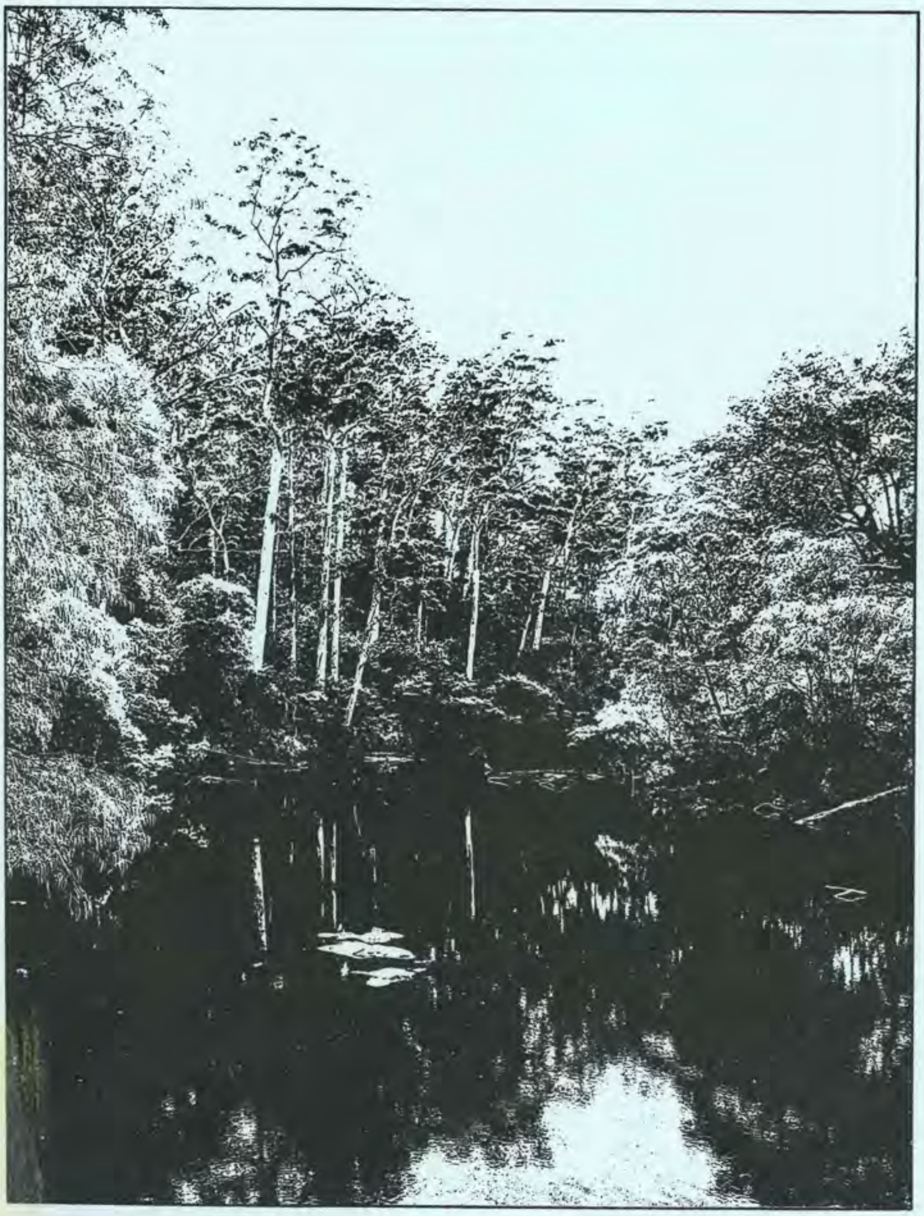
Vegetation Cover and Stand Height as a Function of Time in Regenerating Karri Stands in South-West Western Australia and the Likely Implications for Streamflow

by H. Borg



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Water Authority of Western Australia

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SUMMARY

Vegetation cover and stand height were assessed in 15 karri stands in south-west Western Australia which had been clear-felled and regenerated at known times and compared to those of mature, unlogged stands. The regenerating stands ranged from 1 year to 110 years of age.

Overstorey vegetation cover in regrowth stands reached that of unlogged stands after some 10 years of regeneration, continued to rise for another 10 years and then stabilised at a value above that of unlogged stands. Total vegetation cover returned to the level of unlogged stands within 5 years of regeneration, increased for 5 more years and then also stabilised at a value higher than that in unlogged stands. Stand height increased continuously over the sampled age range, but at a decreasing rate. The height of unlogged stands was approached after some 60 years of regeneration.

Most of the streamflow in south-west Western Australia is generated when water becomes perched on top of the clay horizon, which is typically found below some 30 to 100 cm of sandy to loamy surface soil, and flows downslope into the streams. Because young trees are smaller, they need to overcome less lift and less resistance to get water to the leaves. For the same amount of vegetation cover a young tree can therefore remove water from the surface soil faster than a mature tree. Also, water use increases with vegetation cover and the vegetation cover of regrowth stands soon exceeds that of mature stands.

Hence, after it has recovered from the initial increase caused by clear-felling, which is expected to happen after 10 to 15 years of regeneration streamflow from regrowth stands is likely to become less than from the mature stands they replaced. If the smaller lift and smaller resistance are the main reason for the faster water use by regrowth stands, lower streamflows are likely to persist until the regrowth stands are about 60 years of age. If the greater vegetation cover is the main reason, lower streamflows are likely to persist for much longer.

1. INTRODUCTION

Karri (*Eucalyptus diversicolor*) is endemic to the lower south-west of Western Australia. There are some 188 000 ha of karri forest in the State, most of it south of a line from Nannup through Manjimup to Walpole (Figure 1). Its distribution, ecology and management are described by Churchill (1968), White and Underwood (1974), Bradshaw and Lush (1981), and Bradshaw (1985). At present 1500 to 2500 ha of karri forest are clear-felled and regenerated for wood production each year, yielding 200,000 to 250,000 m^3 of sawlog quality timber, plus 300,000 to 350,000 m^3 of chipwood.

The karri forest also generates substantial water resources. It occupies a large part of the Shannon, Warren and Donnelly river basins. Together these basins yield an average annual streamflow of 1550 x 10^6 m^3 (Collins and Barrett 1980) of which 30 to 40% originate in the karri forest.

Clear-felling reduces evapotranspiration and thus initially leads to an increase in streamflow and soil and ground water storage. As the forest grows back, evapotranspiration increases again and streamflow and soil and ground water storage decrease again. Hydrologic studies suggest that in clear-felled karri stands these parametres are likely to return to their pre-logging values after 10 to 15 years of regeneration (Borg, Stoneman and Ward 1987). However, to date there is no information on their behaviour in regrowth karri stands as regeneration continues.

In mountain ash (*Eucalyptus regnans*) forest in Victoria it has been observed that streamflow from regrowth stands decreases below that from mature stands (Langford 1976). The lower streamflows are likely to persist for many decades (Kuczera 1985) and are due to higher evapotranspiration from regrowth stands compared to mature stands (Langford 1976). Plans to utilise the water resources from the karri forest would be affected if such a reduction in streamflow occurs there.

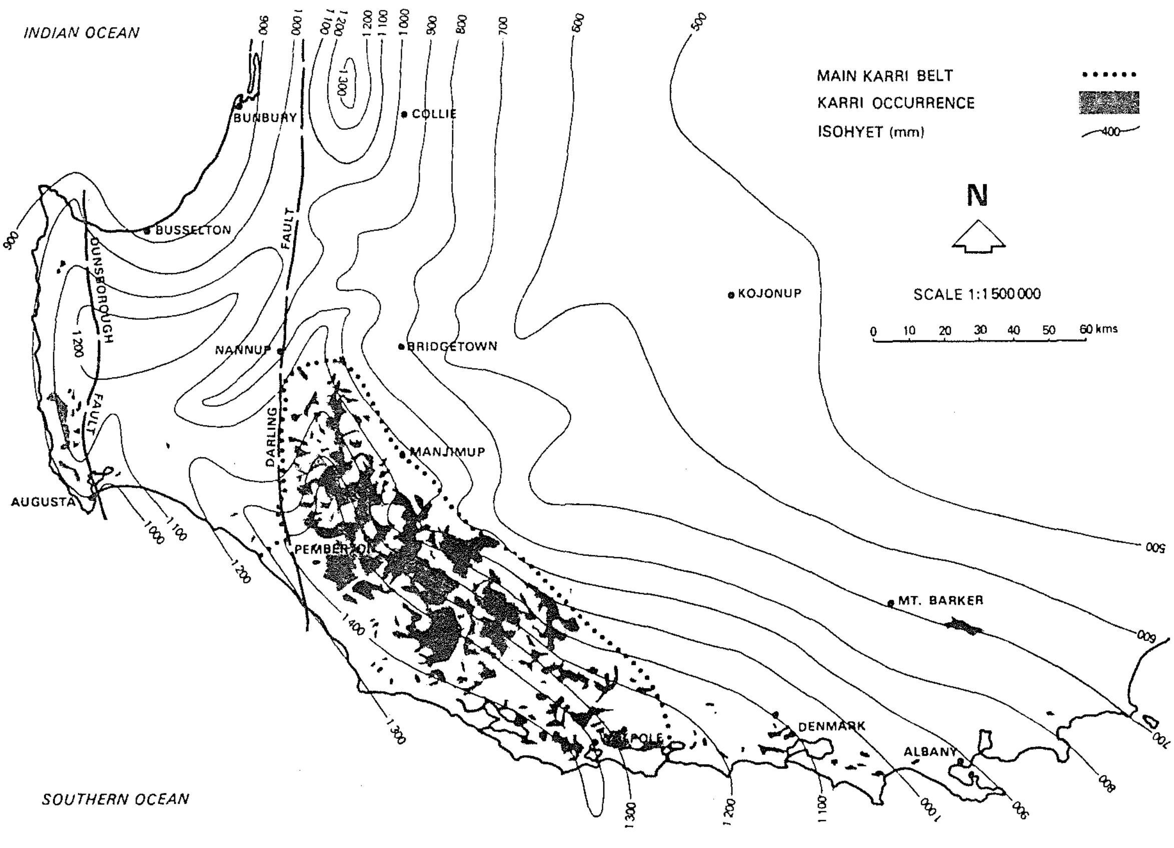

Figure 1

Karri occurrence in south-west Western Australia.

In 1976 hydrologic monitoring began in three small catchments in the karri forest as part of a wider study on the impact of logging on the water resources of the southern forests of Western Australia (Steering Committee 1987a; Borg, King and Loh 1987). Two of these catchments were logged and regenerated in 1982/83 while the third one was left undisturbed as a control. Data forthcoming from these catchments will reveal whether a reduction in streamflow as a result of the replacement of mature stands with regrowth stands does occur. However, about another 10 years of monitoring are required before this could be detected since streamflow must first recover from the initial increase caused by clear-felling. Many more years of monitoring are then needed to ascertain the magnitude and duration of this reduction, if it occurs.

To gain some qualitative information in the meantime, a survey was conducted in 1986 to compare the vegetation cover and average height of regenerating karri stands of various ages to that of mature, unlogged stands, since evapotranspiration from a stand, and hence streamflow and the other components of the water balance, is affected by the vegetation cover and height of the stand. The results from this survey and their likely implications for streamflow are presented here.

2. METHODS

The study was carried out in the main karri belt of south-west Western Australia. Fifteen sites were selected which had been clear-felled and regenerated at known times. The youngest of these regenerating stands was 1 year of age, the oldest 110 years. In addition, three mature stands which had never been logged were surveyed for comparison. The locations of all study sites are shown in Figure 2.

In this paper vegetation cover refers to the percentage of ground area covered by a vertical projection of the vegetation canopy onto the ground surface. It was assessed with a crownometer similar to one described by Montana and Ezcurra (1980). This instrument is designed to give a narrow, vertical line of sight. If the line of sight intercepts vegetation, that is a leaf, a branch or a stem, a 'hit' is recorded. When a number of readings have been taken, vegetation cover is calculated as the number of hits divided by the total number of observations.

Readings were taken at 10 m intervals along line transects, and at least 100 readings were taken in each stand. A preliminary analysis had shown that 100 readings were adequate since after about 80 readings the obtained vegetation cover fluctuated by less than $\pm 2\%$ with additional readings. This was independent of stand age and is exemplified in Figure 3.

Two forms of vegetation cover were computed for each stand. Firstly an overstorey vegetation cover, using only intercepts with tree species, and secondly a total vegetation cover, using all intercepts.

Whenever the crownometer intercepted a tree, the height of that tree was estimated visually. These estimates where then averaged to get a mean height for the stand. Visual estimates of tree height are often inaccurate. No great accuracy is therefore claimed for the absolute values of stand height given below.

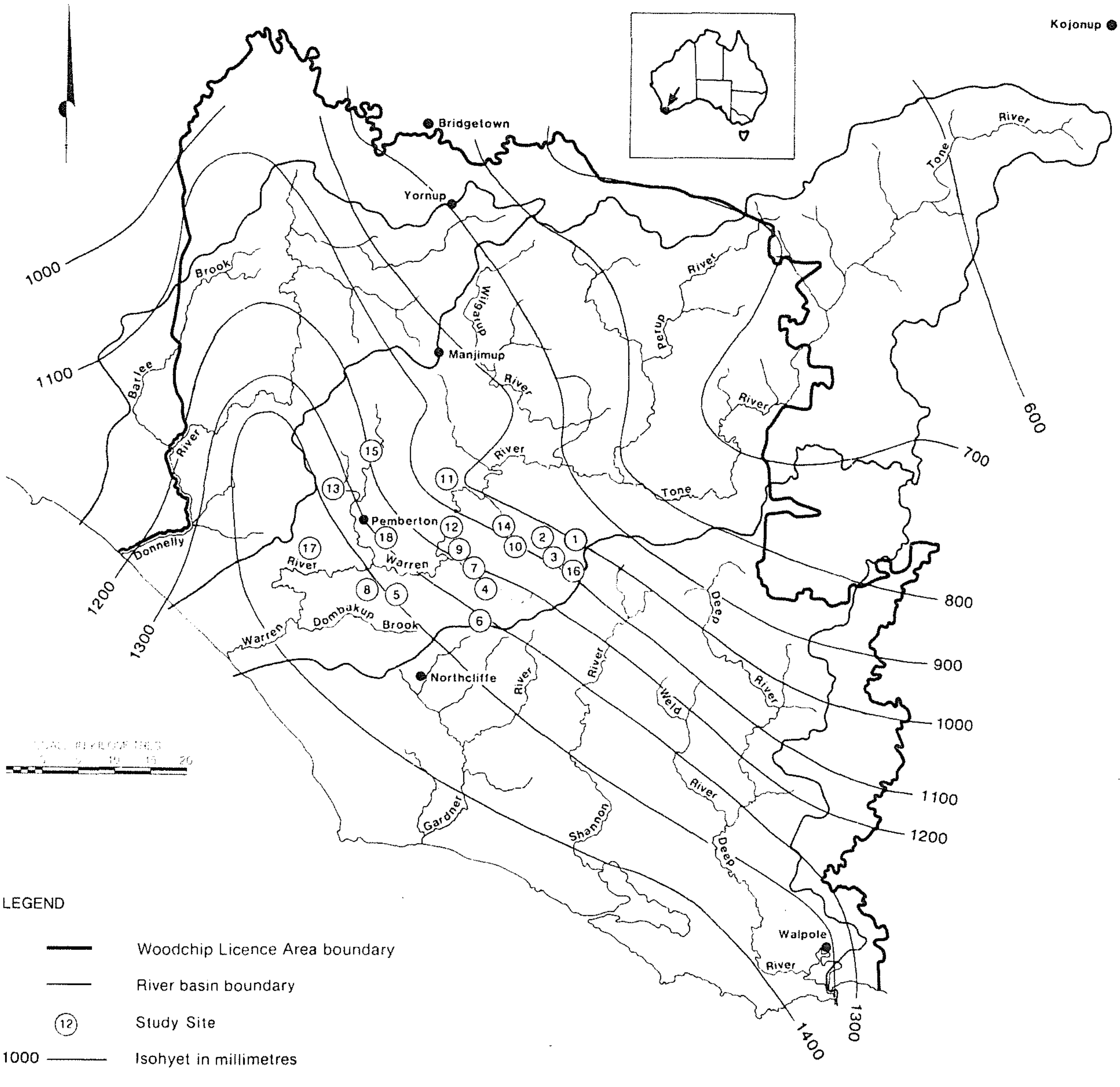

Figure 2

Location of the study sites.

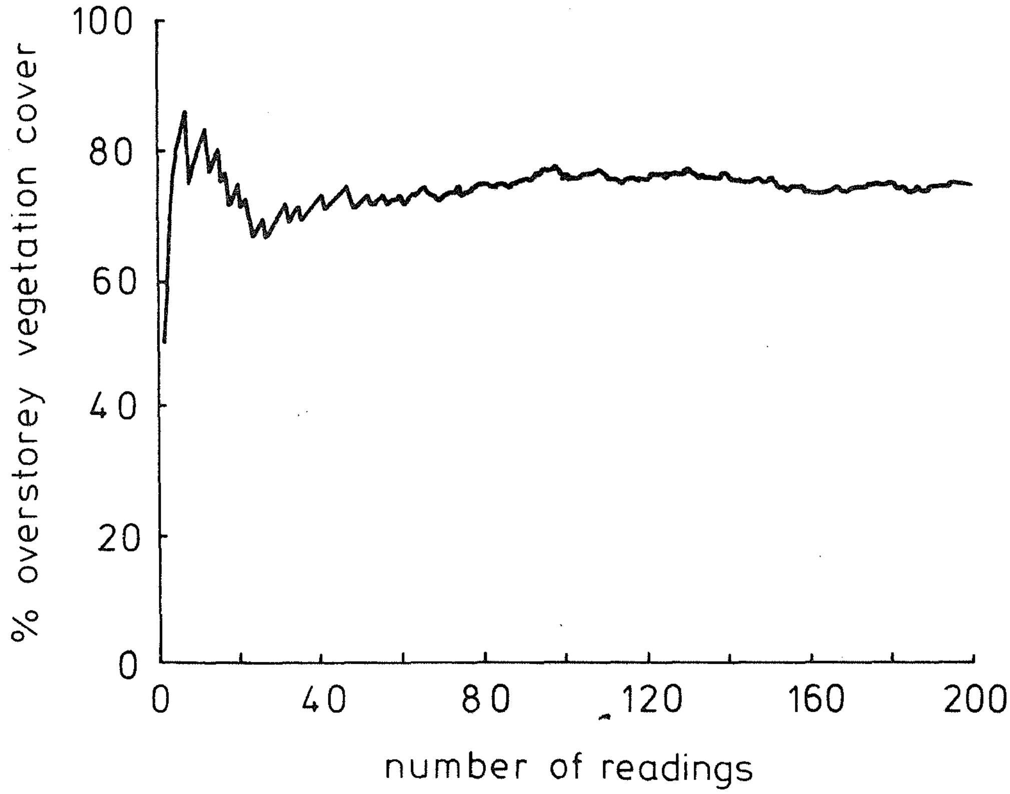

Figure 3

% Overstorey vegetation cover obtained for a 48 year old karri regrowth stand in relation to the number of crownometer readings taken.

However, the height of the regenerating stands relative to that of unlogged stands and the time course of height growth, which are more important in the context of this paper, are unlikely to be seriously affected.

3. RESULTS

The results are summarised in Table 1. For the three unlogged stands the overstorey vegetation cover averaged 64.3%. After clear-felling, overstorey cover increased rapidly, reaching the value for the unlogged stands after some 10 years of regeneration (Figure 4). It continued to rise for about 10 more years, but at a decreasing rate, and then stabilised at 75 to 80%, well above the value for the unlogged stands.

Total vegetation cover returned even faster. It reached the average value for the three unlogged stands (91.7%) within 5 years of regeneration, increased at a decreasing rate for approximately 5 more years, and then stabilised at around 97%, some 5% above the value for the unlogged stands (Figure 4). The relatively low values for the 17 and 41 year old stands were caused by controlled fuel reduction burns carried out shortly before the sites were sampled.

The average height for the three unlogged stands surveyed in this study was 56.5 m. Stand height on the regenerating sites increased continuously over the sampled age range, but the rate of increase declined with age (Figure 5). Height growth was comparatively fast for the first 60 years of regeneration, by which time a stand height of around 50 m was attained, but then reduced to a fairly slow rate.

Table 1: Vegetation cover, stand height and mean annual rainfall for the study sites.

Site Number	Stand age (years)	Vegetation cover overstorey [%]	Vegetation cover total [%]	Stand height [m]	Mean annual rainfall at the site[1] [mm]
1	1	5	27	0.8	1000
2	3	31	91	2.7	1040
3	3	38	87	2.8	1070
4	5	64	92.5	5.3	1140
5	8	64	97.5	8.9	1380
6	8	60	99	9.7	1310
7	13	70	96	17.4	1210
8	17	80	91.5	24.2	1410
9	23	76	95	23.5	1180
10	30	79	97	32.9	1110
11	41	78	89	44.0	1050
12	48	75	99	46.1	1140
13	58	79	97	55.4	1360
14	67	73	97	51.5	1070
15	110	78	100	60.0	1190
16	mature	64	90	53.4	1080
17	mature	66	90	58.6	1470
18	mature	63	95	57.4	1290

[1] estimated from Loh and King (1978)

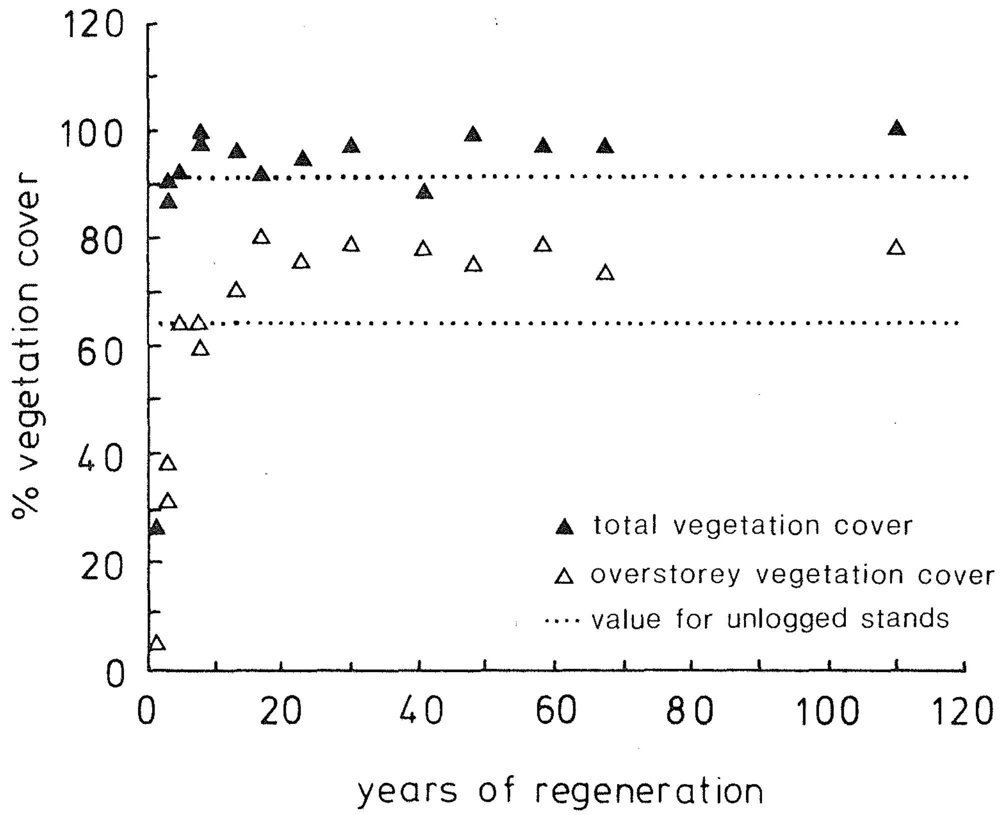

Figure 4

Vegetation cover of regenerating karri stands as a function of time.

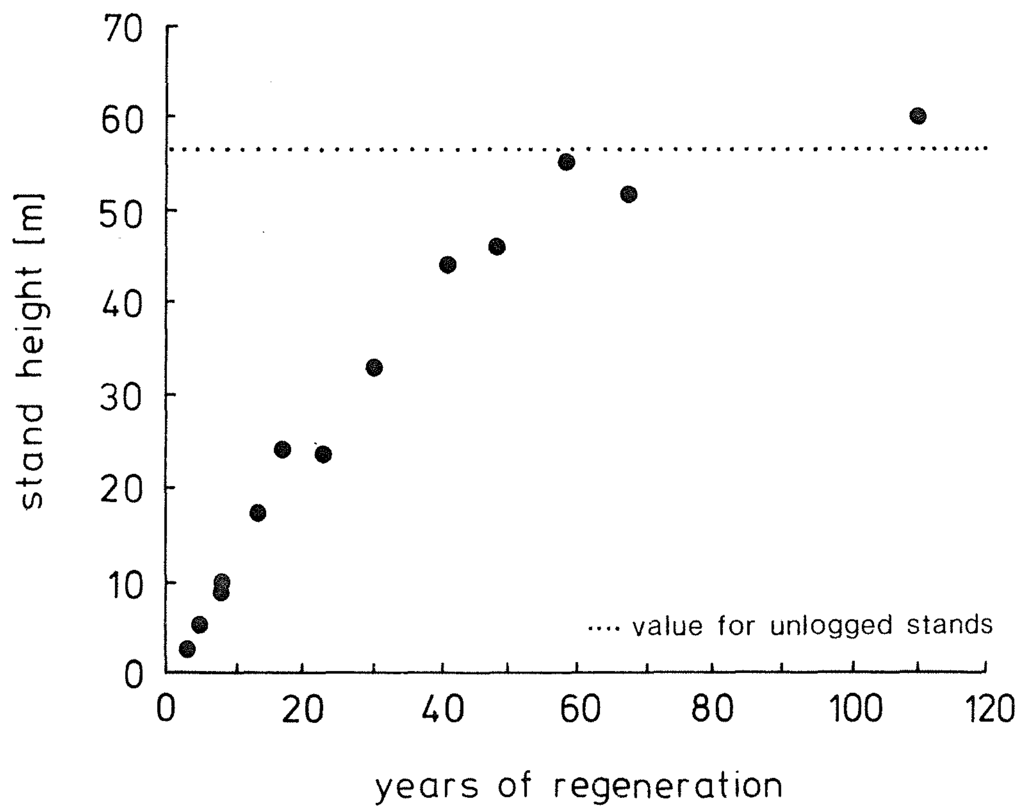

Figure 5

Height of regenerating karri stands as a function of time.

4. IMPLICATIONS FOR STREAMFLOW

Mean annual rainfall in the karri forest ranges from 900 mm to 1500 mm (Figure 1) of which about 80% occurs from May through October. Over these months rainfall exceeds potential evapotranspiration. As a result some 90% of the annual streamflow is usually generated during this period (Collins and Barrett 1980). The soils in the region typically consist of 30 to 100 cm of highly permeable sandy to loamy material on top of 5 to 20 m of clay with low permeability (McArthur and Clifton 1975). Water is frequently perched and then flows downslope on top of the clay. This 'shallow subsurface flow' produces most of the streamflow in the region (Stokes and Loh 1982; Stokes 1985; Williamson et al. 1987). In mature, unlogged stands in areas with less than 1100 mm mean annual rainfall, streamflow typically discharges 10% of the annual rainfall. This value increases to 25% in unlogged stands where the mean annual rainfall exceeds 1400 mm (Public Works Department of Western Australia 1984). Changes in soil and ground water storage are usually small from one year to the next (Sharma et al. 1982) so that evapotranspiration accounts for the other 75 to 90% of the annual rainfall.

All other things being equal, evapotranspiration increases with vegetation cover. However, water encounters a resistance to flow as it moves up in the tree trunk to the leaves. This resistance is proportional to the distance travelled. Due to their greater height old trees must therefore overcome a greater resistance as well as a greater lift to get water to the leaves (Langford 1976). Furthermore, there is some evidence that the resistance per unit trunk length may be greater in mature trees (Legge 1985a,b; Mattson-Djos 1981). These factors can result in a reduction in stomatal opening and thus the transpiration rate of mature trees compared to young trees.

During prolonged periods without rain, transpiration is often limited by the availability of soil water. Since they have a more extensive root system which enables them to access more water, mature trees may then consume more water than young trees for a given amount of vegetation cover. However, this has little effect on streamflow generation in the karri forest, which is largely determined by the water status of the top 30 to 100 cm of soil. This portion of the soil profile is thoroughly explored by roots within a few years of regeneration. Hence, when the height of a regenerating stand is less, but its vegetation cover similar to that of mature stands, a regenerating stand is likely to deplete the water in the upper soil profile faster after a rainfall event, and possibly deplete more of it before the next event. Therefore, after it has recovered from the initial increase caused by clear-felling, streamflow from regrowth stands is likely to fall below that from mature stands.

After some 60 years of regeneration, the height of regrowth stands approaches that of mature stands. The trees in both types of stands must then overcome the same amount of lift to get water to the leaves. If the resistance to water flow per unit trunk length is the same in 60 year old and mature trees, they also have to overcome the same amount of resistance. Regrowth stands from about age 60 onwards and mature stands will then consume water from the upper soil profile at the same rate and therefore yield the same amount of streamflow, provided they have the same degree of vegetation cover. If the resistance per unit trunk length is less in 60 year old karri trees than in mature trees, a 60 year old stand will use water from the upper soil profile faster than a mature stand with the same degree of cover and yield less streamflow. Until the age at which the resistance to flow per unit trunk length in regrowth trees is the same as in mature trees, regrowth stands will continue to yield less streamflow. There are no data to ascertain if the resistance to water flow per unit trunk length is lower in young karri trees, and if so, until what age it would be lower.

Total vegetation cover of regrowth stands stabilises at a value some 5% higher than that of mature stands after about 10 years of regeneration, and overstorey vegetation cover of regrowth stands stabilises at a value some 10 to 15% higher than that of mature stands after about 20 years of regeneration. Vegetation cover differences of this magnitude do not necessarily lead to similar differences in total evapotranspiration by a stand. In the karri forest, evapotranspiration is frequently limited by a lack of available water, even during the period from May through October when the total rainfall exceeds total evapotranspiration (Borg, Stoneman and Ward 1987). The main effect of a stand with higher vegetation cover then is that it uses the available water faster. However, because the available water is used faster, the topsoil is dried out faster and, thus, streamflow reduced. The greater vegetation cover of regrowth stands which persists after some 10 to 20 years of regeneration may therefore be sufficient by itself to reduce streamflow below that of mature stands, but this effect is certainly enhanced by the lower lift and lower resistance to water flow encountered by the smaller and younger trees in regrowth stands.

The arguments presented here suggest that in the karri forest of south-west Western Australia, a reduction in streamflow due to the replacement of mature stands with regrowth stands is likely to occur after 10 to 15 years of regeneration when streamflow has recovered from the initial increase caused by clear-felling. If the smaller lift and the smaller resistance to water flow associated with the smaller height are the main reason for the faster water use by regrowth stands, lower streamflows are likely to persist until the regrowth stands are about 60 years of age. If the greater vegetation cover is the main reason, lower streamflows are likely to persist for much longer.

The hydrologic studies currently in progress in the karri forest (Borg, King and Loh 1987) will eventually provide quantitative information about the timing and magnitude of the anticipated reductions in streamflow from regenerating stands. In the meantime, the qualitative information from the study presented here should stimulate discussions about the necessity and feasibility of thinning karri regrowth stands to increase streamflow. Thinning is an effective tool to increase streamflow from a stand (Shea _et al_. 1975; Steering Committee 1987b) and also has benefits for wood production (Stoneman 1986). Thinning of regrowth karri stands to improve wood production is already common practice (Bradshaw 1985). However, the intensity, areal extent and distribution of thinning may have to be altered to maximise the effect on streamflow.

5. EPILOGUE

The assessment of the likelihood of a reduction in streamflow due to the replacement of mature karri stands with regrowth stands presented here is based on well established plant physiological and hydrologic principles. Nevertheless, it should not be regarded as more than a scientific guess. The purpose of this paper is to point out that lower streamflow from regrowth karri stands is a possibility so that if it occurs, which is by no means certain, there is some understanding of the probable reasons for it, and maybe already some ideas how to overcome it.

The possibility of a reduction in streamflow from regenerating jarrah stands could be assessed in a similar manner. However, the situation there is not as clear. Karri naturally occurs in even-aged stands, while jarrah naturally occurs in mixed-aged stands which contain a variety of tree ages and sizes. Furthermore, jarrah stands are usually logged under the selection cutting system (Bradshaw 1986), which means that even after logging there will be a mixture of the tree ages and sizes in the stand. Also, the vegetation cover of regenerating jarrah stands does not exceed that of unlogged stands. It reaches the value for unlogged stands after 20 to 30 years of regeneration, but then stabilises at that value (Stoneman et al. 1988). Due to these complications a similar analysis for jarrah stands seems unwarranted at this time.

Some points raised during discussions of earlier drafts should also be mentioned here. Due to their greater height, mature stands have a lower aerodynamic resistance to water transfer from the leaves into the atmosphere. However, the stomatal resistance of trees is typically much larger than their aerodynamic resistance (Jarvis 1981). The lower aerodynamic resistance of mature trees does therefore not lead to a significantly lower total resistance to vapour transfer from the leaves into the atmosphere, which is given by the sum of stomatal resistance and aerodynamic resistance. In addition, due to the greater lift and the greater resistance to water flow in the tree trunks associated with the greater height, the stomatal resistance of mature trees is likely to be higher than that of young trees. This is likely to outweigh the effect of a lower aerodynamic resistance.

Borg, Stoneman and Ward (1987) analysed hydrologic data for two small karri catchments which were clear-felled in 1977 and regenerated in 1978. Monitoring in the catchments began in 1976 and ceased in 1985 due to financial constraints. Extrapolation of their data suggests that streamflow is likely to recover from the initial increase caused by logging after 10 to 15 years of regeneration. Extrapolation of data presented by Borg, Loh and King (1987) for two small karri catchments clear-felled and regenerated in 1982/83 suggests that this may take only 5 to 8 years. However, the quicker recovery of streamflow in these two catchments could be a result of the very dry conditions in the region since 1982.

6. ACKNOWLEDGEMENTS

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