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The Hydrologic Effects Of Reforestation In The Darling Range, Western Australia

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1. INTRODUCTION

The impact of agricultural development on the surface water resources of the south west of Western Australia has been dramatic. Prior to agricultural development virtually all the divertible surface water resources were believed to be fresh. Recent updating of the water resources inventory indicates that only 48% remain fresh (less than 500 mg/L TSS) and 35% have become so saline they are no longer potable (greater than 1000 mg/L TSS). The remaining 17% are of marginal quality and require active catchment management to protect their salinity in the long term.

As a first stage of catchment management, legislation was introduced to control further large scale agricultural development on the five most highly valued of these marginal water resources (Collie, Mundaring, Warren, Denmark, Kent). It was recognised at the time, however, that strategies to actively rehabilitate catchments would also be required if some of the catchments were to be maintained as potable water supplies in the future.

To this end a range of experimental sites were established from 1976 onwards to evaluate the effects of different reforestation strategies on the local groundwater responses. While the individual sites were established with slightly different objectives, taken as a group they include areas of reforestation that range from about 6% to 90% of the locally cleared land.

This paper reviews and discusses the effects of the reforestation work at these sites on the groundwater responses and the stream salinity.

2. EXPERIMENTAL SITES

The region where control of groundwater discharge is most important is in the 600 to 900 mm annual rainfall zone of the Darling Range. Typical areas of agricultural development in this zone in the eastern portion of Wellington and Mundaring Reservoir catchments were selected for the initial plantings (Fig. 1). The studies were developed as joint projects between the then Forests Department (now the Department of Conservation and Land Management - CALM), CSIRO - Division of Land Resources Management (now CSIRO - Division of Water Resources Research) and the then Public Works Department (now Water Authority of Western Australia). The effect of reforestation on water yield and stream salinity was also studied at the Balingup Brook subcatchment by the Water Authority and CALM. Other similar sites have also been established by CSIRO and the Department of Agriculture but are not reported here.

Table 1 summarises the planting details and hydrogeological conditions at the sites considered.

2.1 Flynn's Farm

Flynn's farm was an old established farm on Mundaring Catchment which was repurchased by the Government in 1960. In 1978 three groups of plantings were established to evaluate the effectiveness of trees in reducing groundwater discharge in an agroforestry setting. A wide range of planting level and density were initially proposed. At one extreme, a strategy that might be considered to have a substantial effect on groundwater while impacting agricultural production significantly was included. At the other extreme, strategies which might have only a local effect on agricultural production and a relatively minor effect on groundwater responses were also implemented.

Hillslope Planting

The hillslope planting was established to represent the most dense planting likely. Approximately 80% of the hillside was planted to E camaldulensis and E wandoo at 4 metre by 2 metre spacing (1200 stems/hectare). The site had a pronounced saline seep at the base of the hillslope. The hydrogeology of the site was typical of the Carling Range. In situ weathering has produced a variable bedrock topography overlain by an extensive pallid zone clay with high salt storage.

Fig. 2 shows the general trend of the water table in the planted area. Apart from the effect of annual rainfall, the water table under the reforested area has been decreasing, and the 1986 levels were generally about 2m lower than those recorded in 1978.

Landscape Plantings

In an adjacent area, plots of 50 or 100 metres wide were established in the lower sections of the landscape. Depending on the location of these sections, planting area covered between 6% and 20% of the upslope cleared land. The planting density was 667 stems per hectare.

In 1983 additional upslope plantings took place above the plots where only 6% of the cleared land had previously been reforested. The net effect of these plantings on the groundwater response analysed here is considered small.

The hydrogeological setting of these sites is complex. The depth of weathering is highly variable. Rock outcrops occur through the region but weathering depths of 20 metres plus also occur. Depths to the saline groundwater at the base of most plots were less than 2 metres. The range of species planted are summarised in Table 1.

While the water table under the pasture has been rising, a small decrease of 0.4m was recorded in 1986 in the landscape planting area (Fig. 2). The decrease is not as significant as observed in the hillslope planting area. This reflects the relatively low coverage of reforested area at the site, 6-20% as compared with 80% reforested at the hillslope site.

Flynn's Agroforestry Site

The agroforestry site at Flynn's farm is an area of approximately 35 hectares located some 3 kilometres from the landscape and hillside plantings. The site was divided into 32 one hectare plots in which a range of planting densities from 75 stems/ha to 225 stems/ha have been maintained. Some 4 control plots with no trees were left under pasture. The site (including the control plots) covered most of the cleared land in a relatively narrow band of 200 to 400 metres between a forested wandoo creek line and a mid to upslope jarrah-marri forest. With the exception of the control plots virtually all of the remaining pastured areas were replanted. No obvious saline groundwater discharge was apparent and it is unlikely that any groundwater contributed to the site from the upslope forest area. The weathering depth ranged between 3 and 13 metres and was less variable than the hillslope and landscape sites. All sites at Flynn's Farm had a lower an average depth of weathering relative to similar rainfall areas of the Darling Range.

As shown in Fig. 2, the changes of the groundwater level at this site are very similar to those observed at the hillslope planting site. A reduction in water level of about 1.7 metres from 1978 to 1986 has been recorded at this site.

2.2 Stenes Farm

The Stenes Farm site is located in a 750 mm annual rainfall area of the north eastern portion of the Wellington Reservoir catchment. The property was purchased in 1976 to avoid the possible large scale clearing of the remaining forest on the property, just prior to the introduction of clearing controls.

Four separate areas were established on this property as experimental plantings between 1976 and 1979. Three are reported here.

Stenes Valley Plantings Site

Agricultural development had taken place in the 1950's at the lower slopes along the streamline and the upper southern portion of the farm. Saline discharge had developed along most of the watercourses where replanting took place. However at the valley plantings site salt discharge at the stream invert was not present. At this site in 1979 a 200 metre width strip of trees was established across the valley section and a further 400 metres of upslope pastured area was left under the existing sheep grazing land use. From the centre line of this creek, the reforested area represented approximately 30% of the upslope cleared land. Depth of weathering was over 20 metres in the valley (Fig. 3).

No groundwaters contributed from the upslope forested area on the south side of the transect. However groundwater was present beneath the forest on the north side of the transect. Local topography indicated that it was unlikely to extend upslope very far. Further down the same valley where the original wandoo and swamp vegetation along the creek line had not been cleared, the depth to groundwater was over 10 metres.

The groundwater investigation therefore suggested that the main valley had become saturated following agricultural development. However, as the majority of the upslope landscape remained under forest, the valley groundwater systems were not fed by extensive groundwater systems originating from high elevations beneath the ridge lines of the landscape.

Studies on the groundwater profile along a transect across the valley (Fig. 4) reveal that while there has been a steady increase of water level under the pasture, the groundwater level under the valley has been decreasing. The 1986 minimum level at the reforested site was 0.6 metres lower than the 1979 level. This illustrates that with the growth of the rooting zone under the replanting area, transpiration by trees has been able to lower the water level.

Stenes Agroforestry Site

Approximately one kilometre upstream from the valley plantings site an agroforestry experiment was established in 1981. The valley area was planted in 1978 and thinned to a range of stem densities to evaluate their varying effects on pasture production and on local groundwater responses. Four plots were established with densities ranging from 150 stem/ha to 900 stem/ha and covered between 40 and 60% of the upslope cleared land. Local groundwater conditions were similar to those at the valley plantings site except that saline seeps were evident along the stream line.

As shown in Fig. 5, the water level increased about 0.3m in the first 2 years after thinning. It however, has been steadily decreasing since 1983 as the tree community became more established. The 1986 minimum level was about 0.9m lower than the level recorded in 1981 at the time of thinning.

Arboretum Site

In 1979 a large arboretum was established on a nearby site at Stenes Farm to evaluate the performance of 70 eucalypt species likely to be suitable for reforestation in the Wellington Reservoir catchment. Species plots were made as large as practical (0.5 ha), sufficient to provide an inner core reasonably representative of a whole forest. The objective was to provide a base from which the growth and transpiration potential of any of the species could be inferred.

Groundwater monitoring was established across the site and into the adjacent forest. While it was recognised that individual groundwater responses of particular species would not be identifiable, a general picture of the bulk effect of a high percent replanting strategy would be obtainable.

Similar to the other Stenes sites clearing had been restricted to the lower valley slopes. Saline discharge along the main valley was apparent at the time of planting in 1979.

Drilling revealed a deeply weathered profile, generally extending from 15 to 30 metres below the natural surface. Groundwater existed in some locations in the adjacent forest but did not extend far upslope. Strong vertical gradients of groundwater discharge were not apparent in the discharge zone.

Most of the species successfully established although some repeatedly failed. Overall the tree cover is about 80% of the area planted. This high coverage has resulted in significant reduction in groundwater level. The level in the 1986 summer was about 2.7m lower than the 1979 value, as shown in Fig. 5. This figure also shows that the reduction of water level at this site is the most significant of all three sites at Stenes Farm. There was a slight increase in water level in the first three years after planting when the young trees had not been able to transpire much of the soil water storage. The water level has been steadily declining since 1982 reflecting the gradual development of the rooting zone under the reforestation area. This phenomenon is also illustrated in Fig. 6 where the water table under the native woodland has not changed significantly, reflecting the stable conditions under the mature forest.

The Stenes arboretum site was also used to study the water use characteristics of selected eucalypts in 1984-86. This is a joint study by the Water Authority of W.A. and CALM, and was funded by a research grant of the Australian Water Resources Council. Nineteen eucalypt species were selected and their leaf conductance behaviour throughout the year was evaluated.

Reforestation work to reduce stream salinity requires the selection of tree species which have an ability to continue to transpire into late summer-autumn period when the shallow soils are dry and the trees can only extract water in the deeper groundwater system. E.microcarpa, E. woollsiana (Gray Box), E. sideroxylon (Red Ironbark), and E. botryoides (Southern Mahogany) have been found to possess this ability. Variations in local site conditions are also important in affecting both growth performance and water use characteristics. Nevertheless, those four eucalypt species performed better than some of the conventionally selected salt tolerant species such as E. camaldulensis (Red River Gum) at mild to moderately salt affected sites. They should therefore be actively considered for planting at sites adjacent to saline groundwater discharge areas.

2.3 Maringee Farms

In 1980 a partial reforestation programme on a large operational scale commenced on the Wellington Reservoir catchment. One of the early areas to be planted under this programme was a portion of Maringee Farms in the south-eastern part of the catchment. The planting area represented between

18 and 34% of the subcatchments within a small experimental catchment. Extensive surface and groundwater monitoring was established at this experiment site. The catchment had been extensively cleared usually to the ridge line and extensive saline seeps exists along the watercourse. Transects of bores across the lower section of the valleys reveal a deeply weathered profile (in excess of 20 metres) and a strong vertical gradient of groundwater in the valley discharge zones.

The uniform clearing on both sides of the streamline and the fact that clearing has extended to the ridge line presumably contributes significantly to these vertical gradients of groundwater and to the harshness of the site generally in terms of rehabilitation.

Generally, there has been a small decline in the water level under the reforested area while the level under the pasture has continued to increase (Fig. 7). The 1986 minimum level under the planting site was 0.3 metres lower than the 1982 level, while the 1986 level under the pasture was 1.7 metres higher. These changes are similar to those observed at the valley planting site at Stenes Farm (Fig. 5).

2.4 Balingup Site

This study site is a subcatchment of the eastern Balingup Brook Tributary which drains to the Padbury Reservoir, 5km south east of the Balingup Township. Major land clearing took place in the 1930's and 1950's. By 1966 the native jarrah forest was reduced to 12% of the total catchment area.

In 1976, CALM purchased the farms that covered most of the Padbury Reservoir catchment with the intention of planting all the suitable soil types to pines. The area was then progressively planted with pines (P. radiata) and eucalypts (E. globulus and E. resinifera) during the period from 1977 to 1983. At present, 77% of the subcatchment is forested with 6%

being native forest, 56% being pines and 15% being eucalypts. Of the remaining 23% of cleared land, about 10-15% contains the valley of the eastern Balingup Brook Tributary (Fig. 8).

The aim of the study was to investigate the effect of reforestation on water yield and stream salinity. Stream flow and salinity have been continuously measured at the subcatchment site. The results to date are presented in Fig. 9. Rainfall in the area has been generally below average (900 mm/yr) in the last 10 years, the exception being 1980 and 1983 (Fig. 9a). This sequence of low rainfall events has resulted in the reduction of stream flow in all catchments within the region.

Fig. 9b presents the annual water yield of 2 catchments: Balingup Brook with reforestation, and Thomson Brook without reforestation. This figure illustrates that the water yields at the Balingup catchment have been declining relative to Thomson Brook and since 1982 have even become lower probably due to reforestation.

Apart from reducing streamflow volumes, the reforestation may also result in the reduction of total salt load and an increase of stream salinity (Fig. 9C). The relatively steady decline in salt load could be seen as a consequence of tree growing upslope, which reduced recharge to the deep groundwater system in winter. A slight increase in salinity, however, seems to suggest that saline groundwater still continues to discharge to the valley. Thus, it would be desirable to plant additional salt tolerant species at the valley site to further reduce the deep groundwater level below it.

3. CONCLUSIONS

3.1 Tree planting on previously cleared land in the Mundaring and Wellington catchments has resulted in lowering the deep, saline groundwater level. The extend of water level reduction depends on a number of equally important factors such as plant characteristics, soil type, groundwater salinity, planting coverage, tree density and catchment hydrogeology. The results to date however have shown a general correlation between the reduction in groundwater level and the percentage of area being reforested as shown in Fig. 10. Notable reductions in water level can be achieved only if a significant portion of the landscape is reforested.

3.2 Pine planting on fertile side slopes has resulted in a reduction of streamflow yield and a reduction in total salt load but without any apparent improvement in stream salinity. In order to reduce the stream salinity, considerations should be made on additional planting of salt-tolerant trees at the valley site to further prevent the discharge of the saline groundwater to the stream channel (Fig. 11).

3.3 Trees selected for the reduction of stream salinity should have an ability to continue to transpire into the late summer-autumn period. Results to date have shown that E. microcarpa, E. woollsiana, E. sideroxylon and E. botryoides have this ability and should be actively considered.

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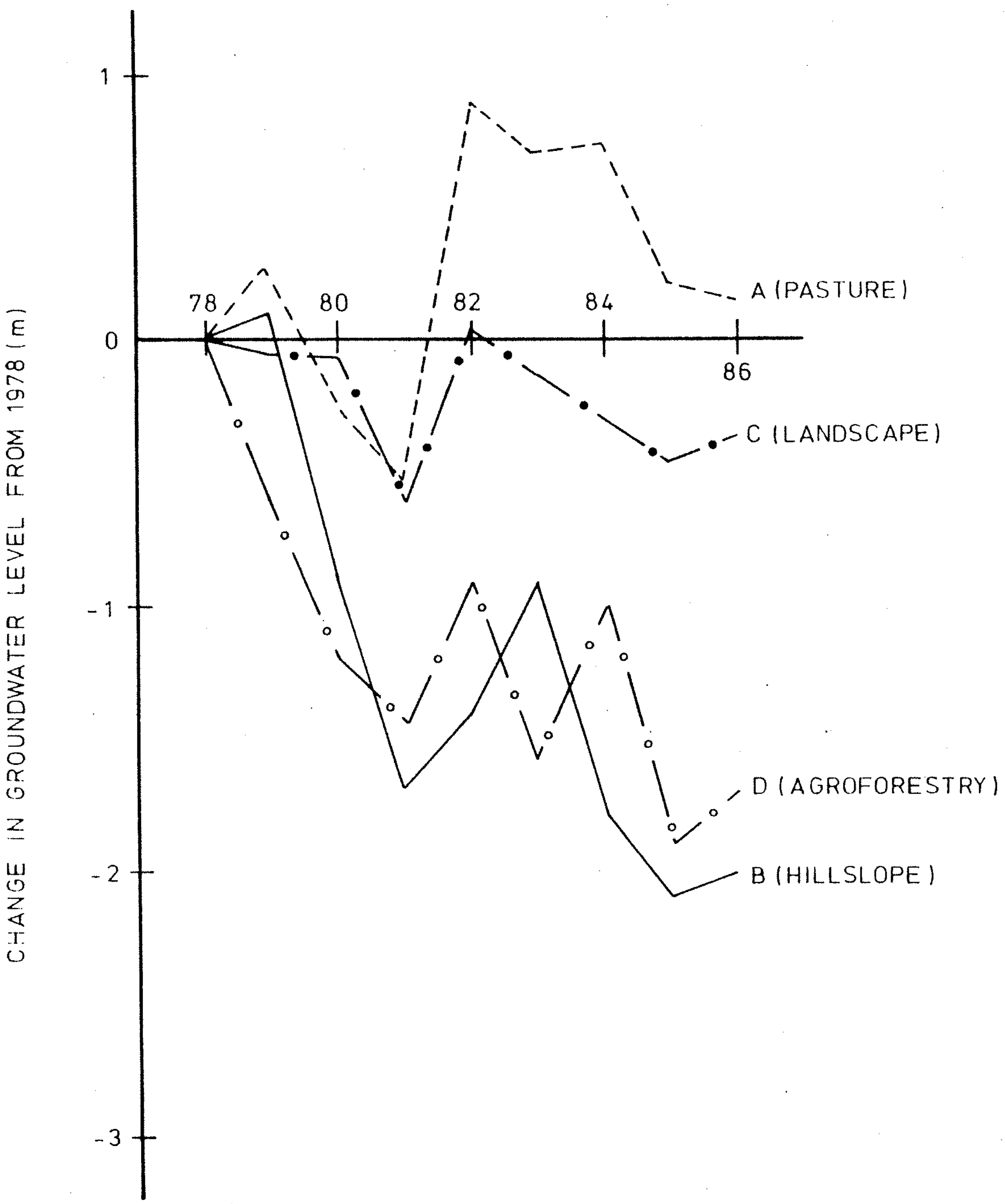


FIG. 2 GENERAL TREND IN WATER LEVEL CHANGE (FLYNN'S FARM)

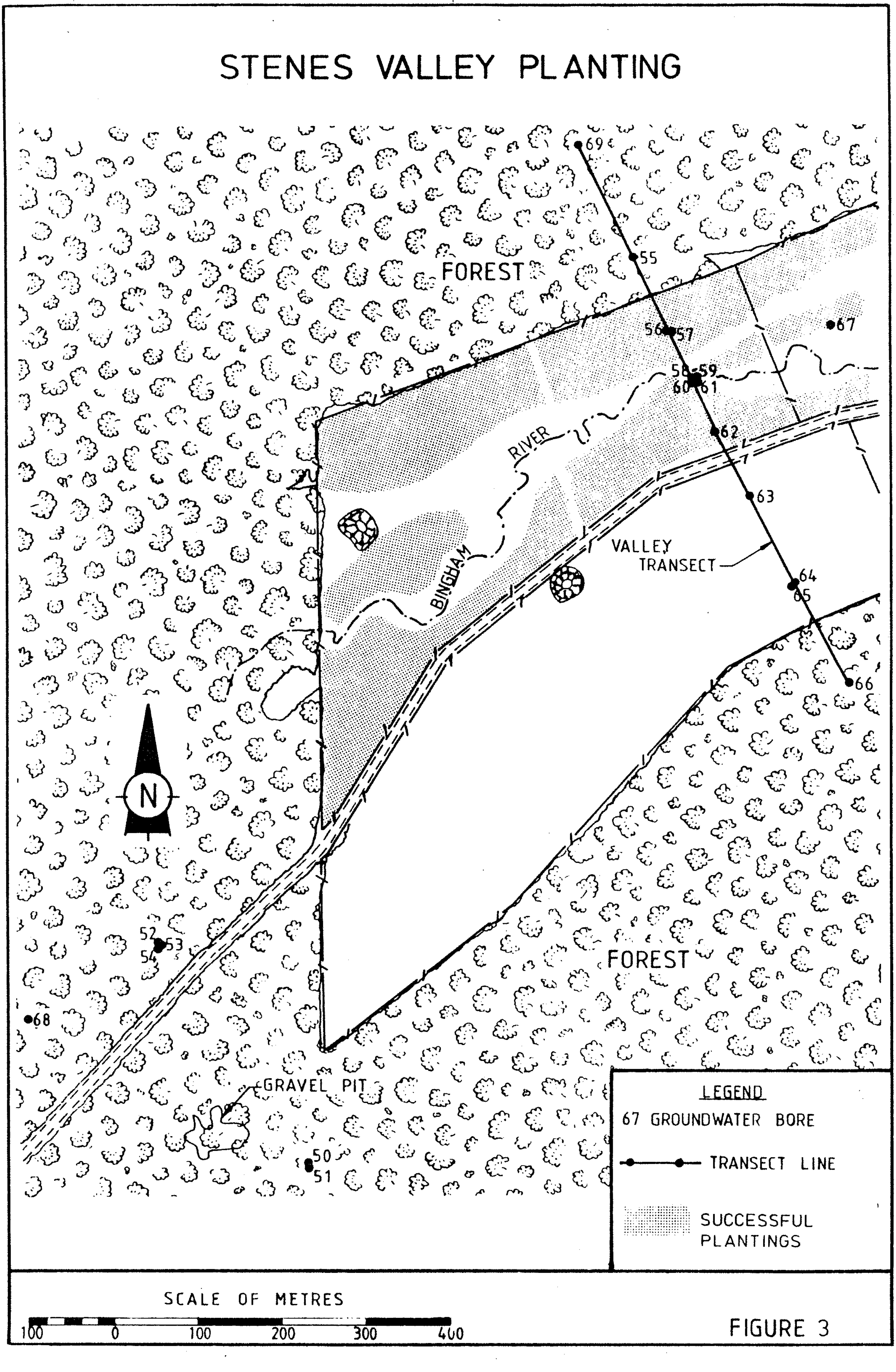

STENES VALLEY PLANTING
FOREST
69
55
56
57
67
58-59
60-61
62
63
64
65
66
RIVER
BINGHAM
VALLEY
TRANSECT
N
52
53
54
68
FOREST
GRAVEL PIT
50
51
LEGEND
67 GROUNDWATER BORE
TRANSECT LINE
SUCCESSFUL PLANTINGS
SCALE OF METRES
100
0
100
200
300
400

FIGURE 3

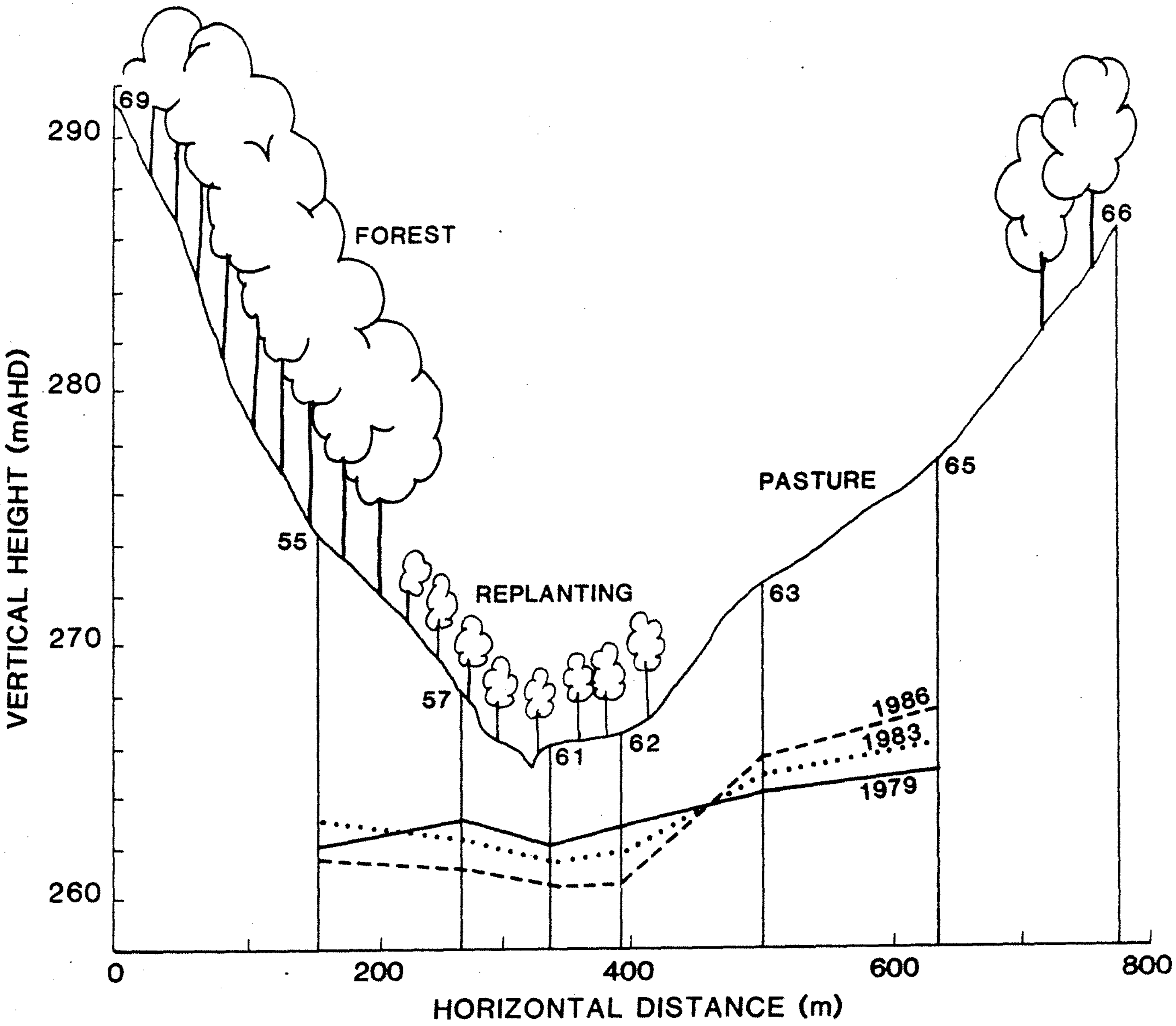


Fig 4 GROUNDWATER PROFILE,STENE'S VALLEY PLANTING

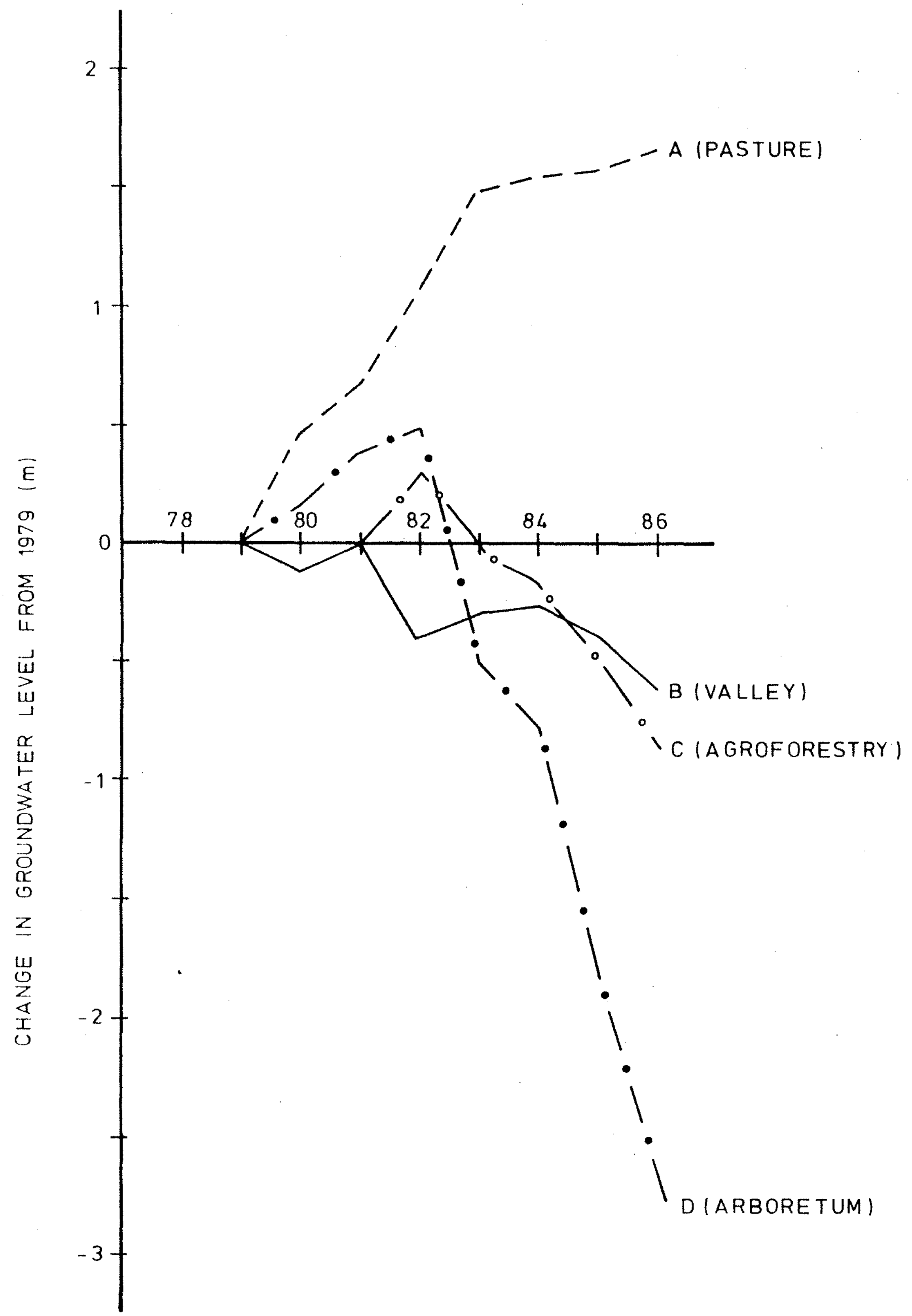


FIG. 5 GENERAL TREND IN WATER LEVEL CHANGE (STENES)

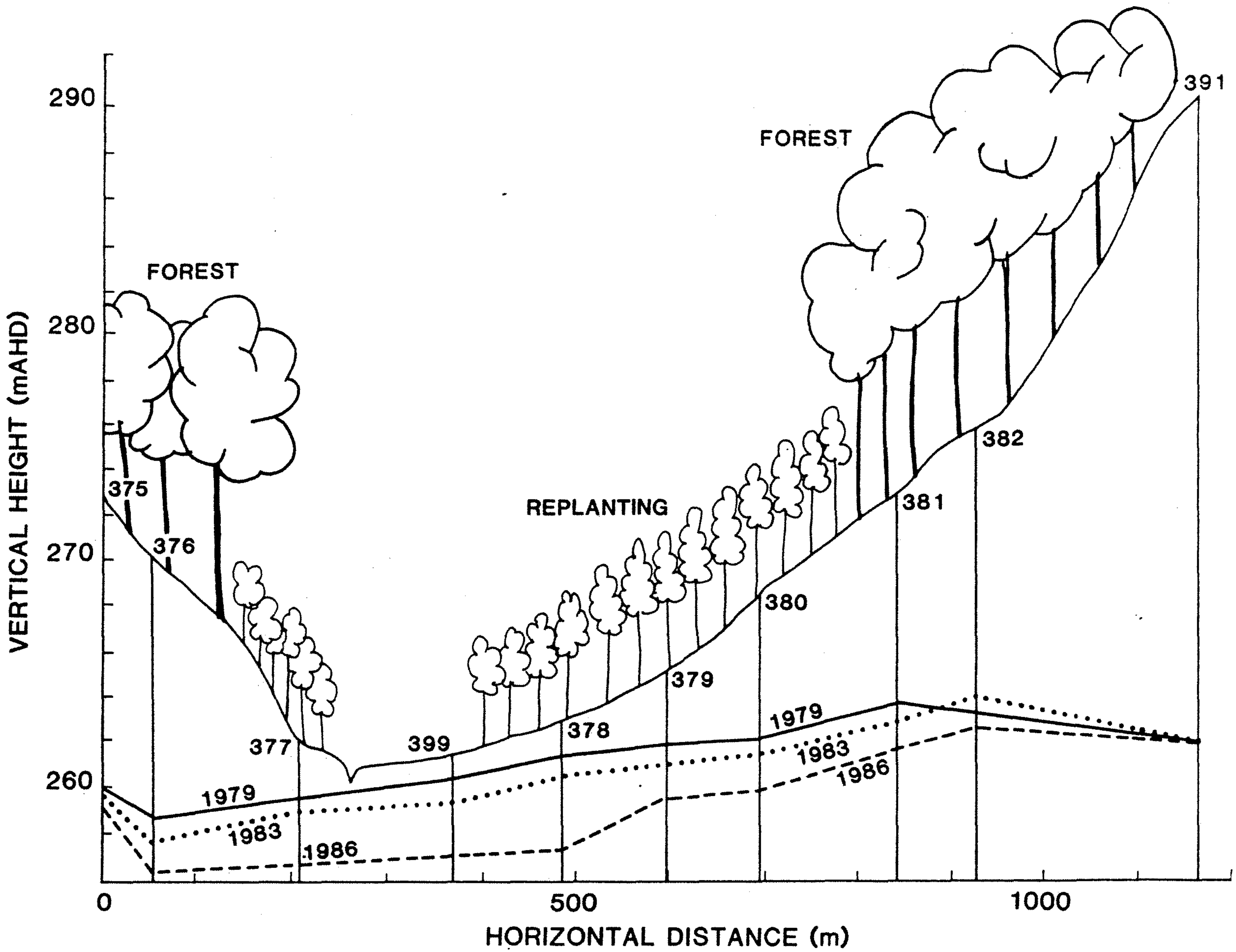


Fig 6 GROUNDWATER PROFILE,STENE'S ARBORETUM

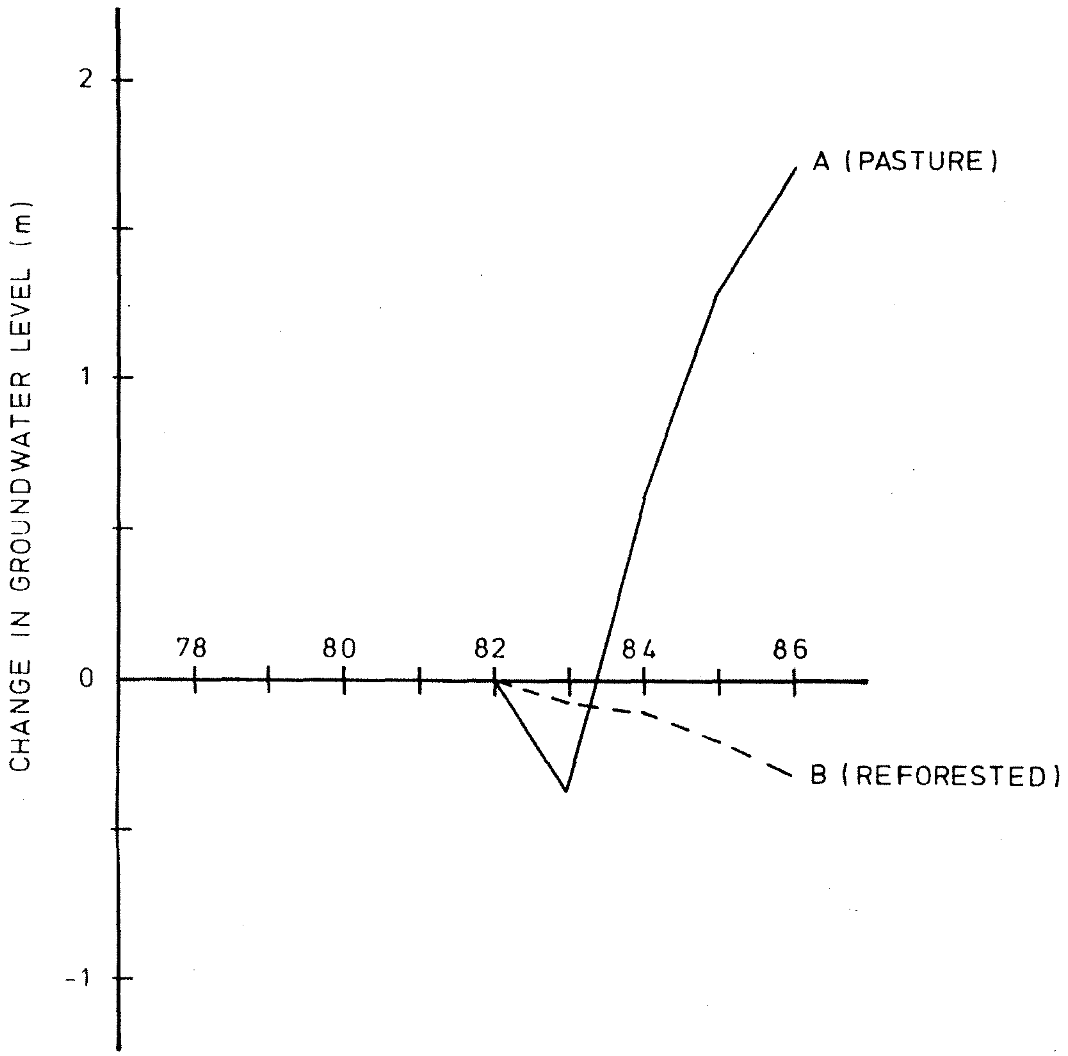
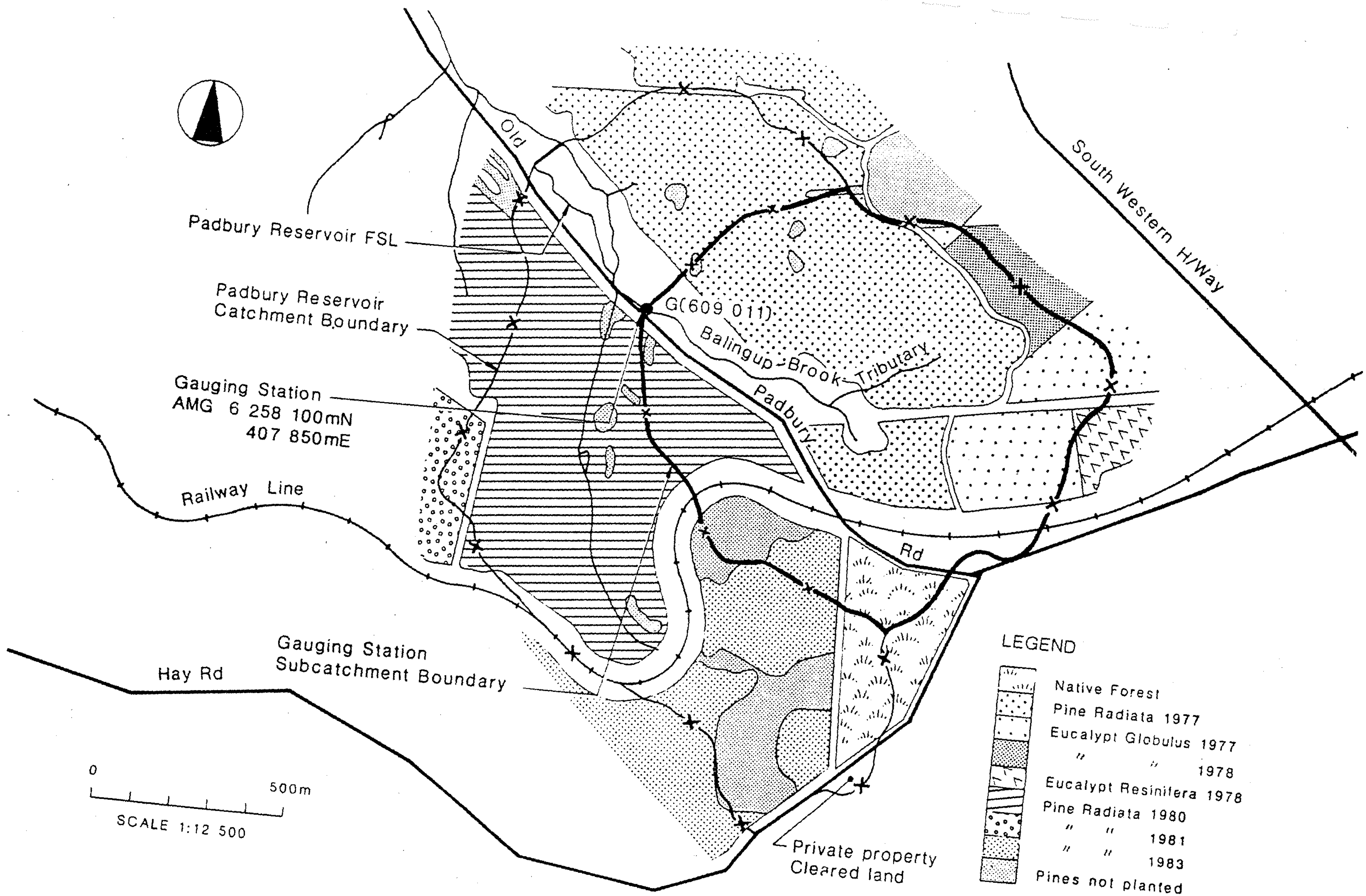


FIG.7 GENERAL TREND IN GROUNDWATER LEVEL (MARINGEE)



Balingup Planting History **Fig 8**

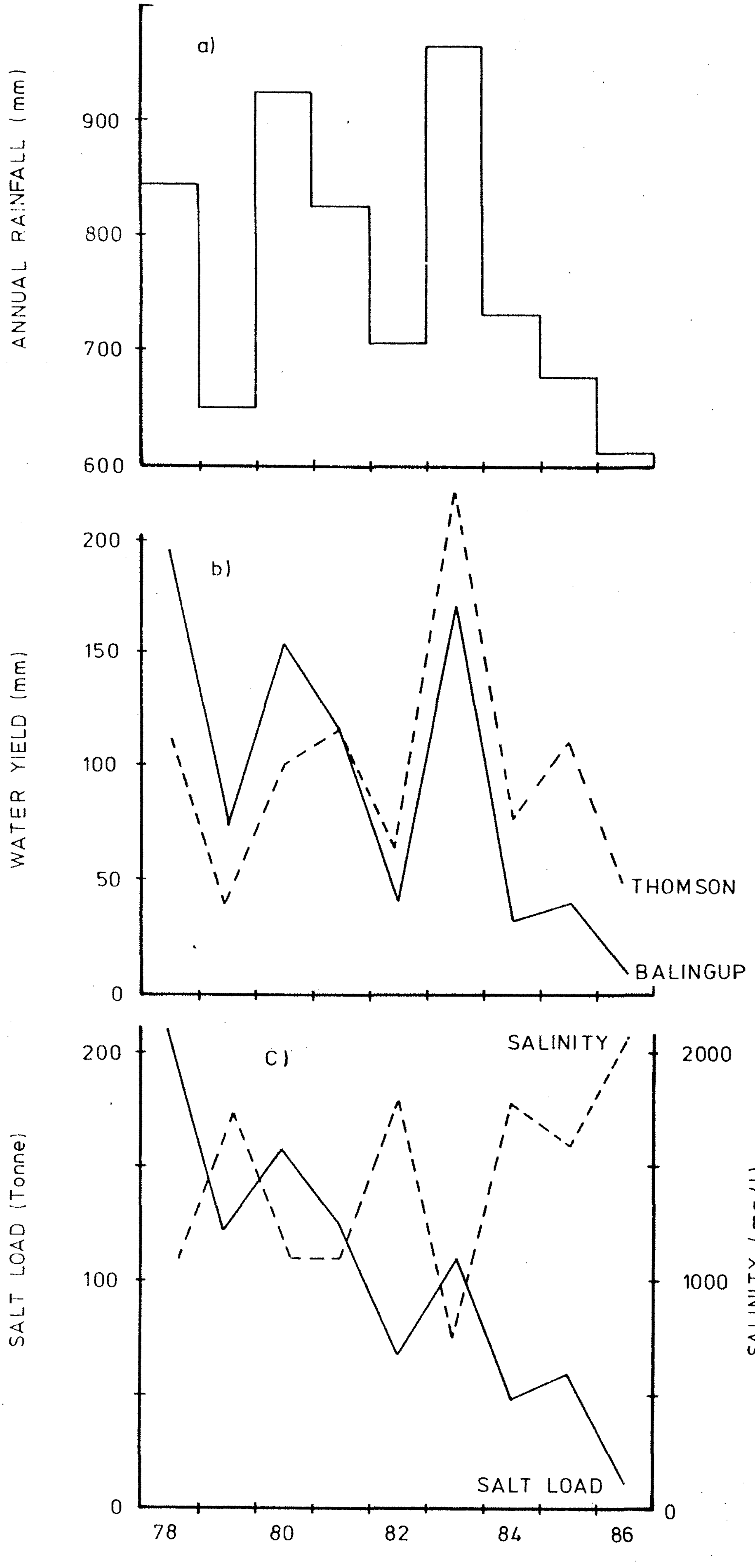


FIG. 9 BALINGUP CATCHMENT STATISTICS

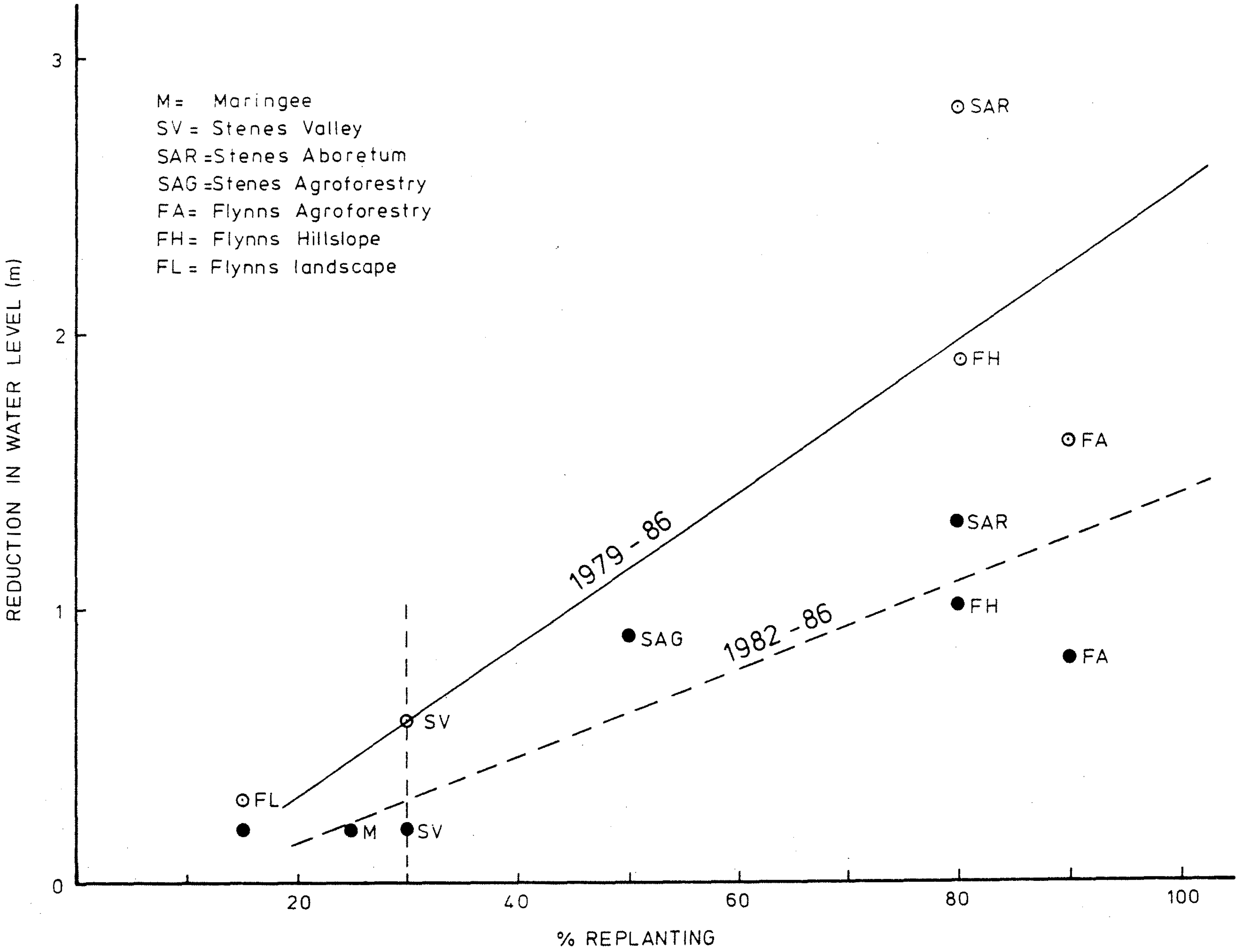


FIG. 10 EFFECT OF REPLANTING AREA ON WATER LEVEL

FIG.11 LONG TERM EFFECTS OF THREE DIFFERENT LAND USES