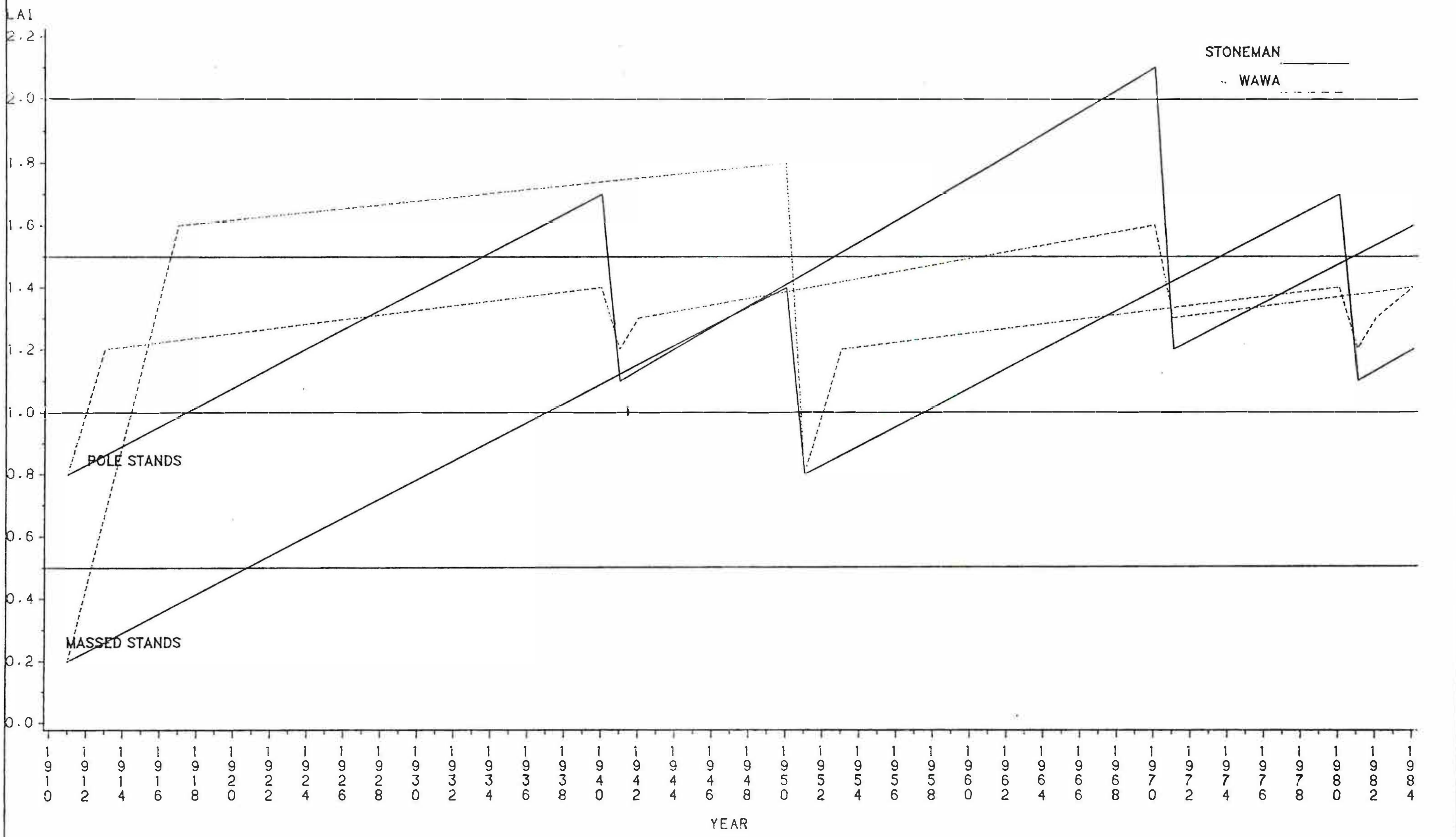
LAI RESPONSE TO MANAGED THINNING



WATER AUTHORITY OF WESTERN AUSTRALIA
POTENTIAL THINNING OF DARLING RANGE CATCHMENTS

FIGURE 10

LAI USED IN MODELLING



GROUND STOREY LAI CONSTANT 0.2

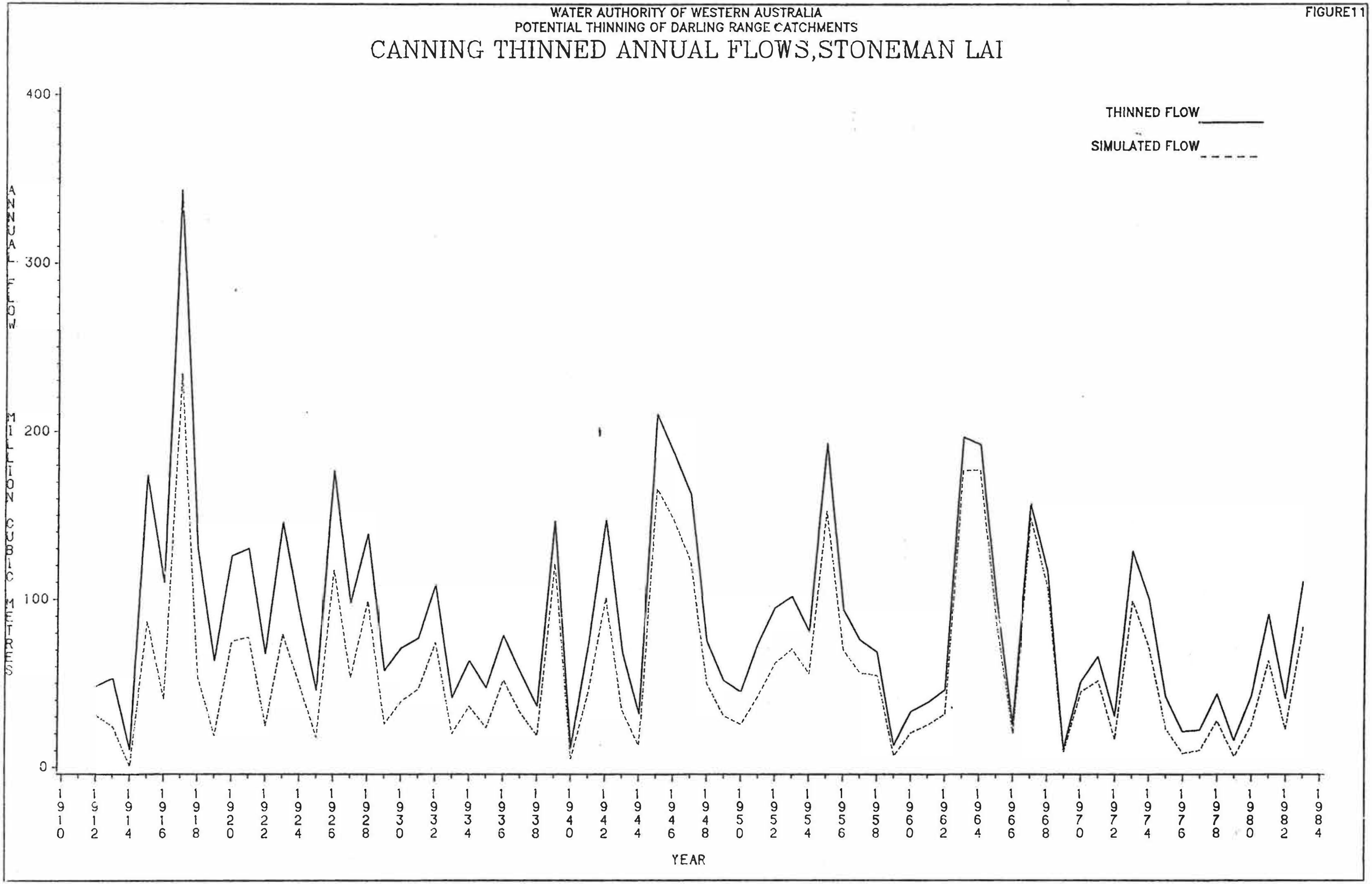
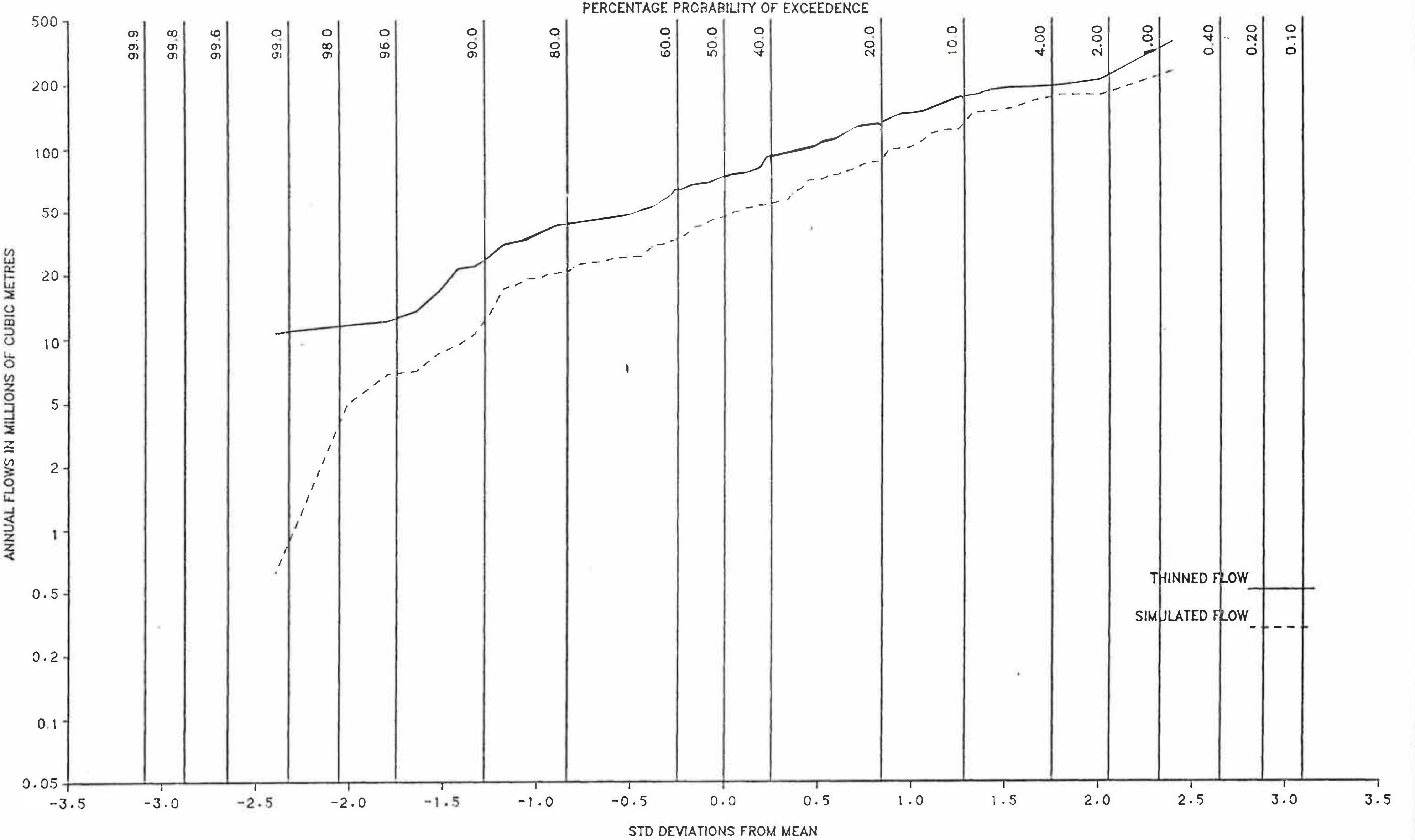

WATER AUTHORITY OF WESTERN AUSTRALIA
POTENTIAL THINNING OF DARLING RANGE CATCHMENTS
CANNING THINNED ANNUAL FLOWS,STONEMAN LAI
FIGURE11
THINNED FLOW
SIMULATED FLOW
ANNUAL FLOW MILLION CUBIC METRES
400
300
200
100
0
1910
1912
1914
1916
1918
1920
1922
1924
1926
1928
1930
1932
1934
1936
1938
1940
1942
1944
1946
1948
1950
1952
1954
1956
1958
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
YEAR

FIGURE 12

WATER AUTHORITY OF WESTERN AUSTRALIA
POTENTIAL THINNING OF DARLING RANGE CATCHMENTS

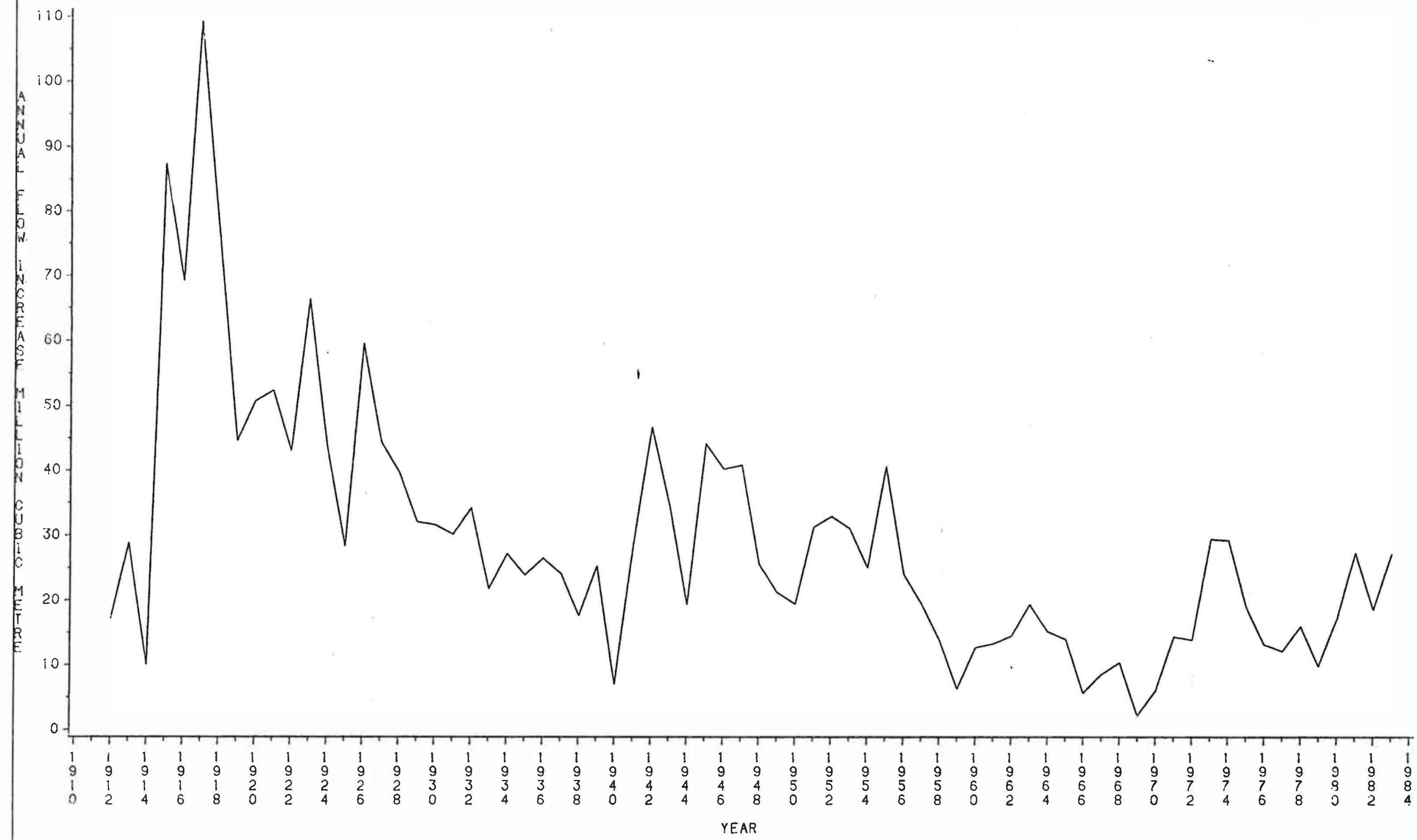
PROBABILITY OF THINNED CANNING FLOW,STONEMAN LAI



WATER AUTHORITY OF WESTERN AUSTRALIA
POTENTIAL THINNING OF DARLING RANGE CATCHMENTS

FIGURE 13

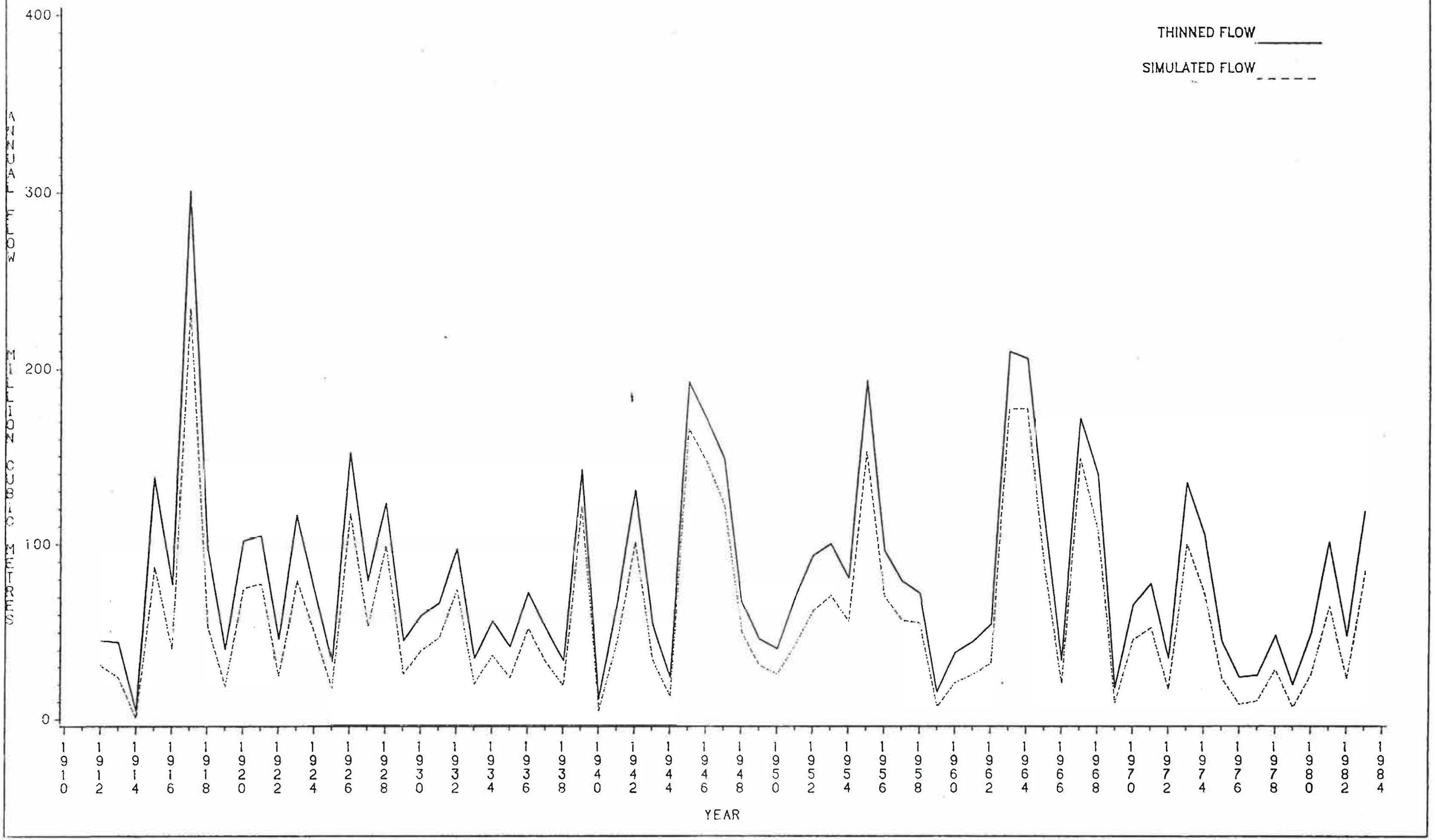
CANNING THINNED FLOW INCREASE,STONEMAN LAI



WATER AUTHORITY OF WESTERN AUSTRALIA
POTENTIAL THINNING OF DARLING RANGE CATCHMENTS

FIGURE14

CANNING THINNED ANNUAL FLOWS,WAWA LAI



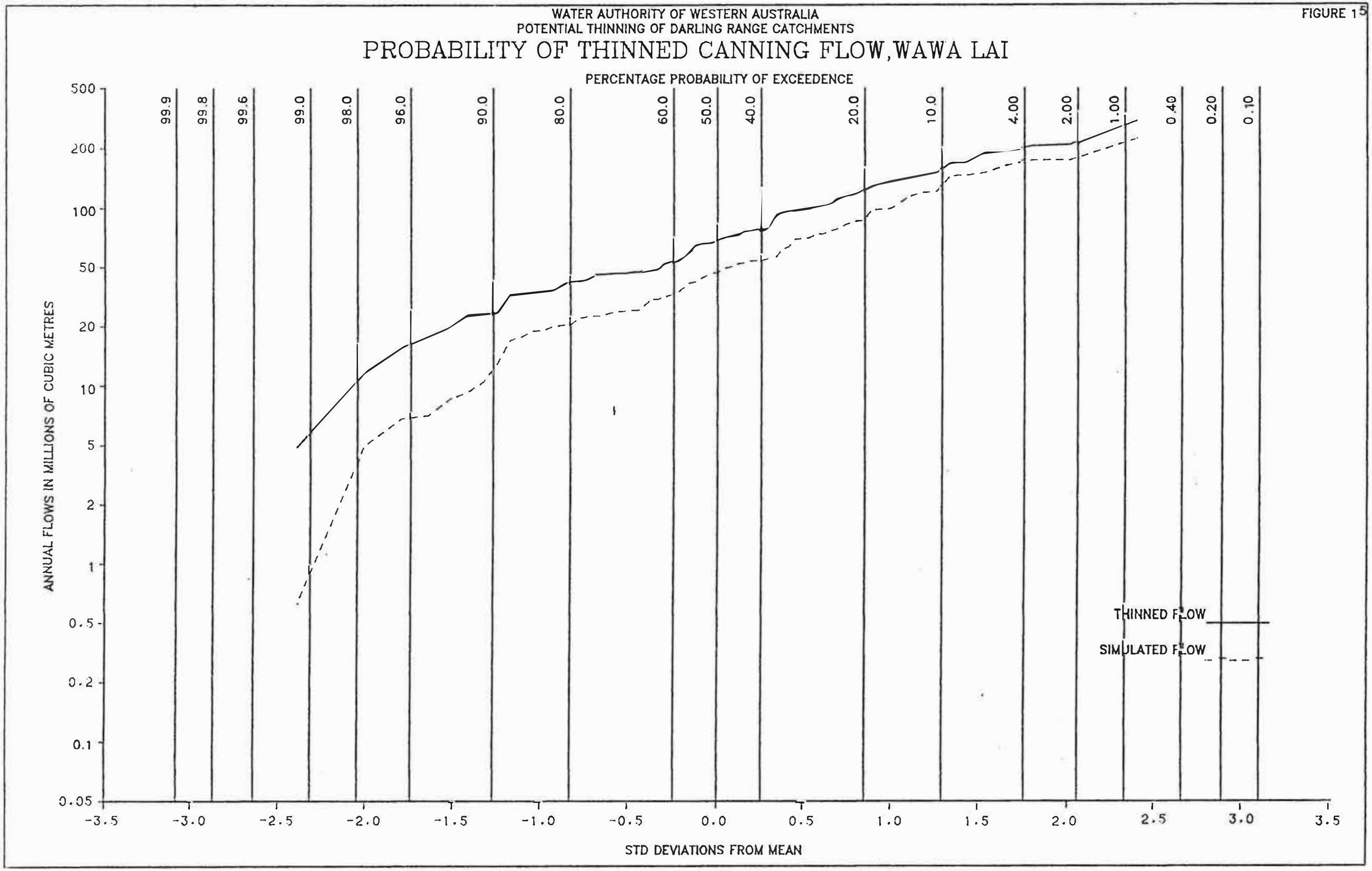
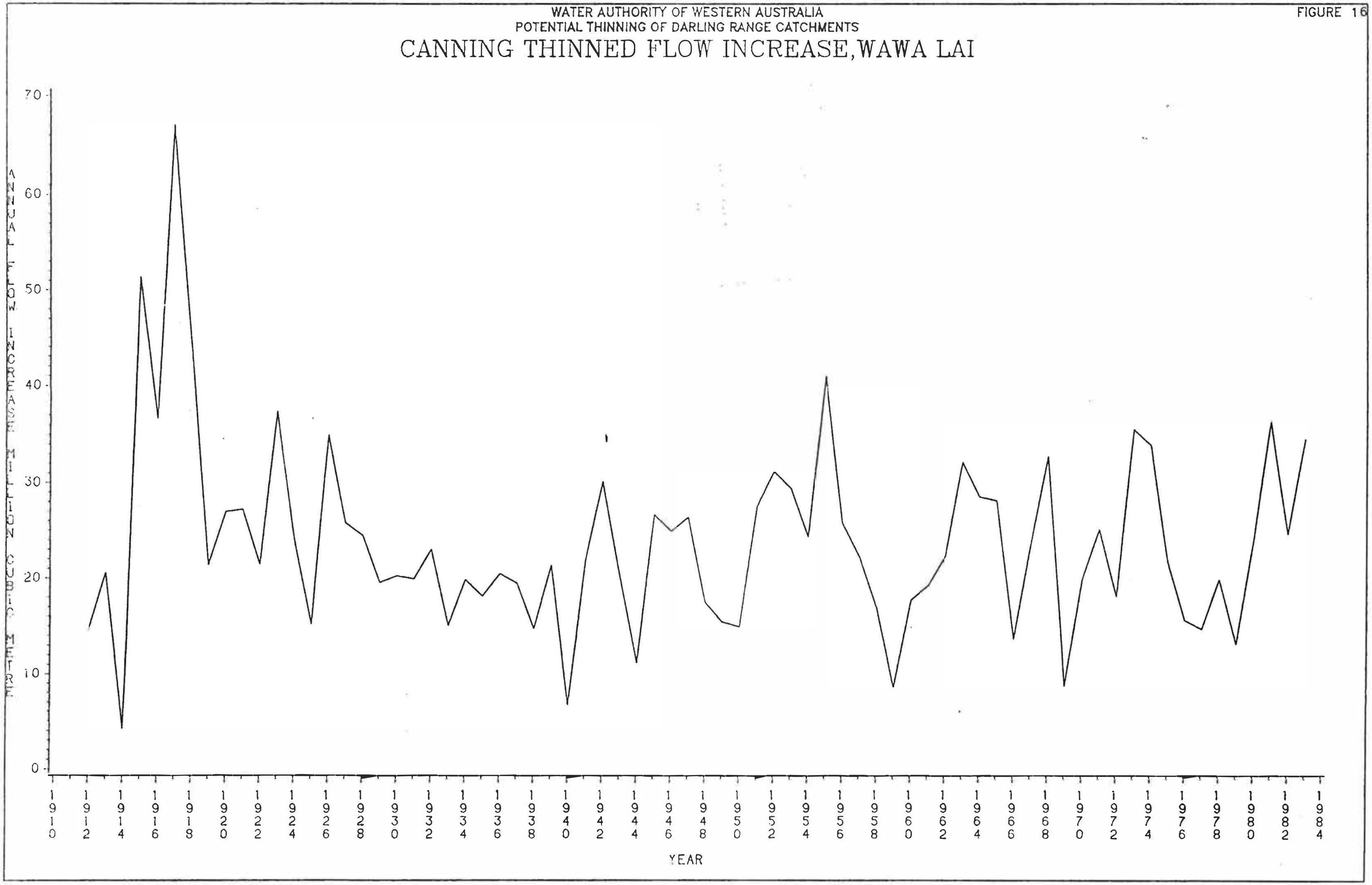

WATER AUTHORITY OF WESTERN AUSTRALIA
POTENTIAL THINNING OF DARLING RANGE CATCHMENTS
PROBABILITY OF THINNED CANNING FLOW, WAWA LAI
FIGURE 15
PERCENTAGE PROBABILITY OF EXCEEDENCE
99.9
99.8
99.6
99.0
98.0
96.0
90.0
80.0
60.0
50.0
40.0
20.0
10.0
4.00
2.00
1.00
0.40
0.20
0.10
ANNUAL FLOWS IN MILLIONS OF CUBIC METRES
500
200
100
50
20
10
5
2
1
0.5
0.2
0.1
0.05
-3.5
-3.0
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
STD DEVIATIONS FROM MEAN
THINNED FLOW
SIMULATED FLOW

FIGURE 16


WATER AUTHORITY OF WESTERN AUSTRALIA
POTENTIAL THINNING OF DARLING RANGE CATCHMENTS
CANNING THINNED FLOW INCREASE,WAWA LAI
ANNUAL FLOW INCREASE MILLION CUBIC METRES
0
10
20
30
40
50
60
70
1910
1912
1914
1916
1918
1920
1922
1924
1926
1928
1930
1932
1934
1936
1938
1940
1942
1944
1946
1948
1950
1952
1954
1956
1958
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
YEAR