THINNING FOR WATER PRODUCTION IN THE NORTHERN JARRAH FOREST : A POSITION PAPER

G.Stoneman
Dept of Conservation and Land Management,
Research Station,
Dwellingup,
W.A. 6213.

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1. SUMMARY

This paper summarises results of research on the effect of thinning on the hydrology of the northern jarrah forest. Throughfall was found to be 19% more in a thinned stand than an unthinned stand, equal to nearly 250 mm more net rainfall (at 1300 mm annual rainfall). Groundwater was found to rise 1 m/yr in response to thinning. Using the ratios of extra water going to unsaturated water storage and saturated water storage (Williamson et al. 1986) indicates a reduction in evapotranspiration of 195 mm/yr. Over a 20 year period leaf area index was reduced 32% by thinning, indicating an equal reduction in transpiration unless transpiration per unit leaf area is increased. Relationships between streamflow and crown cover in the high rainfall zone and intermediate rainfall zone indicate thinning may increase streamflow by 280 mm and 115 mm respectively. Estimates of increases in streamflow for thinning in the high rainfall zone may therefore be considered between 100-200 mm, and in the intermediate rainfall zone between 50-100 mm. One hundred thousand hectares of suitable forest in each of the HRZ and IRZ would therefore yield up to an extra 300 million m^3/yr. The cost of generating the extra water is less then 8 cents/m^3.

However, more work is still required to better define how much streamflow would be generated by thinning, the effect on streamflow distribution, areas suitable for thinning, and conflicts with bauxite mining, dieback and stream salinity. These problems and the research programme designed to answer them are discussed.

2. INTRODUCTION

Most of the northern jarrah forest has been cut over in the last 80 years, and much of it now carries dense regrowth stands. These are slow growing because of intense competition and a slow process of self thinning (Wallace and Podger 1959; Abbott and Loneragan 1983). Moreover, densely stocked catchments which are relatively unaffected by jarrah dieback (Podger 1972) yield as little as one percent of rainfall as streamflow, whereas catchments which have a lower density of trees may yield considerably more. Most of the northern jarrah forest is managed as water catchment for Perth's water supply and rural irrigation. Potential sources of water to supply future demand are limited and it has been estimated that within 50 years all fresh and marginal water resources in the south west will be fully committed (Sadler and Field 1976). Shea et al. (1975) have suggested that thinning of dense regrowth jarrah stands could result in substantial increases in the production of both high quality water and merchantable timber.

A joint research programme involving the Department of Conservaton and Land Management and the Water Authority of Western Australia was initiated in 1976 to study the potential to increase water and wood production in the northern jarrah forest. This paper describes the results of this research, and attempts to provide some preliminary anwsers to the questions of how thinning affects the hydrological cycle in the jarrah forest, what is the likely increase in yield from thinning, and what are the various unknowns about thinning for water production. The paper also describes the research programme aimed at setting much firmer anwsers to these questions.

3. EFFECT OF THINNING ON THE HYDROLOGICAL CYCLE

3.1. Interception

Throughfall was measured over the winter of 1985 in thinned and unthinned stands of sixty year old regrowth jarrah near the 1100 mm rainfall isohyte near Dwellingup. The thinning had taken place twenty years previously. In the unthinned stand (which had a basal area of 35 m^2/ha) throughfall was 79% of rainfall whereas, in the thinned stand (basal area of 12 m^2/ha) throughfall was 98% of rainfall ie. 19% more thoughfall in the thinned stand. With an annual rainfall of 1100 mm this is equivalent to 209 mm more net rainfall. At 1300 mm rainfall it is equal to 247 mm more net rainfall.

3.2. Soil Moisture and Groundwater Recharge

One of the features of the jarrah forest hydrological system are the soils, their depth and large soil moisture storage capacity. This capacity is illustrated by the clearing of Wights catchment near Collie where Sharma et al. (1982) found in the first year following clearing that soil moisture storage in the top 6 m increased by 220 mm in comparison to the still forested Salmon catchment.

The Yarragil 4L catchment on the western edge of the intermediate rainfall zone was thinned from a basal area of 35 m^2/ha to 11 m^2/ha early in 1983. Stoneman (1986a) has attributed the lack of a substantial streamflow response in the first two years following the thinning of the catchment to substantial increases in soil moisture storage.

The two boreholes in the catchment showed rises in groundwater level (in comparison to control boreholes) of about 1 m/yr. By accepting Bestow's (1976) estimate of the storage coefficient of similar material (0.039), and neglecting lateral flow of the groundwater, the thinning has led to an increase in saturated water storage of 39 mm/yr. The magnitude of this rise in groundwater level, which is about 70% of that found for total clearing (Peck 1983), supports the contention that there have also been large increases in unsaturated soil water storage such as those reported by Sharma et al. (1982). Williamson et al. (1986) found reductions in evapotranspiration from clearing for agriculture to go to unsaturated soil storage and saturated soil storage at a ratio of about 4:1 in the first year following clearing (assuming a storage coefficient of 0.039). Extrapolating this to the Yarragil 4L case would indicate a reduction in evapotranspiration of 195 mm/yr.

In a study of the factors affecting groundwater recharge on a hillslope Stoneman (1986b) found for those boreholes where depth to groundwater was greater than 8m, that recharge was most strongly related to stand basal area and best described by an equation including both basal area and depth to groundwater. Using this multiple regression equation to predict groundwater recharge from the reduction in stand density in the Yarragil 4L catchment, would predict an increase in recharge of 2 m/yr. However the increase in recharge has only been 1 m/yr (Stoneman 1986a). There are obviously problems in extrapolating this equation outside its calibration range and to other hillslopes.

3.3. Transpiration

Thinning may affect the transpiration of a stand of jarrah by altering the stand:

i) leaf area, and/or
ii) transpiration per unit leaf area.

3.3.1. Leaf area

The effect of thinning on tree and stand leaf area has been studied in thinning plots established in 1964 in Inglehope forest block, near Dwellingup. Various dimensions and characteristics of selected trees were measured, the tree's were felled, all leaves harvested and the tree's leaf area measured. Dimensional relationships to predict the leaf area of individual trees have thus been established and these have been used in the thinning plots to predict stand leaf area. Figure 1 shows the effect of thinning on stand leaf area immediately after thinning, the average for the 20 year post-thinning period, and 20 years after the thinning. Twenty years after the thinning there is still a very substantial reduction in stand leaf area, and the average for the twenty year period shows that a thinning to 10 m^2/ha of basal area results in a stand with an LAI of 0.95 in comparison to an unthinned stand at 35 m^2/ha with an LAI of 1.40, a reduction of 32%.

We can use this data to make a crude prediction of the reduction in transpiration as a result of thinning, if we firstly assume that the transpiration per unit leaf area does not change as a result of thinning i.e. that transpiration per unit leaf area does not change. We will also assume the water balance is a simple one where:

$$P = I + T + Q$$

where P = precipitation = 1300
Q = streamflow = 5% of rainfall i.e. 75
I = interception = 21% of rainfall i.e. 273
T = transpiration = 1300 - 273 - 75 = 952

a 32% reduction in LAI and transpiration for the thinned stand means

$$T = 952 * 0.68$$
$$= 646$$

This predicts that in the unthinned stand we have transpiration of 952 mm/yr, and in the stand thinned to 10 m^2/ha of basal area transpiration is only 646 mm/yr, a reduction of 306 mm/yr.

3.3.2. Transpiration per unit leaf area

The above calculations are based on the assumption that transpiration per unit leaf area is not affected by thinning and increased soil moisture levels. However, it is likely that this is not the case. Jarvis (1975), Whitehead and Jarvis (1981) and Whitehead (1984) argue that a thinned stand will compensate for the reduction in leaf area that thinning imposes. They argue that if half the leaf area is removed, the total stem resistance to water flow will double, individual crowns will absorb more radiation, stand transpiration will fall, but flow within the individual stems will increase, and needle water potential will be lowered i.e. transpiration per unit leaf area will increase. The stand will then tend to regrow towards the unthinned leaf area, thereby doubling leaf area per tree. Transpiration will increase back to unthinned levels, flow of water within each tree will double, leaf water potential will return to unthinned levels, thus avoiding adverse low water potentials, and total stem resistance to water flow will return back to unthinned levels.

However, Bartle (pers.comm.) found no higher levels of transpiration in spring (when soil moisture is high) compared to autumn (when soil moisture is low) on a tree in the high rainfall zone. Unfortunately, the site may not be representative of the whole of the northern jarrah forest, and the soil moisture status may not have reached a critical point where it starts to limit transpiration. It may more readily reach this point on other soils in the high rainfall zone and more particularly in the lower rainfall zones. Transpiration per unit leaf area thus may be increased by thinning, and this is likely to be more so in the lower rainfall zones. However, this in only a hypothesis and is a subject requiring research.

There is some indirect evidence to support this in the work of Stokes and Batini (1985). A 30% reduction in stand density in the Wellbucket catchment in the lower rainfall zone had no effect on groundwater recharge or streamflow. Thus evapotranspiration appeared to remain the same even though leaf area had been reduced by approximately 30%. Transpiration per unit leaf area may have increased accordingly.

On the other hand Crombie (pers.comm.) found no difference in water stress of both a range of understorey species (some shallow rooted and some deep rooted) and jarrah in thinned and unthinned stands in the high and intermediate rainfall zone over the spring and early summer of 1985/86.

3.4. Streamflow

There are a number of sources of indirect evidence to support the contention that thinning will increase streamflow.

3.4.1. High rainfall zone

Figure 2 shows the relationship between streamflow and crown cover for seven research catchments. The dense regrowth catchments yield only one or two percent of rainfall as streamflow i.e. 10-20 mm, whereas catchments with less crown cover yield vastly more streamflow. The relationship would predict approximately 300 mm streamflow for a 20% crown cover (a 20% crown cover is about what we would expect in thinning to 10 m^2/ha of basal area) i.e. 280 mm more than for a 50% crown cover.

Figure 3 shows the salt balances of these catchments, and relates them to streamflow. The dense regrowth catchments are rapidly accumulating salts (O/I = 0.2). This is occuring in the high rainfall zone where there are no substantial pre-existing accumulations of salt in the soil, and it is thus presumably a function of the density of the regrowth forest. The dense regrowth catchments appear to have streamflows of about 80 mm less than the oldgrowth forests they replaced.

3.4.2. Intermediate rainfall zone

Streamflow in the intermediate rainfall zone appears to be influenced by more factors than in the high rainfall zone, and therefore the relationship between streamflow and crown cover is much more variable (Figure 4). However by selecting catchments with similar physical characteristics we can reduce this variability and get a better idea of how streamflow is affected by forest density in the IRZ (Figure 5). The range of crown cover's is fairly small (40-55%) as in the range of streamflows (10-60 mm), but if we extrapolate this relationship to a crown cover of 20%, a streamflow of 131 mm is predicted i.e. 115 mm more than for a 50% crown cover. The potential to increase streamflow in the IRZ is thus substantially less than in the HRZ and this is a reflection of the smaller winter excess between rainfall and evaporation.

3.4.3. Low rainfall zone

The soils in the low rainfall zone have accumulated substancial quantities of salt, and clearing of the forest for agricultural development has been shown to lead to stream salinization. Therefore reducing the forest density in the LRZ is a very risky proposition. However, there is potential to increase streamflow and the evidence is presented below.

Stokes and Batini (1985) reported a streamflow increase of 1.5 - 3.0 mm for a 30% reduction in basal area in a small catchment with average annual rainfall of 700 mm. The saline deep groundwater did not respond to the treatment. Williamson et al. (1986) found streamflow to increase by up to 50 mm in response to partial or complete clearing of Earnies and Dons catchments. Groundwaters did respond to the clearing and are likely to cause stream salinization within 20 years of clearing.

Whilst the potential increases in streamflow per unit area are quite small, the areas involved are large and there is potentially a significant additional resource in the LRZ.

3.5. Soil Evaporation

Hewlett (1984) states soil evaporation is minor under full forest cover because the forest insulates the forest floor from radiation and prevents air movement over it. However, Greenwood et al. (1985) found evaporation from the groundlayer (groundflora, litter and soil) to be 37% of annual rainfall on a site in the northern jarrah forest.

When a forest is thinned soil evaporation will in part replace the reduction in transpiration and interception (Hewlett 1984). Thinning increases the amount of energy reaching the forest floor, and this energy is available to drive the evaporation process. Thinning will also increase the amount of bare soil, and reduce the amount of leaf litter and its mulching effect, both of these adding up to an increase in soil evaporation (Ritchy 1972, Marshall and Holmes 1979).

The depth to a water table also has a pronounced effect on soil evaporation. In a clay loam soil the evaporation rate is about 1 mm/day when the water table is 1.7 m deep and 5 mm/day when the water table is 0.7 m from the soil surface (Marshall and Holmes 1979). Thinning, by raising the groundwater level may facilitate soil evaporation to increase substancially in the lower landscape positions.

3.6. Understorey Response

There are many examples in the literature of the understorey responding in density and height to a reduction in overstorey density. (FFOLLIOT and CLARY 1982) However, from observations in the jarrah forest there appears to be no response by the understorey to thinning of the overstorey.

3.5. Darling Range Catchment Model (DRCM)

DRCM (Hopkins 1984, Mauger 1986) was used to predict the effect of thinning the Yarragil 4L catchment on streamflow over a 15 year period. Only small increases in streamflow were predicted in the first few years, but after 4 or 5 years substantial increases were predicted. Over the 15 year period streamflow for the catchment unthinned was predicted at 150 mm, whereas for the catchment thinned it was predicted at 1030 mm, an increase of 880 mm or nearly 60 mm/yr (Figure 6). The results from the model were to a large extent dependent on the rate at which leaf area was grown back following the thinning. The growth rate used in the model was substantially more than the leaf area response reported in section 3.3.1., and so the results from the model may be considered a conservative estimate of the increase in streamflow from thinning.

4. POTENTIAL INCREASES IN STREAMFLOW AND THEIR COSTS

The preceding discussion has given a number of predictions about reductions in evapotranspiration or increases in streamflow resulting from thinning jarrah stands from a basal area of 35 m^2/ha to 10 m^2/ha. These can be summarised as:

1) Interception and transpiration reductions. The estimate here is for a reduction in evapotranspiration of 550 mm (1300 mm rainfall),

ii) Groundwater rise and soil moisture storage increases. The estimate is reductions in evapotranspiration of 195 mm (1120 mm rainfall),

iii) Streamflow versus crown cover relationships. The estimates here are 280 mm more streamflow (1300 mm rainfall) and 115 mm more streamflow (1050 mm rainfall).

Given that ther may be compensating methods of water loss i.e. increased transpiration per unit leaf area, soil evaporation, understorey response, and increased water use by vegetation downslope of thinned areas then estimates of increases in streamflow for dense forest in the high rainfall zone may be considered between 100-200 mm, and in the intermediate rainfall zone 50-100 mm.

Table 1 shows the volumes of extra water that would be generated by thinning with varying levels of streamflow increase and areas suitable for thinning. The most conservative estimate of areas might be: 50,000 ha suitable, which is all in the IRZ, where an increase of only 50 mm is likely, giving a total increase in streamflow of 25 M m^3/yr. A much less conservative estimate might be: 100,000 ha suitable in HRZ giving an extra 200 mm i.e. 200 M m^3/yr plus 100,000 ha in the IRZ giving an extra 100 mm i.e. 100 M m^3. A total of 300 M m^3/yr extra.

Preliminary estimates of the cost of producing this water by thinning jarrah forest stands is shown in Table 2. The range of costs of treatment are dependent on how commercial the thinning is. A very expensive non-commercial thinning (i.e. the State to cut down and kill the unwanted trees) which would be very thorough and produce an aesthetically pleasing result could cost $400/ha. Using less aesthetically pleasing methods of thinning would reduce the cost to around $200/ha. Alternatively if markets are developed and there is a demand for all of the thinnings (see Stoneman 1986c) then the cost to the State may be very little e.g. $10/ha. The $10/ha annual maintenance cost allows for a coppice control programme and the cost of additional or alternative use of fire.

Even the most expensive non-commercial thinning treatment ($37/ha/yr) and most conservative estimate of increase in streamflow (50 mm/yr) yield extra streamflow at the small cost of 8 cents per cubic metre. This 8 cents/m^3 compares very favorably with alternative sources for future water supplies, and obviously costs of 0.5 cents/m^3 compare even more favorably.

5. EFFECTS OF THINNING ON WOOD PRODUCTION

Figure 7 shows the general relationship found between stand growth and stand density. In density type I the trees are so far apart that they do not influence each other and growth is directly proportional to stand density. The effect of slight competition in density type II is indicated by a declining rate of increase in increment with respect to stand density. In the broad range of density indicated by density type III, increment is virtually independent of variations in stand density; the usual objective of thinning is to keep the stand density somewhere within this optimum range. In density type IV the effects of extreme competition are reflected in a decline in growth with increasing density (Smith 1962).

A relationship of this general form has been found for jarrah (Figure 8). Stand increment is virtually independent of stand density over the range of 10-30 m^2/ha of basal area. The silvicultural prescription for thinning in the jarrah forest (Bradshaw 1985) specifies thinning to the lower end of this range i.e. 10 m^2/ha. By accruing all the growth of the stand onto the fewest number of trees, we are therefore growing each tree at the fastest rate consistent with maintaining the maximum stand increment. Figure 9 shows the relationship between diameter increment of trees and stand density. By thinning from 35 m^2/ha to 10 m^2/ha the growth rate of the fastest growing trees is approximately doubled. Therefore the time taken for these crop trees to reach a sawlog size is halved. Halving the time taken to reach a sawlog size has a big impact on the economics of wood production, and if there are also returns from the thinning rather than costs, then the economics of wood production are much more favorable with thinning than without.

6 UNKNOWNS

6.1. How Much Extra Streamflow Is Generated By Thinning?

Whilst a number of estimates of this have been made earlier in this paper, these have all been derived indirectly and mostly with simplifying assumptions and crude numbers. There is an active research programme designed to answer this question, which will be described later in the paper.

6.2. Distribution Of Streamflow

The effect of thinning on the distribution of streamflow in time has implications for flood management and spillway design. If thinning mainly increases the peak flows then it is much more likely that a higher proportion of this water will not be harnessed than if thinning greatly increased the flow period and the baseflow contribution.

It is likely that most of the increased yield will be produced as additional sub-surface seepage. This has been the experience with bauxite mining and agricultural development (Loh _et_ _al_. 1984, Stokes and Loh 1982). Increases in flood plain management problems are of concern, but are probabably secondary. An important advantage of forest thinning is that large percentage increases occur in dry years. This has the effect of reducing the annual variability of streamflow volumes and therefore will contribute to decreasing the probability of water restrictions from the total metropolitan system. Contrary to this however, some reservoirs currently have a small storage relative to their mean annual flow and much of the increased water could result simply in additional spillage.

It is difficult to quantify these efects without running detailed simulations of the storage system in conjunction with the changed flow regime. The ultimate aim of work on the DRCM and the Sources Development Programme within the Water Authority has been to evaluate the incremental benefits from changes in vegetation cover on the total system yield of the metropolitan supply system.

Some preliminary comments can be made however, on the value of water yield increases on different catchments of current water storages.

The storage most likely to catch additional water yield from thinning would be that of South Dandalup Dam (storage/inflow ratio of over 5 and current inflow of 105 mm). The storage least likely to catch the extra yield (without the construction of additional storage volume) would be Canning Dam (storage/inflow ratio of about 1.5 and inflow of 84 mm). Wungong and Serpentine resrvoirs have storage/inflow ratios of 2.2 and 2.5 respectively with inflows of 210 mm and 113 mm respectively. Serpentine is likely to have more scope to harness additional yield than Wungong, although both (with storage/inflow ratios of less than 2.5) are likely to spill a significant proportion of the additional water yield.

6.3. Area Suitable For Thinning

Foresters have estimated somewhere between 50,000 and 200,000 ha of the northern jarrah forest as suitable for thinning i.e. between 5 and 20%. These estimates are at best educted guesses and a systematic inventory of the land resources is required. Where is the suitable forest, what is its present density, is it in a harnessed catchment, does the dam have the capacity to store extra streamflow, what rainfall zone is the forest in, and where is the suitable forest in the local landscape? Thinning for water production also has potential conflicts with bauxite mining and dieback management.

6.3.1. Distribution of suitable areas

The most suitable site types for thinning are generally high in the landscape on the upper slopes, ridges and plateau. These areas are the most removed from the streams, and extra water generated high in the landscape may be used by vegetation lower in the landscape (see section 3.3.).

Suitable site types are distributed throughout the region and may occupy only a small proportion of any given catchment. For example, in the Yarragil catchment suitable site types occupy between 10% and 80% of the area of any subcatchments.

6.3.2. Conficts with bauxite mining

It has been recognised for many years that the best forest is associated with the best bauxite development. The most dense stands of jarrah are found high in the landscape where the unsaturated thickness of the soil profile is greatest (Havel 1975, Stoneman 1986b). Jarrah's preference for these sites is a reflection of its adaption to using water all year round from the large stores of unsaturated water in the soil. The best bauxite is also in the high landscape positions where the soil profile is deepest.

What is the degree of overlap between areas suitable for bauxite mining and those suitable for thinning for water and wood production?

6.3.3. Conflict with dieback management

Jarrah dieback is caused by a tropical, soil-borne fungus Phytophthora cinnamomi. Conditions which favor the fungus are moist and humid. In 1983 Shea et al. found severe disease on upland apparently well-drained laterite profiles to be associated with poor internal drainage, such poor drainage creating conditions highly favorable for subsurface fungal activity and transmission.

This work suggested that high impact disease might be exclusively associated with sites exhibiting impeded drainage (or where such a condition was artificially created) all other sites being relatively safe. Unfortunately, this has not been confirmed in subsequent research. Examination of a large number of diseased sites failed to reveal the existance of an obvious impedance to drainage on all high impact sites. Other factors in addition to drainage may therefore be contributing to high impact disease. One possible factor is indicated in work by Tippett et al. (1986) who found that the normal summer water deficits experienced by jarrah on Z and H site types in the eastern forest inhibited fungal activity whereas a P site type did not experience summer water deficits and displayed sustained fungal activity through summer. The absence of summer water deficits in lower rainfall forest appears to be a feature of the P site type and may contribute to its widely observed disease vulnerability. However in high rainfall western forest no significant differences in summer water deficits or lesion extention were found. Thinning therefore may have the potential to favor dieback by increasing soil moisture levels and decreasing summer water deficits.

6.4. Stream Salinity In The IRZ

Rising groundwater level is not of concern in the HRZ (salt free zone) where it can only lead to increases in fresh water yields, but is of concern in the salt sensitive intermediate and low rainfall zones. Whether or not thinning results in water quality problems depends on a number of factors:

(i) How long will groundwater levels continue to rise? They have risen at 1 m/yr in the first few years following thinning in the Yarragil 4L catchment. Will this trend continue?

(ii) The processes of water movement in the soil. What are the relative amounts of any extra water in the soil that move through the fresh perched aquifer and the deep relatively saline aquifer? If the ratio of the extra amount of water that moves through the fresh relative to the saline and contributes to streamflow is greater than or similar to the ratio of their present or potential salinity, then stream salinity should not be significantly affected. This could be important in the intermediate rainfall zone where groundwater salinity and soil salt storage is moderate.

(iii) How does the salinity of the extra water generated by thinning compare to the average salinity of water yielded to each particular reservoir.

(iv) The depth to groundwater which determines the time the vegetation has to re-establish its water use before salt mobilization occurs. In the low rainfall zone there are much greater depths to groundwater and therefore a greater buffer in the system.

(v) Does the extra soil moisture allow leaf area or transpiration per unit leaf area to increase?

(vi) The distribution of suitable areas. What proportion of any given catchment is suitable and how will the thinning be distributed in time?

7. RESEARCH PROGRAMME

7.1. Catchment Studies

Catchment studies to test the effect of thinning and other forest management options were initiated in 1976 and 1977 in the IRZ and HRZ respectively. It is intended to thin 3 catchments in each rainfall zone, the 3 covering the range of densities of interest from both the silvicultural and hydrological point of view. So far, the Yarragil 4L catchment (1120 mm rainfall) has been thinned to 11 m^2/ha in early 1983, and Hansens catchment (1300 mm) was thinned to 7 m^2/ha in early 1986.

Aspects being studied include streamflow and groundwater, forest structure, composition, density and growth.

7.2. Interception

Interception studies are continuing and the stand being studied has recently had a second thinning.

7.3. Conflicts With Bauxite Mining

A study is planned to quantify the degree of overlap between areas suitable for thinning for water or wood production, their dieback susceptibility, and those suitable for bauxite mining from west to east across the northern jarrah forest.

7.4. Dieback

Present research is aimed at developing techniques to identify site vegetation types in relation to their dieback susceptibility, and to test the effect of thinning on dieback susceptibility on a range of site types. Other work is investigating the effect of water relations on host susceptibility.

7.5. Transpiration

Methods to estimate leaf area need to be able to cope with a range of temporal and spatial scales. The leaf area of a tree changes markedly in very short periods of time, therefore the method needs to be able to predict both the actual leaf area at that time and the leaf area over the last "x" years (depending on the use these estimates are to be put). Methods are required that are able to predict the leaf area of individual trees, of stands and research catchments and of regional catchments. These methods are currently being developed in the northern jarrah forest (Whitford and Stoneman 1985).

Research is also planned to study the effect of thinning on the water relations of jarrah from west to east across the forest. Do trees in thinned stands in the high rainfall zone experience less water stress (and more transpiration per unit leaf area) than trees in unthinned stands? Is this more so in the lower rainfall forest?

7.6. Groundwater

The effect of thinning on groundwater levels is being studied in the various catchment experiments. It is also being studied on the old Hunt Steering Committee, Project 4, Site 4 area along Coach Rd on the western edge of the IRZ near Dwellingup.

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Area suitable (ha)	Increase in streamflow (mm)		
	50	100	200
50,000	25	50	100
100,000	50	100	200
150,000	75	150	300
200,000	100	200	400

Table 1: Sensitivity of total streamflow increase (Millions of m^3) from thinning to streamflow increase per unit area, and area suitable for thinning.

Cost of thinning ($/ha/yr)	Increase in streamflow (mm)		
	50	100	200
11(1) →	2	1	0.5
23(2) →	4	2	1
37(3) →	8	4	2

Table 2: Sensitivity of cost of generating extra water by thinning (cents/m³) to streamflow increase per unit area and the cost of thinning.

Note: (1) $10/ha initial cost plust $10/ha maintenance costs averaged over 15 year period.

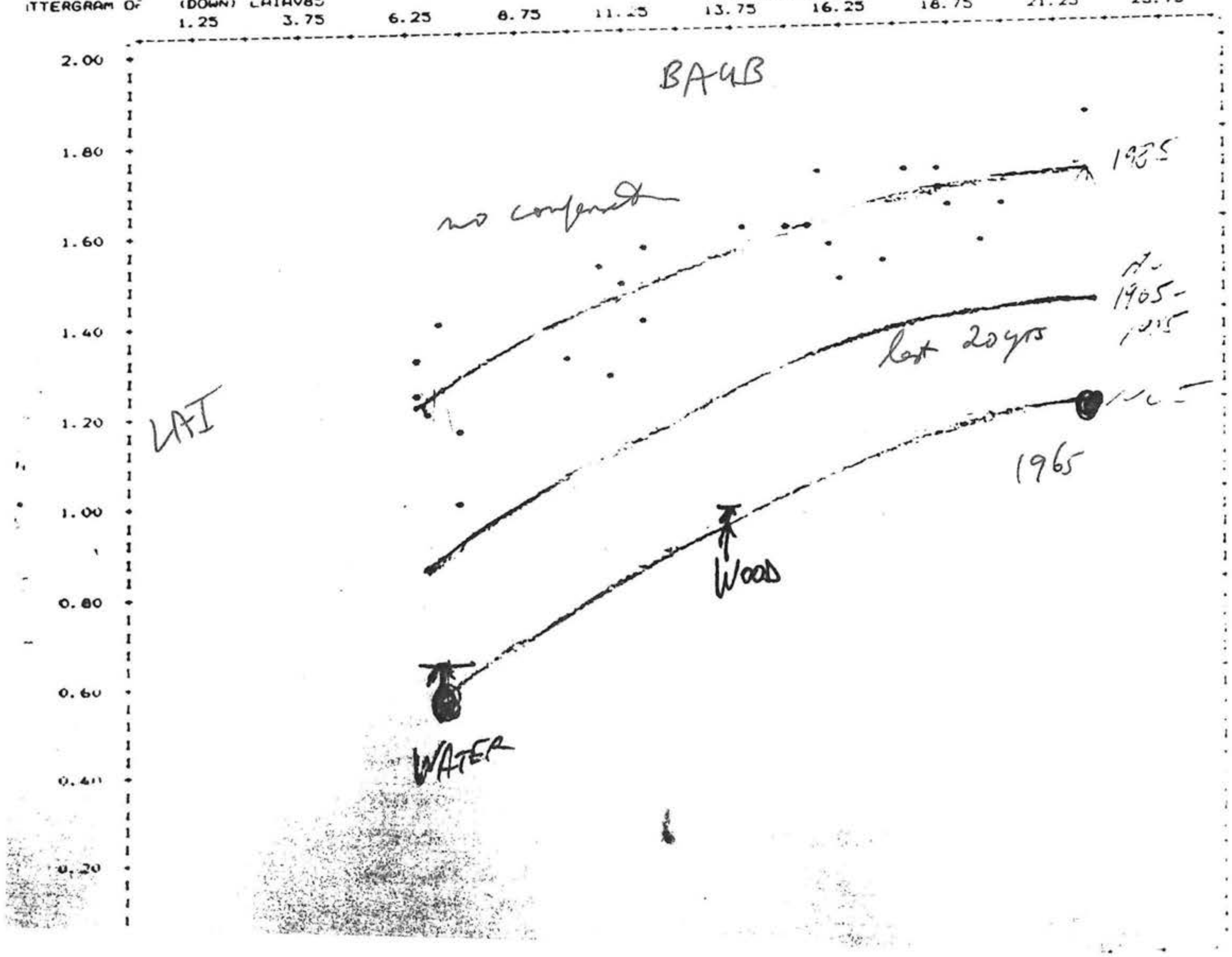
(2) $200/ha initial cost plus $10/ha maintenance costs averaged over 15 year period.

(3) $400/ha initial cost plus $10/ha maintenance costs averaged over 15 year period.

Figure 1

F AREA REGRESSIONS FOR INGLEHOPE THINNING PLOTS 30/10/85 PAGE 2

E NONAME (CREATION DATE = 30/10/85)
ITTERGRAM OF (DOWN) LAIAV85 (ACROSS) BAUB65



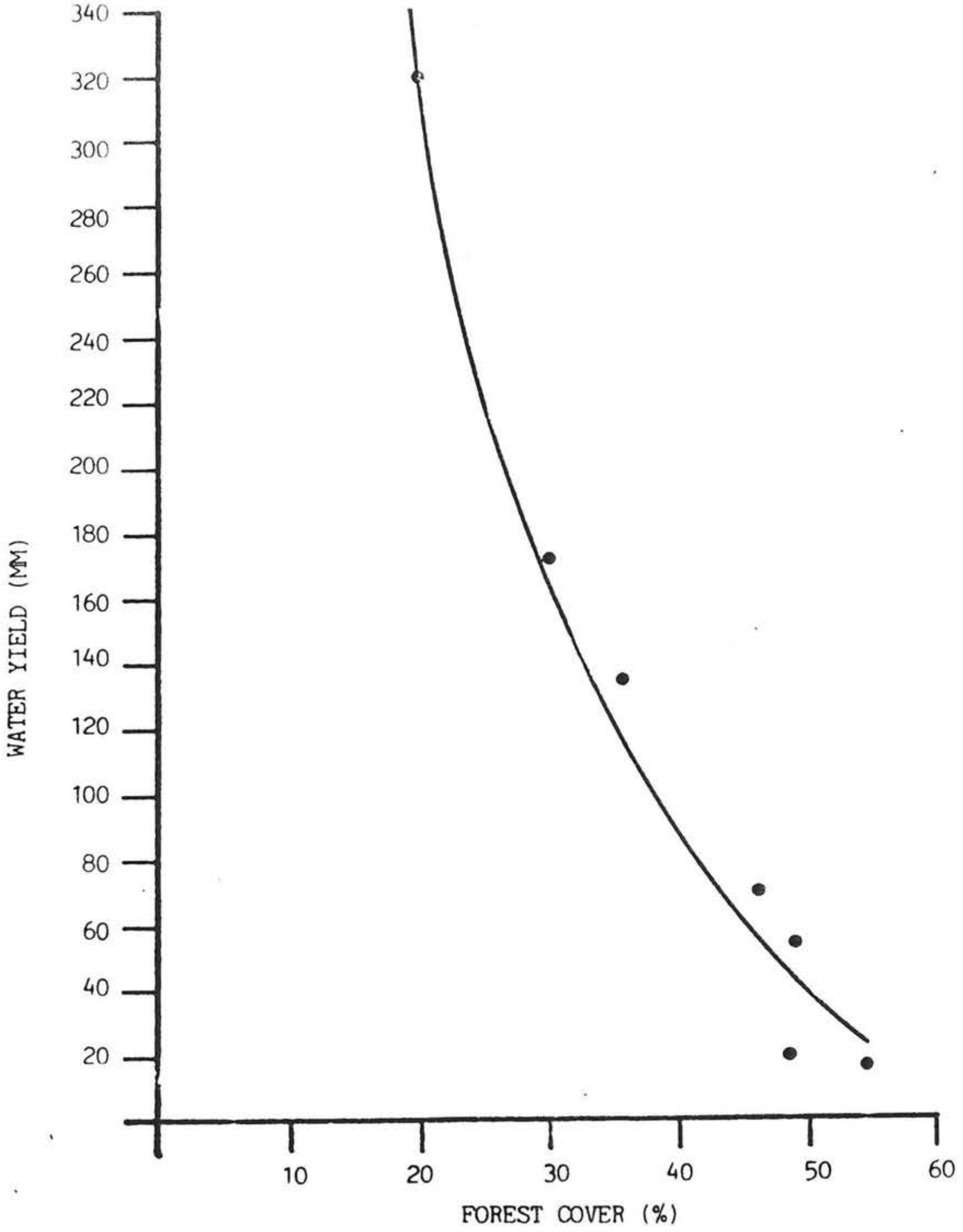


Figure 2: Relationship between water yield (mm) and forest cover (%) for seven catchments in the western zone of the northern jarrah forest. $y = 9{,}615 \div x - 152$ $r^2 = 0.978$ $p < .001$.

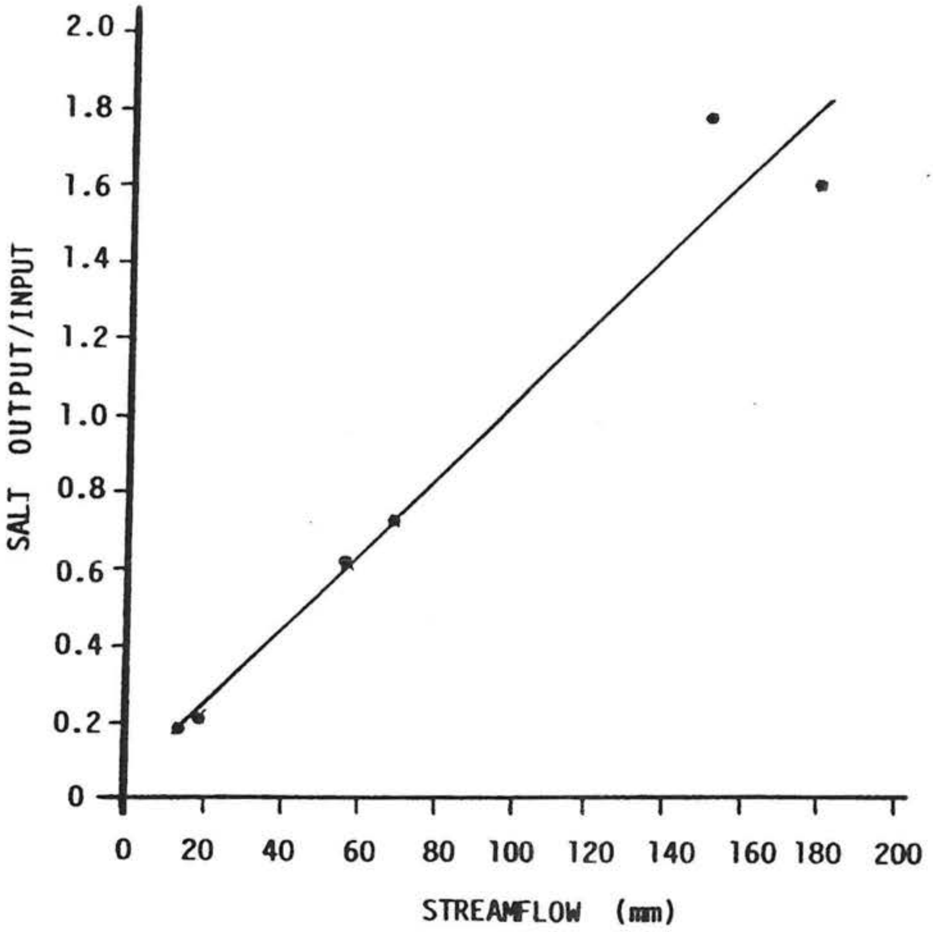


FIGURE 3 : RELATIONSHIP BETWEEN STREAMFLOW (mm) AND SALT BALANCE FOR SIX CATCHMENTS IN THE HIGH RAINFALL ZONE. $y = 0.06 + 0.00978x$ $r^2 = 0.96$

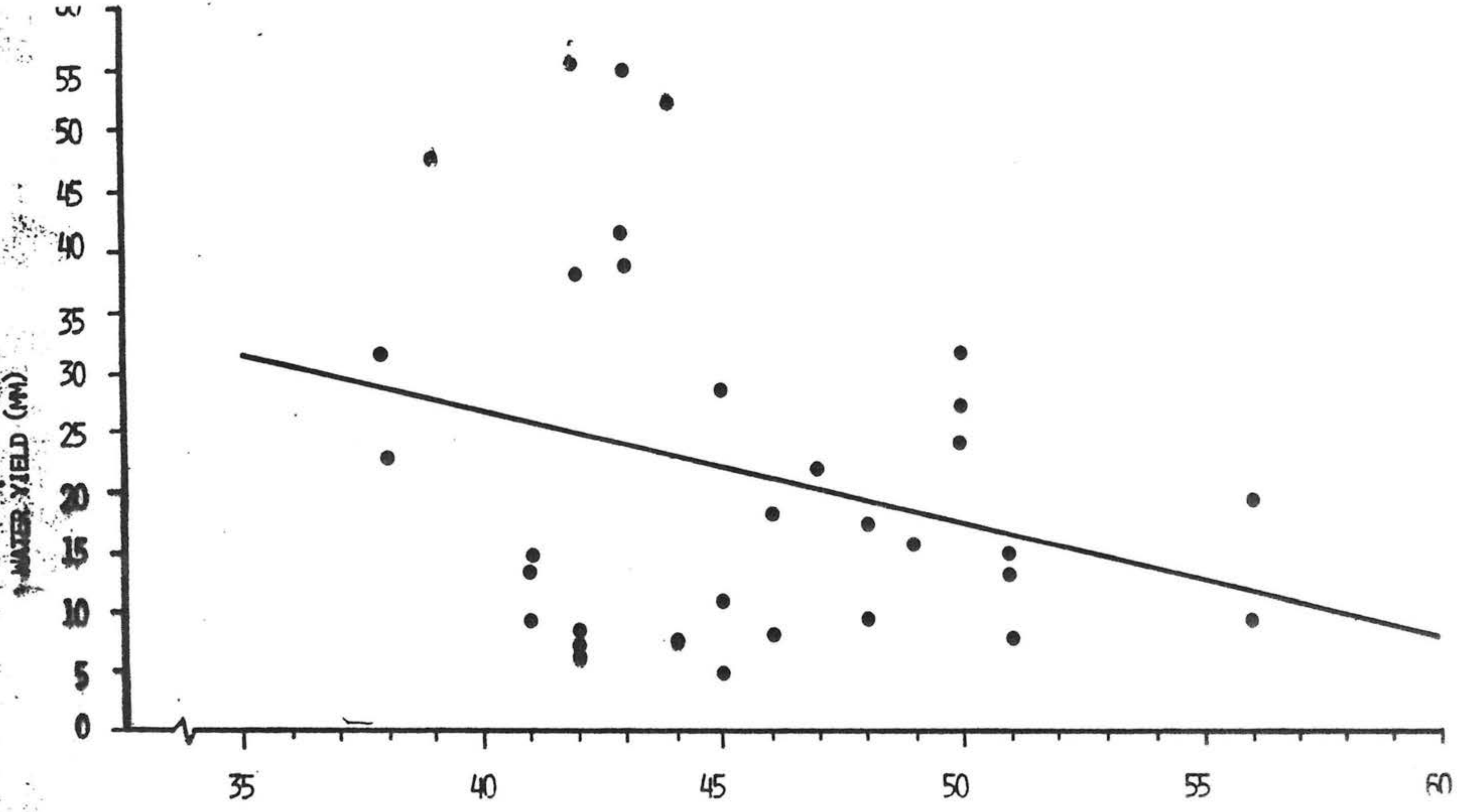
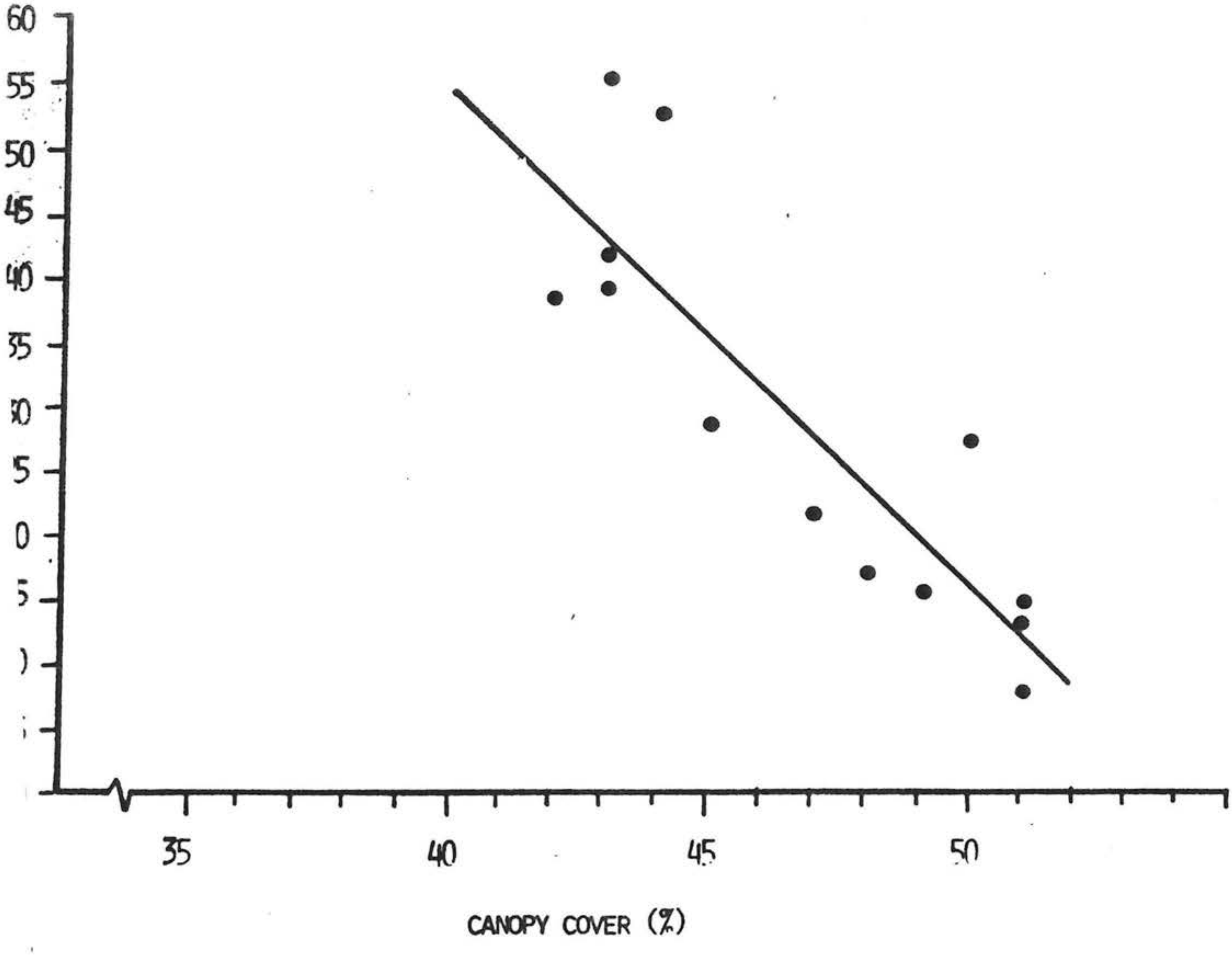


FIGURE 4: RELATIONSHIP BETWEEN WATER YIELD (MM) AND CANOPY COVER (%) FOR ALL SUBCATCHMENTS OF THE YARRAGIL CATCHMENT, IN THE INTERMEDIATE RAINFALL ZONE OF THE NORTHERN JARRAH FOREST.

$Y = -0.95X + 64.9$ $R^2 = 0.081$ $N = 34$

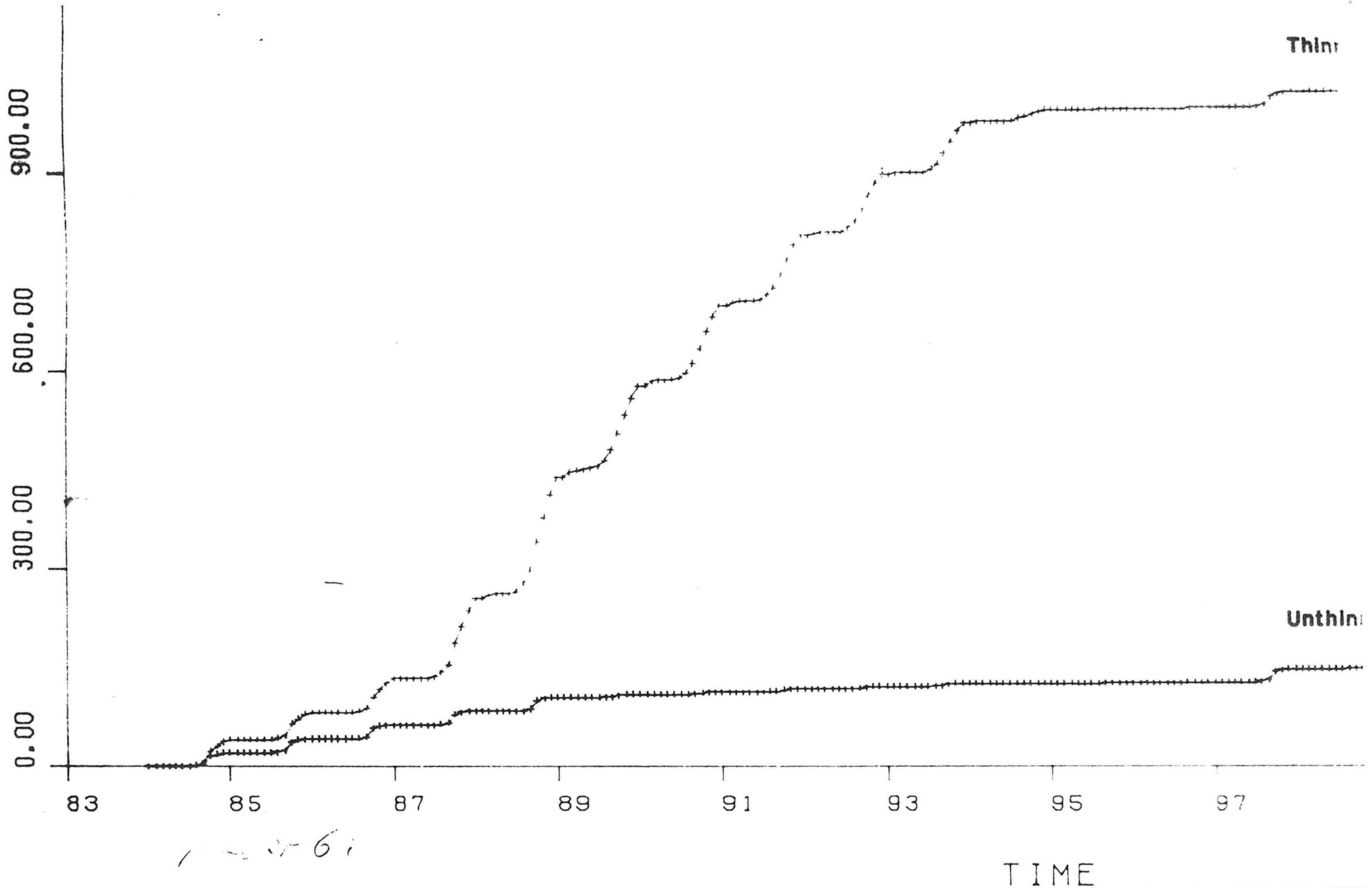
NS



GURE 5: RELATIONSHIP BETWEEN WATER YIELD (MM) AND CANOPY COVER (%) FOR A NUMBER OF SUBCATCHMENTS OF THE YARRAGIL CATCHMENT WITH SIMILAR PHYSICAL CHARACTERISTICS.

$$Y = -3.83x + 207.7 \qquad R^2 = 0.754 \qquad N = 13$$

$$P < 0.01$$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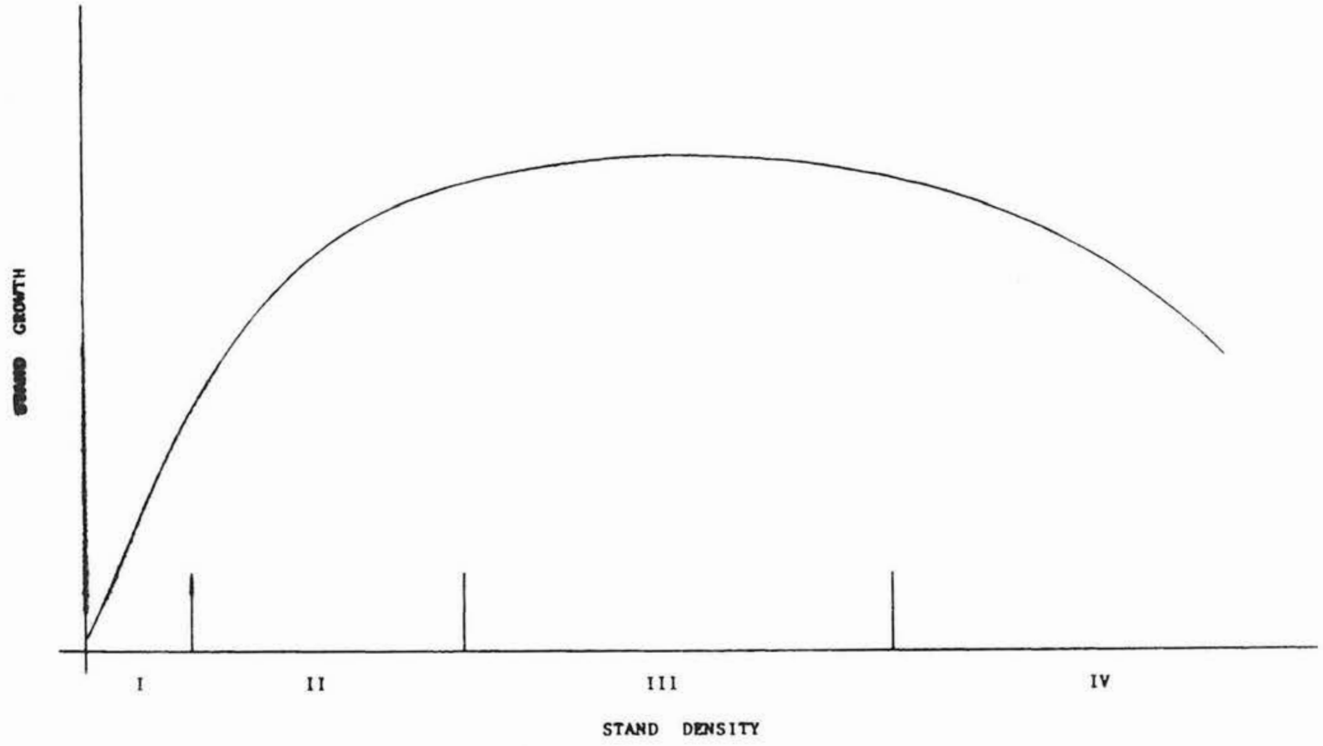
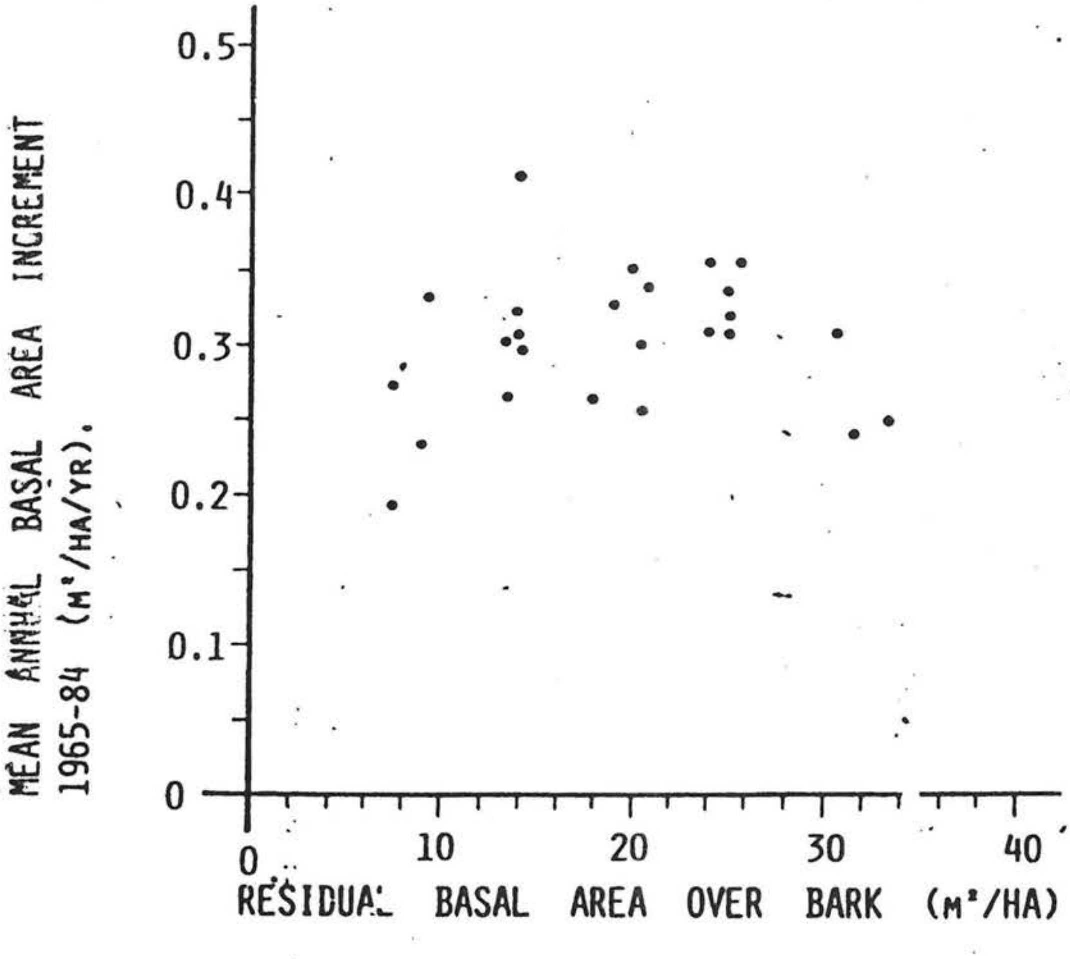
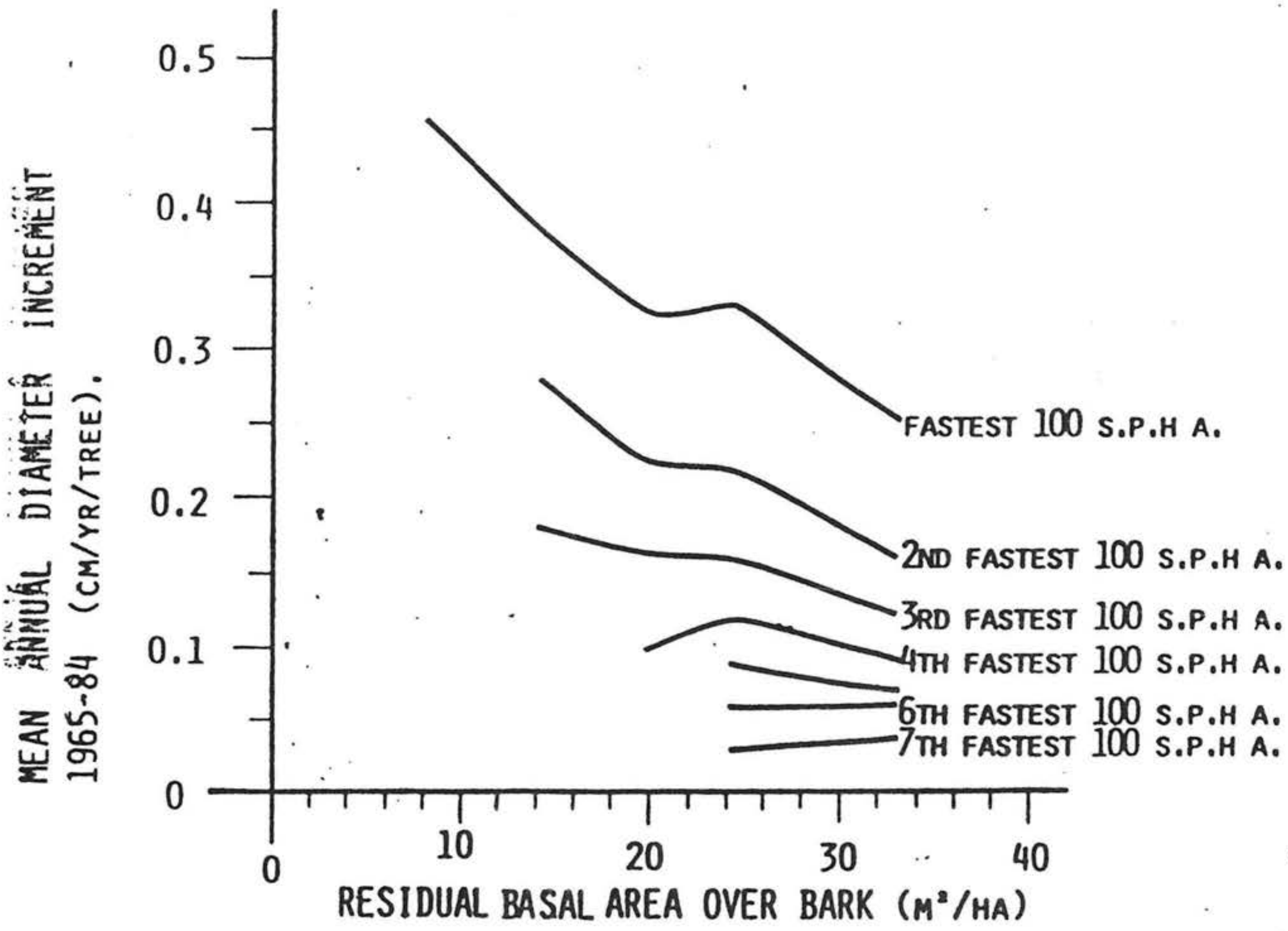


FIGURE 7 : The relationship between stand density and stand growth. In density type I the trees stand so far apart that they do not influence each other and growth is directly proportional to the volume of growing stock. The effect of slight competition in density type II is indicated by a declining rate of increase in increment with respect to stand volume. In the broad range of stocking indicated by density type III, increment of cubic volume is virtually independent of variations in stocking; the usual objective of thinning is to keep the growing stock somewhere within this optimum range. In density type IV the effects of extreme competition are reflected in a decline in growth with increasing density.



THE EFFECT OF THINNING A 40 YEAR OLD REGROWTH JARRAH STAND ON BASAL AREA INCREMENT (M²/HA/YR).



THE EFFECT OF THINNING A 40 YEAR OLD REGROWTH JARRAH STAND ON DIAMETER INCREMENT (CM/YR/TREE) OF THE FASTEST GROWING 100 S.P.H.A., 2ND FASTEST GROWING 100 S.P.H.A.....7TH FASTEST GROWING 100 S.P.H.A.