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SUMMARY Early in 1983 a small jarrah forest catchment (Yarragil 4L) was thinned, resulting in a two thirds reduction in forest density. The thinning was to test the hypothesis that a reduction in forest density will increase the production of both high quality water and timber, without increasing the spread or impact of jarrah dieback. In the first year following the thinning there was not a significant increase in streamflow, and in the second year a small increase of 3.1mm ± 0.9mm was evident. After two years groundwater levels had risen about two metres in each of the two boreholes. In the midslope borehole the response was immediate and steady, whereas in the valley borehole the response was delayed with a jump following a fire which killed nearly all leaves in this valley area. The lack of a streamflow response is in marked contrast to other similar catchment experiments reported in the literature and the difference is attributed to the large soil water storage capacity of the deep lateritic soil profiles. It is argued that evapotranspiration has been reduced considerably and that soil water storage has increased markedly. The groundwater rise observed supports this argument. A time lag of several years between thinning and peak streamflow response is expected. The groundwater rise of 1m yr^{-1} is about 70% of that reported for complete clearing in a catchment with similar rainfall in the northern jarrah forest, and has the potential to cause stream pollution in forest which has substantial accumulation of salt in the soil.

1 INTRODUCTION

The hydrology of the northern jarrah (*Eucalyptus marginata* Donn ex Sm) forest of south Western Australia is unusual, the feature being that evapotranspiration dominates the water balance and consequently there is little streamflow from the moderate rainfall. This is attributed to the very deep soil profiles and large soil water storage capacity which jarrah is well adapted to exploit, as well as to the evaporative potential of the atmosphere (Shea *et al*. 1975; Doley 1967; Dell *et al*. 1983; Colquhoun *et al*. 1984). Superimposed over this is a climatic and landform gradient across the forest. From west to east across the forest rainfall falls from nearly 1400mm to 700mm, evaporative potential increases, streamflow decreases, saltfall decreases, and the valleys become progressively less incised and the slopes more moderate (Shea *et al*. 1975; Hingston and Gailitis 1976; Mc Arthur *et al*. 1977). In the higher rainfall area there is sufficient rainfall and steep enough topography to keep the soil leached of salt, however in the lower rainfall area this is not the case and virtually all rainfall is evapotranspirated resulting in substantial accumulations of salt in the soil (Johnston 1981; Stokes *et al*. 1980). In the lower rainfall area there is very real potential for the mobilization of this soil salt to cause massive pollution to streams if the water balance is disturbed. This has been well documented for the case following agricultural clearing (Peck and Hurle 1973; Peck 1983; Williamson *et al*. 1986).

Most of the northern jarrah forest has been cut over in the last 80 years, and now much of it 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 less than one percent of rainfall as streamflow, whereas catchments which have a lower density of trees may yield up to thirty percent of rainfall as streamflow (Stoneman, unpublished data). 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.

Early in 1983 the Yarragil 4L catchment was thinned to test the hypothesis that a reduction in forest density will increase the production of both high quality water and timber, without increasing the spread or impact of jarrah dieback. This paper reports the effect of the thinning on streamflow and groundwater after 2 years.

2. METHOD

2.1 Yarragil Catchment

The Yarragil catchment, an area of 7070ha is about 15km south east of Dwellingup and is in the intermediate rainfall and salinity zone of the northern jarrah forest (Figure 1). It comprises a range of geomorphological and vegetational types typical of this zone. Twelve catchments have been instrumented since 1976 with combination V-notch weirs and Stevens F type recorders to measure streamflow, and a number of transects of boreholes to monitor groundwater level (Herbert *et al*. 1978; Ritson *et al*. 1981).

The Yarragil catchment is fully forested (except roads), the forest dominated by regrowth jarrah which has regenerated from cutting mainly between 1920 and 1945. The forest has been subject to burning on about a 7 year cycle. Jarrah dieback

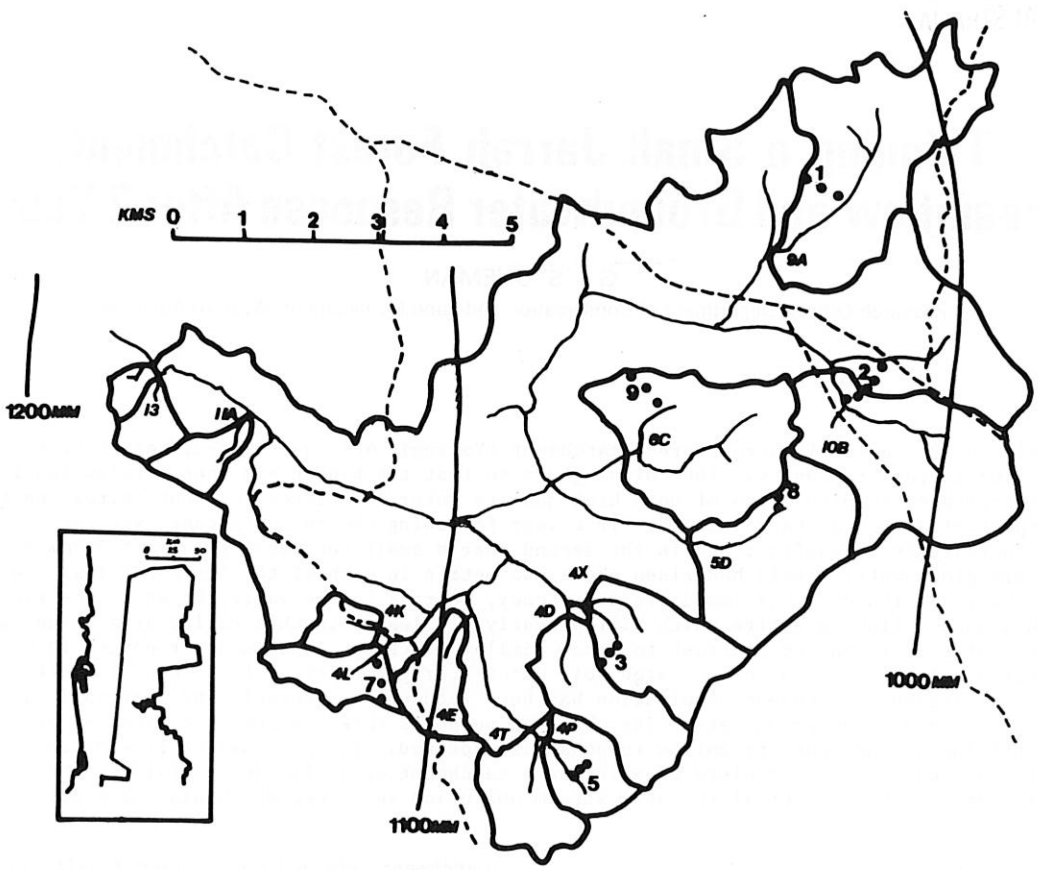

Figure 1 Yarragil catchment showing subcatchments monitored, borehole transects and annual rainfall isohyets

is evident mainly in the valley bottoms and some areas have been cleared and replanted with eastern states eucalypts.

The soils and landforms vary with increasing dissection from the broad valley systems in the east and centre of the catchment with truncated laterite profiles (Yarragil landform), to the steep sided valleys in the west with shallower soils formed over more recently exposed basement granite and dolerite (Murray landform). The uplands generally have fully developed lateritic profiles which are greater than 30 metres in depth (Dwellingup landform) (McArthur et al. 1977; Herbert et al. 1978).

2.2 The Yarragil 4L Catchment

The Yarragil 4L catchment is a relatively small catchment of 125ha, which is located quite high in the local landscape and has relatively subdued topography and incision of the streambed. The forest is of mixed age class and composed of the P, PW, T, TP and WC site-vegetation types (Havel, 1975). Average annual rainfall is 1120mm, and from the three boreholes in the catchment groundwater salinity is about 200 mg L^{-1} T.D.S., and salt storage is low at 6.5 kg m^{-2} T.D.S. (Ritson et al. 1981).

2.3 Thinning of the Catchment

The catchment was commercially logged for general purpose sawlogs in February-March 1983. Following this all other trees not marked for retention were cull fallen in a non-commercial thinning operation which was completed by mid May 1983. A fire to remove logging slash was completed over about two-thirds of the catchment in late winter 1983 and over the remainder in winter of 1984. A tops disposal operation to remove debris from around the base of crop trees was done over the summer of 1983/84, and the catchment received a burn in the spring of 1984. This fire resulted in crown scorch over about 10% of the catchment, with virtually 100% crown scorch in the swamp and valley portion.

2.4 Forest Density Measures

Canopy cover was estimated using an instrument similar to the one described by Montana and Ezcurra (1980). Basal area and stocking were estimated from sampling lines established 200 metres apart and running north-south across the catchment. Trees ⩾ 15cm dbhob but < 30cm dbhob which were within 5m on the right hand side of the centre line were measured, and trees ⩾ 30cm dbhob within ten metres of the centre line were measured. The dbhob measurements were also used to estimate leaf area index using the regression equation of Carbon et al. (1979).

2.5 Analysis of Streamflow Response

Regression equations were established for yearly streamflow between the 4L catchment and another 10 Yarragil catchments for the pretreatment period of 1976 to 1982. The regression equations had coefficients of determination between 0.75 and 0.98. The number of regression equations which were used to derive Figure 2 varied from year to year, and was as follows: 1976-1977 11, 1980-1982 12, 1983 11, 1984 10. Streamflow in 1983 was outside the range experienced in the pretreatment period for all control catchments.

TABLE I

FOREST DENSITY IN THE YARRAGIL 4L CATCHMENT BEFORE AND AFTER THINNING

	Canopy Cover (%)	Basal Area (m^2 ha^{-1})	Stocking (spha ⩾ 15cm dbh)	Leaf Area Index
Before Thinning	55	35	275	1.9
After Thinning	22	11	100	0.6

2.6 Analysis of Groundwater Response

Regression equations were established for each month of the year between the 4L midslope and valley boreholes and other boreholes in similar landscape positions with reasonable pretreatment regression fits. Coefficients of determination range between 0.52 and 0.94 for the valley boreholes and 0.74 and 0.99 for the midslope boreholes.

3. RESULTS

3.1 Forest Density

The effect of the thinning on forest density is presented in Table 1. The thinning led to about a two-thirds reduction in forest density.

3.2 Streamflow

In the first year after thinning there was not a significant increase in streamflow (Figure 2). The much greater standard errors for 1983 also reflect the fact that streamflows were outside the calibration range for all control catchments, and that regressions have been extrapolated out to this point. In the second year after thinning there was a slight increase in streamflow of 3.1mm ± 0.9mm.

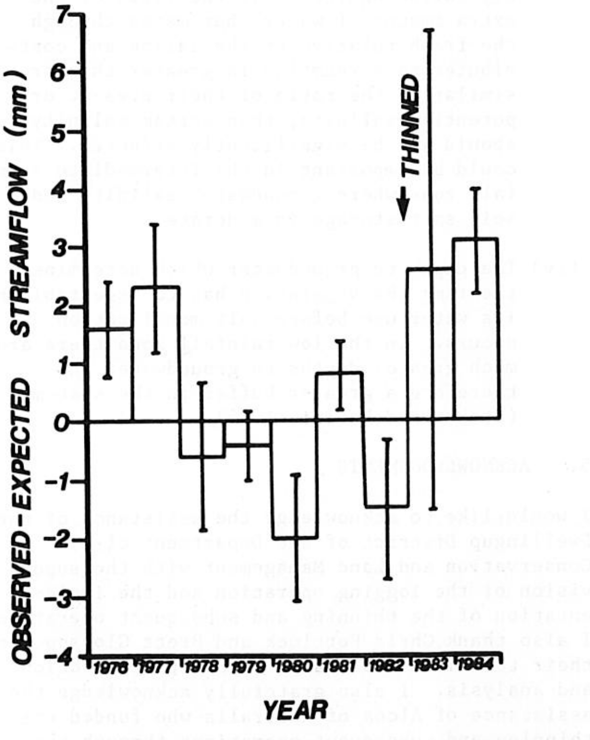

Figure 2 Observed-expected yearly streamflow (mm) for the Yarragil 4L catchment

3.3 Groundwater

The midslope borehole in 4L showed a steady rise relative to control bores in the two years following the thinning (Figure 3). After two years groundwater level in this borehole had risen 2 metres in comparison to control boreholes. The pattern of response of the valley borehole was different however, with little increase in level in the first year but a large response in the second year after the thinning (Figure 4). A great deal of this response was following a spring fire in the catchment which burnt off most of the swamp vegetation in the valley. After two years groundwater level in the valley borehole had risen more than 2 metres in comparison to control boreholes.

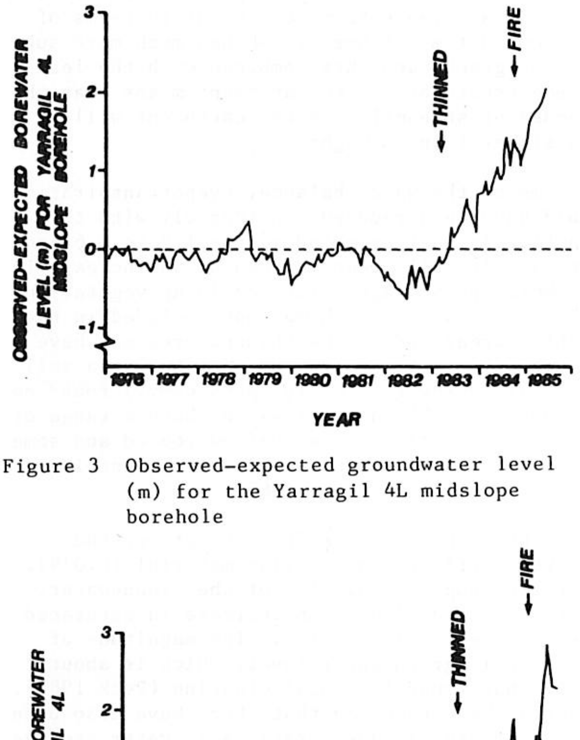

Figure 3 Observed-expected groundwater level (m) for the Yarragil 4L midslope borehole

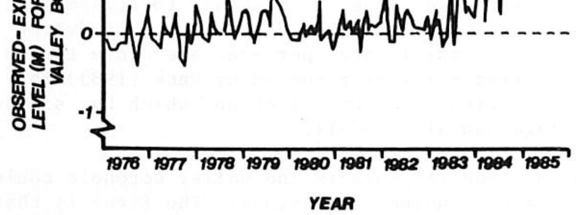

Figure 4 Observed-expected groundwater level (m) for the Yarragil 4L valley borehole

4. DISCUSSION

The lack of a substantial streamflow response following a two thirds reduction in forest density is in marked contrast to the results of other catchment experiments reported in the literature (Bosch and Hewlett, 1982). Moreover, all of these experiments have reported the largest increase in streamflow in the first couple of years following treatment, with streamflows subsequently diminishing as the forest regrows and leaf area builds up. This suggests that the prospect of increasing streamflow by thinning jarrah forest catchments is poor.

However, there is a feature of the jarrah forest that will make its response different from those reported in the literature. This is the soil, its depth and large soil moisture storage capacity. The capacity of jarrah forest soils to absorb increases in water yield is illustrated by the clearing of Wights catchment, near Collie, Western Australia. Sharma et al. (1982) found that in the first year following the clearing of Wights, soil moisture storage in the top 6 metres increased by 220mm in comparison to the still forested Salmon catchment. Williamson et al. (1986) have also shown that streamflow from Wights took many years to reach a new equilibrium i.e. there was a considerable lag between clearing of the catchment and the peak response in streamflow. Wights is also an extreme catchment in terms of incision in the catchment. 4L has much more subdued topography and this combined with the less extreme treatment of the catchment means that the response of streamflow in the catchment will be much slower than in Wights.

In terms of the water balance, evapotranspiration should have been reduced considerably with the reduction in leaf area index from 1.9 to 0.6 and this has virtually been matched by an increase in soil moisture storage. The remaining vegetation, both in the swamp (which was not included in the thinning area) and in the thinned area may have the capacity to transpire some of the extra soil moisture. However, Crombie (pers.comm.) found no difference in the water stress of both a range of understorey species (some shallow rooted and some deep rooted) and jarrah in thinned and unthinned stands over the spring of 1985.

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^{-1}. 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 for the complete clearing of Wights catchment (Sharma et al. 1982).

Groundwater response, in contrast to streamflow response, has been quite dramatic. Groundwater rises of about 1 metre per year are close to the 1.4 metres per year reported by Peck (1983) for the clearing of Wights catchment which has similar average annual rainfall.

The delayed response in the valley borehole could be due to a number of factors. The first is that thinning was not done in the forest around this borehole and the swamp area, and maybe it took a year for the rise in the groundwater table upslope to flow down the 50 metres into the unthinned area. Another possible explanation is increased water use of the swamp vegetation. Perhaps in the first year following thinning it had the capacity to use the extra soil moisture, but not so in the second year particularly following the fire which virtually reduced the leaf area index of this zone to zero for some months. Following the fire in spring 1984 groundwater level in the valley borehole jumped nearly two metres in comparison to control boreholes (Figure 4).

The rise in groundwater, particularly for the mid-slope borehole, is over most of the year except for the spring groundwater recharge period. It therefore appears that the thinning has not altered the rate of groundwater recharge in this peak recharge period, but has both extended the period of recharge and reduced extraction by vegetation from the groundwater aquifer.

This rapid and substantial response in groundwater level is not of concern in the high rainfall and salt free zone of the northern jarrah forest where it can only lead to increases in fresh water yields, but would be of concern in the salt sensitive intermediate and low rainfall zone. Whether or not thinning (and groundwater rises) results in water quality problems depends on a number of factors including-

(i) The response of the forest to the thinning, particularly the long term effect on leaf area index.

(ii) The effect on water use efficiency i.e. does thinning and the increased soil moisture lead to an increase in transpiration per unit leaf area.

(iii) 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.

(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 (Stokes and Batini, 1985).

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