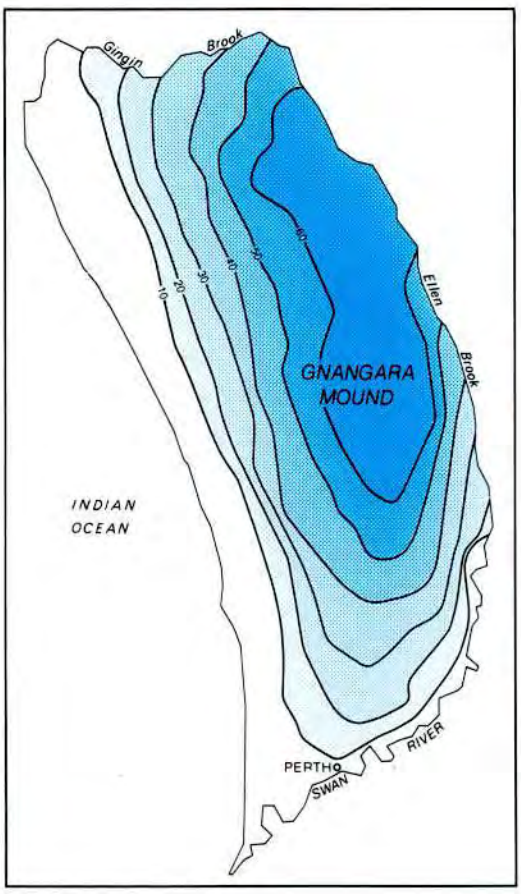
Water Authority
of Western Australia

GNANGARA MOUND GROUNDWATER RESOURCES

ENVIRONMENTAL REVIEW
AND
MANAGEMENT PROGRAMME



APPENDICES
November 1986

Water Authority
of Western Australia

WATER RESOURCES DIRECTORATE
Water Resources Management Branch

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AND
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NOTE

These appendices were prepared using preliminary groundwater drawdown modelling data. In a number of cases, potential effects due to groundwater drawdown are identified in these appendices using this preliminary modelling data. These appendices provided valuable input on areas likely to be sensitive to groundwater drawdown. This input has been used in the planning of modifications to the schemes as originally proposed to account for these potential sensitivites.

When reading these appendices, it should be remembered that they were commissioned to point up potential problems as an aid to detailed wellfield planning. Changes have now been made to the wellfields based on the input provided by these appendices. Further detailed modelling with these changes in place has often shown different, usually less marked, effects than those discussed in the appendices. The refined modelling results are discussed fully in the ERMP.

APPENDIX A

EFFECTS OF GNANGARA MOUND GROUNDWATER DEVELOPMENTS ON NATIVE VEGETATION OF THE NORTHERN SWAN COASTAL PLAIN

Prepared by
E. M. Mattiske & Associates
for
Dames & Moore
December 1985

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1.0 VEGETATION CLASSIFICATION ON THE GNANGARA MOUND

1.1 INTRODUCTION

The vegetation complexes on the Northern Swan Coastal Plain are determined mainly by the range of aeolian soil deposits, climatic conditions, depth to groundwater and European man's influences.

There is wide variation in structural and floristic composition within the Northern Swan Coastal Plain. This variation has been increased by the activities of man, either through clearing, burning or the introduction of plants, animals and diseases.

There have been a few detailed ecological studies on the Coastal Plain. In general these have been on the coastal flora of the islands and dune systems. Speck (1952) subdivided the native vegetation of the Metropolitan area into two formations, forest and scrub. He further split the dry sclerophyll forest into sclerophyll savannah forest dominated by Eucalyptus gomphocephala (Tuart) and scrub forest dominated by Eucalyptus marginata (Jarrah). The scrub formation was divided further on the basis of height (tall and low) and then in relation to dry and moist phases. This classification was later simplified and published by Seddon (1972).

Havel (1968) expanded on the earlier work of Speck by delineating a series of site-vegetation types on the Bassendean and Spearwood Dune Systems (see Addendum A-I). Havel reinforced the idea of a continuum, with species distributions being determined by the degree of leaching and the moistness of the site. This work emphasized the relationship between landforms, soils and vegetation. Consequently, on the Spearwood Dune Systems, Havel subdivided the groups according to soil characteristics and landform positions as follows:

- Species restricted to shallow soils and limestone outcrops, eg. Acacia cochlearis, Trymalium ledifolium, Melaleuca huegelii, Grevillea thelemanniana and G. vestita.

- Species of moderately shallow soils, extending somewhat into both deep and shallow soils, eg. Calothamnus quadrifidus, Lechenaultia linarioides, Jacksonia hakeoides, Conospermum triplinervum var. linearis, Melaleuca acerosa, Petrophile brevifolia and P. serruriae.

- Common species on both shallow and deep soils, eg. Stirlingia latifolia, Mesomelaena stygia, Xanthorrhoea preissii and Hibbertia hypericoides.

- Species restricted to deep soils, eg. Melaleuca scabra and Calothamnus sanguineus.

On the Bassendean Dune System Havel (1968) classified the tree and shrub species according to their tolerance of differing depths to water table at the end of the winter, depths to the depositional horizon and soil moisture levels in the upper soil profile. Based on these criteria the trees were subdivided into four categories:

- Tree species tolerant of excessive wetness - Melaleuca preissiana and Banksia littoralis. Other species that also belong to this category include Melaleuca rhaphiophylla, Eucalyptus rudis (Heddle et al., 1980).

- Tree species of optimum moist sites, intolerant of extremes of moisture conditions - Eucalyptus marginata, E. calophylla, Banksia ilicifolia and less frequently on the Northern Swan Coastal Plain - Banksia grandis.

- Species with wide tolerance, but with maximum development on dry sites - Banksia attenuata and B. menziesii.

- Species without clearcut site preferences - Eucalyptus todtiana and Nuytsia floribunda. Another species falling into this group, noted by Heddle (1980a) in the coastal studies at Tick Flat, is Banksia prionotes.

Havel (1968) also divided the understorey species into four groups:

- Species tolerant of excessive wetness - Patersonia xanthina, Hibbertia stellaris, Calothamnus lateralis, Pericalymma ellipticum, Astartea fascicularis, Pultenaea reticulata, Regelia ciliata, Euchilopsis linearis and Hypocalymma angustifolium.

- Species of optimum moist sites - Adenanthos obovatus, Melaleuca seriata, Dasypogon bromeliaefolius, Xanthorrhoea preissii and Phlebocarya ciliata.

- Species with maximum development on dry sites - Beaufortia elegans, Conostephium minus, Hibbertia helianthemoides, Leucopogon conostephioides, Scholtzia involucrata, Oxylobium capitatum, Melaleuca scabra, Eremaea pauciflora, Jacksonia floribunda, Astroloma xerophyllum, Leucopogon strictus and Boronia purdieana.

- Species without clearcut site preference - Hibbertia subvaginata, Leptocarpus tenax, Conostephium pendulum, Bossiaea eriocarpa and Calytrix flavescens.

The studies carried out as part of the System 6 study clarified these relationships on a regional basis (Churchward and McArthur, 1980; Heddle et al., 1980).

The Bassendean and Spearwood Dune Systems are dominant within the Gnangara Mound development area. Minor areas influenced by the proposed development include small pockets of the Quindalup Dune System to the west, the Alluvial Terrain to the east and the series of wetlands and drainage lines.

1.2 BASSENDEAN DUNE SYSTEM

Havel (1968) recognized five site-vegetation types (G,H,I,J and K - Coastal) on the Bassendean Dune System. Heddle et al., (1980) subdivided the Bassendean Landform and Soil Unit as defind by Churchward and McArthur (1980) into four vegetation complexes on the basis of the plant communities. The Bassendean (Central and South) and Bassendean (North) units were related to climatic conditions through the changing floristic and structural composition from south to north. The woodland of Eucalyptus marginata - Allocasuarina fraseriana - Banksia spp. which dominates the area south of Gnangara Road is replaced in the north by a low open forest of Banksia spp. and Eucalyptus todtiana. Recent mapping by McArthur (Figure 1) defined these upper slopes as the Jandakot (Ja) landform and soil unit. The types G and H (Havel, 1968) would occur on this Jandakot unit in the Gnangara Mound area.

The other two Bassendean vegetation complexes relate to transition areas where the layering of pale yellow sands and pale grey sands support vegetation types F and G as defined by Havel (1968). McArthur's recent mapping has designated these higher dunes with layered sand as the Jandakot-steep unit (Ja-Steep). These areas of high dunes are floristically distinct and warrant further investigation.

Understorey species include Stirlingia latifolia, Jacksonia floribunda and Conospermum stoechadis as yellow sand indicators and Astroloma xerophyllum and Scholtzia involucrata as grey sand indicators. The Bassendean - Central and South Transition vegetation complex occurs on the area to the north of the Commonwealth Bombing Range, northeast of Lake Pinjar. It is associated with a mosaic of jarrah and marri with Banksia ilicifolia and Melaleuca preissiana on the lower slopes. This area is relatively flat with water table depths ranging from 6 - 14m (data supplied by the Water Authority of Western Australia). Significantly it includes the northern most major stand of jarrah, which reaches heights of 20m, left on the Northern Swan Coastal Plain.

The Gavin (G) landform and soil unit, on the eastern fringes of the Gnangara Mound, supports a mixture of Bassendean upland vegetation. On the lower slopes it has greater affinities with the Yanga complex as defined by Heddle et al., (1980). The dominant vegetation is a woodland of Eucalyptus calophylla - Banksia spp. with the occasional jarrah, especially south of Gnangara Road, and Eucalyptus todtiana north of Gnangara Road. Associated species include Kunzea ericifolia, Beaufortia elegans, Macrozamia riedlei, Xanthorrhoea preissii, Jacksonia spp. and Viminaria juncea. Large sections of the Gavin unit have been cleared and developed for small agricultural activities. Where the lower slopes become moister, the Gavin unit supports stands of Melaleuca preissiana with a range of shrub and reed species in the understorey depending on the degree of disturbance and moisture levels.

Further downslope, Havel's (1968) site-vegetation types I and J occur on the lower slopes of the Joel (J) landform and soil unit (see Table 1). These lower slopes are dominated by Banksia ilicifolia with some jarrah in the south and species of Melaleuca; predominantly M. preissiana and occasionally M. rhaphiophylla.

The fringing vegetation near the swamps and wetlands is less variable due to the more uniform soil moisture condition and the shallow depth to water table. In seasonally wet areas the woodlands and forests on the lower slopes are replaced by heaths dominated by species belonging to the families Myrtaceae and Leguminosae, sedgelands dominated by species from the families Restionaceae and Cyperaceae and open water (McComb and McComb, 1967). Where these wetlands in the Bassendean Dune System become extensive they have been designated as the Pinjar complex by Heddle et al., (1980). McArthur (see Appendix C of this ERMP) has subdivided these swamps and wetlands in the Bassendean and Pinjar areas into units known as Seasonal Swamps (Ws), Permanent (DL).

The latter subdivision has allowed a finer level of definition to be achieved; although a great deal of variation still exists. The communities range from woodlands of Eucalyptus rudis, low woodlands of Melaleuca preissiana, low open forests of Melaleuca rhaphiophylla, closed heath of predominantly Melaleuca spp. including M. lateritia, M. hamulosa, M. teretifolia and M. viminea, sedgelands with Typha spp., Baumea articulata, B. juncea, Leptocarpus spp. and Schoenus spp. to aquatic species (McComb and McComb, 1967).

The Pinjar unit is of particular interest because it includes the major low lying areas with less than 4m to the water table. Examples are Lake Pinjar, in the centre of the proposed Pinjar water abstraction scheme and Tick Flat to the north of the Pinjar Scheme. The vegetation on both of these sites has been altered; by agricultural activities as at Lake Pinjar and climatic changes at Tick Flat (see Heddle, 1980a).

1.3 SPEARWOOD DUNE SYSTEM

The vegetation overstorey on the Spearwood Dune System reduces in height and foliage cover with distance northwards. Consequently, the central and southern forests of Eucalyptus gomphocephala - E. marginata - E. calophylla (tuart - jarrah - marri) and woodlands of jarrah - Banksia spp. are replaced by a woodland of tuart and a low open forest of Eucalyptus todtiana (Prickly bark) - Banksia spp. in the north. The Karrakatta soil unit occupies a significant part of the Spearwood Dune System. Although the over storeys of the northern Bassendean and Karrakatta complexes are similar, the understorey compositions are not (Havel 1968; Heddle et al., 1980). Similar transitional complexes occur where yellow sand indicators reflect the mixing and dominance of yellow over grey sands (Heddle et al., 1980). Recent mapping by McArthur and Bartle (1980) has subdivided the Spearwood areas into a further series of landform and soil units described below.

The Karrakatta-yellow (Ky) and Karrakatta-grey (Kg) soil units occur on undulating dunes of the Karrakatta sands with varying depths to limestone and water table; often greater than 20m (data supplied by Water Authority of Western Australia, see Figure 2). Vegetation varies from woodlands of Eucalyptus gomphocephala, E. marginata to Banksia spp. with dense shrub layers.

The Cottesloe vegetation complexes occur along the western fringes of the Gnangara Mound area. This complex is associated with shallow limestone soils (Kls) which characteristically support a heath dominated by Dryandra sessilis, Conospermum triplinervum var. linearis, Calothammus quadrifidus, Jacksonia hakeoides, Grevillea thelemanniana and G. vestita (Havel 1968 - see Addendum A-I; Heddle et. al., 1980).

The remaining two units, Spearwood (Sp) and Beonaddy (B) support denser stands of tuart and jarrah on the fringes of the seasonal swamps (see site-vegetation types D and E as defined by Havel 1968; Addendum A-I). The Beonaddy unit may also include a fringing woodland of Flooded Gum (Eucalyptus rudis) with the occassional Melaleuca spp. Other associated species include Acacia saligna, Jacksonia sternbergiana and Viminaria juncea. The wetlands on the western section of the mound are generally deep. Fringing vegetation includes woodlands of flooded gum, low open forests of Melaleuca rhaphiophylla, Banksia littoralis, heaths and sedgelands often with Typha sp. on wetter sites (McComb and McComb, 1967; Heddle et. al., 1980). These wetlands have been affected to a large degree by clearing for market gardens, residential and industrial activities north of Wanneroo (Metropolitan Water Authority, 1985).

1.4 ALLUVIAL TERRAIN

The wetlands on the eastern fringe of the Gnangara Mound are a mixture of the seasonal and permanent Yanga (Ya) swamps and drainage lines in the Gingin Brook area (GG). The former supports a range of communities from woodlands of Melaleuca preissiana and M. rhaphiophylla to heaths of Melaleuca spp. with the occassional pocket of Actinostrobus pyramidalis, while sedgelands and open water occur on the wetter sites.

In these eastern areas the swamps include dense low thickets of Melaleuca spp. which provide habitat for the rare and endangered Short-necked Tortoise. If lowering the water table leads to loss of vegetative cover, the chances of protecting these animals in their native environment could be lessened.

2.0 BIOLOGICAL EFFECTS OF DRAWDOWN

The groundwater resources of the Gnangara Mound include shallow unconfined aquifers. The series of wetlands on the Northern Swan Coastal Plain reflects the proximity of these shallow aquifers to the soil surface. A lowering of the water table by abstraction may be expected to affect the native vegetation in a variety of ways. As summarised in the Notice of Intent (Metropolitan Water Authority, 1985) these are:

- Operation of the scheme will result in a general lowering of unconfined groundwater levels in the project area, superimposed on the natural seasonal fluctuation in levels.
- Preliminary modelling by the Water Authority of Western Australia has predicted long term drawdowns on a regional basis. For the proposed Pinjar Scheme these drawdowns range from 0 to 3m.
- "Cones of depression" of 3 to 4m of drawdown are predicted near the abstraction wells, with lesser declines occurring further from the wells.
- The effects of drawdown on the chain of wetlands, west of the proposed Pinjar Scheme, are expected to be negligible.

Overriding all these predictions is the complex distribution of different land uses and native vegetation on the Northern Swan Coastal Plain. For example, drowned fencelines in Lakes Jandabup, Joondalup and Bambun are regarded as indicators of recent changes in wetlands. Thus, there may be local rises as well as declines in water table levels. Predictably, there are difficulties associated with correlating changes in native vegetation to alterations in the soil moisture and water table levels. All plant communities are dynamic and respond to alterations in a range of environmental conditions - eg. fire, nutrient status and climate as well as changes in the water regime. Therefore the ability to predict changes in the native plant communities depends on understanding the natural systems and the plants' responses to changing water regimes.

Research has been carried out on the Northern Swan Coastal Plain by the Department of Conservation and Environment - particularly the Wetlands Advisory Committee, the Department of Conservation and Land Management - formerly the Forests Department, the Water Authority of Western Australia - formerly the Metropolitan Water Authority; C.S.I.R.O.; McComb and McComb, 1967; Havel, 1968, 1975; Aplin, 1976; How 1978; Heddle, 1980a; Dodd et al., 1984 and Dodd, 1986.

Based on this research it is possible to theoretically predict some of the likely effects of the proposed drawdown. These likely effects can then be compared realistically with previous results from dry periods (for example, drought in the 1970s) when water tables fell naturally and with the impacts of the current pumping programmes in the existing Wanneroo and Mirrabooka Schemes.

Grieve (1957) and Grieve and Hellmuth (1968, 1970) summarised a series of studies on the eco-physiological adaptations of the native vegetation. They found that many of the native species appeared to restrict their physiological activity to a point of near dormancy with increasing drought. On the Northern Swan Coastal Plain, drought occurs seasonally in the months of March and April. Examples of such species include Banksia menziesii, Stirlingia latifolia, Hibbertia hypericoides, Bossiaea eriocarpa and Eucalyptus calophylla. A notable exception is Eucalyptus marginata, which remains physiologically active throughout the summer months. Other mechanisms for avoiding drought include shedding of leaves, eg. Phyllanthus calycinus, avoidance of fine root development in the upper soil layers, eg. species of the family Epacridaceae (data from Heddle and Dodd) and growth only in more favourable periods, eg. annual species and geophytes.

Recent morphological studies undertaken by Heddle have thrown light on the root and shoot characteristics of some 43 species on the Northern Swan Coastal Plain (Dodd et al., 1984; Heddle - unpublished reports to the Water Authority of Western Australia 1982 and 1984), see Addendum A-II. These studies defined a series of root types based on the types defined by Cannon (1949). Essentially the deep-rooting species were recognised as being more likely to be dependent on the water table and the adjacent moist soil layer. On the other hand, shallow-rooted species are likely to be highly responsive to large seasonal fluctuations in soil water content and hence are not affected by groundwater changes. Consequently the deeper-rooted species are more likely to be affected by water table drawdown than the shallow-rooted species. To date, results collected by Heddle (1980b, 1981, 1982, 1984 and 1986) support this prediction. For example, the older, deep-rooted trees on the moister slopes, such as swamp banksia - Banksia littoralis and B. ilicifolia have died where water tables have declined. Other results from the root studies have explained earlier relationships of vegetation to soil moisture regimes as noted by Havel (1968). Heddle (1980a) has shown that the shallow-rooted species tend to avoid dessication or are adapted to periods of drought. For example, Hibbertia subvaginata dies under stress and re-establishes under more favourable conditions from seed.

Both Havel (1975) and Aplin (1976) predicted a vegetation shift to the xeric end of the continuum if water tables were lowered. Consequently they predicted that species tolerant of wet and moist sites would be replaced by species tolerant of drier conditions. For example, Banksia littoralis (a species tolerant of wet site conditions) might be replaced by Banksia ilicifolia (a species tolerant of moist conditions). Muir (1983) predicted a similar shift from Banksia attenuata to Banksia menziesii, which grows on the driest sites. Further, he suggested a reduction in height and average foliage density as sites became drier. The latter is predictable in light of a similar regional effect as a result of decreasing effective rainfall (Heddle et al., 1980).

Dodd and Bell (1982) also carried out studies of vitality, water utilization and other eco-physiological responses to drought for selected tree and shrub species in the Banksia woodlands on the Northern Swan Coastal Plain. They concluded that the environmental variables with most influence on transpiration rates were air temperature, vapour pressure deficit and solar radiation. Consequently, pumping of shallow aquifers when plant stress is greatest and when groundwater levels are normally lowest, may alter water availability and effect transpiration rates, thereby inducing mortality in trees close to the wells.

In 1966 the Forests Department established a series of vegetation transects on the Northern Swan Coastal Plain to investigate the suitability of sites for establishing pines (Havel, 1968). Selected transects were later relocated by Havel and Heddle as a means of monitoring changes in soil moisture and vegetation. Consequently it was possible to study the influence of a series of dry years in the 1970s on the native vegetation (Heddle, 1980a). The transect sites were South Kendall (located in the Bassendean Dune System, 1.5km east of Lake Gnangara), West Gironde (located in the Bassendean Dune System, 3km east of Lake Jandabup), Neaves (located in the Bassendean Dune System, at the western edge of Melaleuca Park) and Tick Flat (located 8km northeast of Yanchep on the fringes of the Bassendean and Spearwood Dune Systems).

Responsibility for monitoring these sites was transferred to the Metropolitan Water Authority in later years (Heddle - unpublished reports to the Water Authority of Western Australia in 1981, 1982, 1984 and 1986). Two additional sites were located in 1976 at Lakes Jandabup and Joondalup. Unfortunately earlier records for comparison were lacking at these two latter sites. Initial results showed the influence of drought at the four transects; South Kendall, West Gironde, Neaves and Tick Flat.

Following the commencement of pumping from the Wanneroo Scheme in 1976, all six transects were maintained to monitor the impact of abstraction. The first three transects were within the zone of pumping influence to varying degrees. Tick Flat was not and thus serves as a control. The results presented to date by Heddle show that:

- Soil moisture levels and water levels fluctuate in response to changing rainfall events, eg. soil moisture levels and water tables declined in the 1970s and 1980s at all sites, including Tick Flat, which serves as a control, due to low rainfall.

- The majority of native species can tolerate a series of below average rainfall years.

- Selected tree and shrub species did not tolerate the drier period in the 1970s and decreased in vigour and numbers. These changes were recorded prior to the impact of pumping on the Northern Swan Coastal Plain. Notable losses were the deeper-rooted Banksia littoralis and B. ilicifolia which were known to prefer wet and moist sites respectively. In the case of Banksia ilicifolia in particular, this loss was balanced by successive new seedlings. Results since 1976 reflect a continued growth of these seedlings after establishment, indicating their ability to adjust to the modified moisture regime. Their development to maturity has not yet been demonstrated, however. Similar trends were observed in the understorey species typical of moist sites. These results therefore suggest that a regional lowering of the water table would lead to a shift towards vegetation more tolerant of drier conditions, with an inital loss of older trees and shrubs. Concern arises for areas where wet sites cannot be maintained in the long term with the new water regime. This 'wet' end of the vegetation continuum may therefore be lost from some sites.

  Although lowered water tables might be acceptable or even desirable in agricultural areas, where seasonal waterlogging has posed difficulties, eg. Lake Pinjar, they are not desirable in conservation areas such as Melaleuca Park.

- Banksia attenuata and Banksia menziesii, which tolerate drier sites, increased in numbers. Regionally the distribution of these drier site species which dominate the regional landscape would be expected to extend following any long term lowering of the water table.

- Species such as Hibbertia subvaginata and Gompholobium tomentosum, with shallow-roots, were able to tolerate the drought conditions. This trend differed slightly for the wet site species like Euchilopsis linearis and Aotus ericoides which decreased in frequency (Heddle, 1980). Once again these results indicate the adaptation of many native species to fluctuations in the soil water regime.

- Some species did not respond as predicted. For example, Melaleuca preissiana produced more suckers from the roots or branches in response to stress, while Eucalyptus rudis produced epicormic shoots in response to stress. The groups defined in terms of tolerance of site conditions by Havel (1968), must therefore be treated with some caution. Ideally more information would be required on all the native species to understand how they will react under different conditions. The latter is an enormous task. Classification at the morphological level using selected species as models, may be a useful approach (Pate et al., 1984).

In general, most of the native species appear able to tolerate some decline of the water table on a regional basis, with some loss of older trees and shrubs and slight shifts in distribution. In specific instances, however, recent pumping from the Wanneroo Scheme led to the loss of tree and shrub species on the Bassendean Dunes in response to the sudden lowering of the water table by 3 to 4m within the cones of depression and from nearby lower slopes (Heddle, 1986). The latter observations may indicate that the rate of withdrawal is as critical as the extent. That is, the plant communities may not have had time to adjust to the lowered soil moisture levels. These impacts were more evident in the plant species that favour the moister sites or are deep-rooted.

In reviewing the likely impact of the proposed extension of the pumping scheme on the native vegetation there appear to be two aspects. Firstly, the impact on modified communities and secondly the impact on uncleared native communities.

The initial response in the modified communities is a loss of the older trees (eg. Marri's on Gnangara Road near production wells). This response can be minimised by the removal of older dead trees and replacement with younger trees and shrubs which can adjust to the altered soil moisture regime (eg. as noted by Heddle, 1980a). In this way, the natural landscape can still be maintained in disturbed environments. Another example is the modification of Lake Adams by dredging to facilitate a mosaic of reeds and open water.

The ability to predict the likely impacts on the range of native communities is dependent on the location of the wellfields, regional drawdown, depth to water table and the topographical position of the native vegetation. Observations and findings to date reflect that the impacts are greater where there are wetlands, low-lying areas and shallow water tables. The following groupings attempt to summarise the likely impacts on the native communities in the Conservation Reserves, National Parks, State forest and Public Lands (Figure 3). As such it supplements earlier comments with regard to vegetation on the respective landform and soil units and the summaries in Addendum A-III and Appendix D of the ERMP.

1. High Potential Impact Areas - Gnangara Mound

Wanneroo Wetlands - Eastern Chain (M8).

These occur in close proximity to the wellfields and consequently any shift in the shallow water table or water levels of the lakes will result in a shift in the vegetation towards the xeric end of the continuum.

Melaleuca Park Management Priority Area (M9).

Although this conservation area occurs southeast of the proposed Pinjar Scheme, it straddles the mound on the western fringe of the regional zone of influence. The relatively shallow water tables (less than 5m to less than 10m) which dominate the reserve, may be influenced by further pumping, with a resultant shift in vegetation.

Whiteman Park (Mussel Pool) (M13).

This park (like the former one) is already within the regional zone of influence of the current schemes; however, it is south of the proposed Pinjar Scheme. If any pumping schemes are extended south or east of the current areas, the potential impact is high.

Yeal Nature Reserve (M5).

This reserve and proposed extensions to the south include a large range of wetlands and low-lying areas. As such, if these extensions are included, it would provide one of the more extensive areas of Bassendean Dune System in a conservation reserve. Consequently it is recommended that the proposed wellfields to the west are located so as to minimise any likely impacts on the native communities.

Vacant Crown Land (Commonwealth of Australia, "Bombing Range").
This area occurs to the southeast of the Yeal Nature Reserve and includes the last substantial stand of jarrah-marri on the northern area of the Swan Coastal Plain. The low-lying swamp (see Figure 2) is particularly vulnerable due to the shallow water table. It is recommended that the conservation status of this area be reviewed and that impacts be kept to a minimum.

Wabling Management Priority Area (C13).
This area includes several low-lying areas which would be vulnerable if the borefield extends northwards near the reserve.

Other areas of Native Vegetation in the State Forest (eg. low-lying areas near Little Coogee Swamp and Gallagher Road).
These areas have already been affected by recent pumping and any further lowering of the water table would increase the regional effect. However, they provide an area for research on the effects of the cone of depression on the native vegetation, thereby providing an example of the extreme scenario.

2. Moderate Potential Impact Areas - Gnangara Mound

Yanchep National Park (M3), Neerabup National Park (M6) and Lakes Joondalup and Goollelal (M7).
All of these occur to the west of the proposed scheme. Due to the distance from abstraction wells and the deeper lakes (Wp) any influence must be considered moderate and likely to be restricted to the fringing lower slopes in these steeper dune systems. The clearing associated with agriculture and residential areas would have had a greater effect on the soil moisture regimes in this western region.

3. Low Potential Impact Areas - Gnangara Mound

Mound Springs - Muchea (C25), Pearce Aerodrome (M15) and Ellen Brook and Twin Swamps Nature Reserve (M17).
All these occur on the eastern fringes of the mound and are unlikely to be influenced by the proposed Pinjar or current pumping schemes. However, if pumping is extended eastwards of the mound, then these areas (which are dominated by wetland and swamp communities) would require reclassification to a higher impact category.

Caraban Management Priority Area (C12), Two Rocks Open Space (M1) and Ridges Management Priority Area (M4).

All these occur to the west of the proposed scheme; and due to the deeper water tables are unlikely to be influenced by the pumping.

Warwick Woodland (M11) and Reserve A20091, Marangaroo (M12).

Both of these occur south of the proposed extension and like the previous three reserves are unlikely to be influenced by the proposed pumping. Clearing and disturbance associated with the nearby residential areas are more likely to have been the main influences on the communities in these reserves.

Other remnant areas of native vegetation in the State Forest.

The small pockets of remnant limestone ridges and Jandakot dunes located amongst the pine plantations are unlikely to be influenced by the pumping due to the greater depth to water table.

It is strongly recommended that the areas of native vegetation in Conservation Reserves, National Parks, State Forest No. 65 and Public Lands which may be vulnerable to a lowering of the water table be protected from any likely impact of water abstraction. Table 4 (Appendix D of this ERMP) lists the reserves in the potential zone of impact and re-stresses the need for a conservative approach. Of particular concern are the Bassendean Dune System (Joel and Wetland areas - water table depths 0 to 10m), the lower slopes in the Spearwood Dune System (Beonaddy) and wetlands where the depth to water table is substantially less than 5m (see Figure 2 - data supplied by Water Authority of Western Australia and Geological Survey, Department of Mines, Table 1).

3.0 CONCLUSION

The majority of native species can tolerate fluctuations in the soil moisture regime. Others, however, are intolerant of such changes. In some cases the species can adapt by establishing new generations of plants or maintaining dormancy over drier periods. As the level of information is scanty, it is recommended that a conservative approach is adopted and that alternative pumping areas are sought if there is a chance of detrimental effects on the nature reserves within the Gnangara Mound.

The established monitoring system should be expanded, with particular emphasis on the following points:

- Regular monitoring of lake levels.

- Regular monitoring of fringing vegetation for condition and physiological stress should be undertaken around wetlands (within the Bassendean, Spearwood, Herdsman and Pinjar wetland areas).

- Establishment of transects within the Spearwood Dune System, particularly near the wetlands and swamps. The drier sites are less likely to be influenced by pumping due to the substantial depths to the water table.

- Both predicted impact and control areas should be monitored (eg. regular monitoring of studies established by Dodd in Banksia communities near the bores).

- Further biological studies in the area should be encouraged, to increase our knowledge of the vast range of native species in the area and to assist with their proper conservation and management, eg. detailed vegetation mapping of reserves in the area of influence and monitoring programmes established in representative communities.

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ADDENDUM A-I

HAVEL'S SITE VEGETATION TYPES

Summary of Havel's site-vegetation types for the Bassendean and Spearwood Dune Systems on the Northern Swan Coastal Plain (extracted from Havel, 1968). Several taxonomic changes have occurred since the earlier studies of Havel; these have been corrected in the following text by reference to Green, 1985.

Type A - indicated by presence of Melaleuca huegelii and M. cardiophylla, Acacia cochlearis, Trymalium ledifolium, Grevillea thelemanniana and G. vestita, Dryandra sessilis, characteristics of bare limestone (travertine) outcrops with pockets of reddish-brown sand.

Type B - indicated by presence of Jacksonia hakeoides, Conospermum triplinervium var. linearis, Calothamnus quadrifidus, Melaleuca acerosa and Lechenaultia linarioides characteristic of shallow yellowish-brown sand with scattered limestone pinnacles, occurring on slopes below limestone outcrops.

Type C - indicated by presence of Hibbertia hypericoides and H. racemosa, Hakea costata, Petrophila serruriae and P. brevifolia, Jacksonia hakeoides and J. sternbergiana, Mesomelaena stygia, Xanthorrhoea preissii and Stirlingia latifolia, characteristic of moderately deep yellow sands with weakly leached surface, occurring mainly on lower slopes below limestone outcrops.

Type D - indicated by presence of Mesomelaena stygia, Synaphea polymorpha, Calothamnus sanguineus, Eremaea pauciflora, Melaleuca scabra, characteristic of deep yellow sands with moderately leached surface, occurring on broad plains within the Spearwood Dune System.

Type E - indicated by presence of Eremaea fimbriata, Xanthorrhoea preissii, Synaphaea polymorpha, Stirlingia latifolia and Melaleuca scabra, characteristic of deep, moist pale yellow sands in depressions within the Spearwood Dune System.

Type F - indicated by presence of Daviesia quadrilatera and D. juncea, Allocasuarina humilis, Pimelea sulphurea, Calectasia cyanea, Conospermum stoechadis, Acacia sphacelata, Eremaea pauciflora and Jacksonia floribunda, characteristic of deep pale yellow sands with strongly leached surface, occurring on slopes and dune crests within the transition zone.

Type G - indicated by the presence of Leucopogon conostephioides, Scholtzia involucrata, Eremaea pauciflora, Melaleuca scabra, Boronia purdieana, Astoloma xerophyllum, characteristic of deep dry pale grey sands which are strongly leached throughout, and occur on lower slopes in the transition zone, and slopes and dune crests within the Bassendean Dune System.

Type H - indicated by presence of Leucopogon conostephioides, Scholtzia involucrata, Xanthorrhoea preissii and Dasypogon bromeliaefolius, characteristic of deep pale grey sands, dry at the surface, moist at depth, strongly leached throughout; occurring on sub-flats and around swamps in transition zone and within the Bassendean Dune System.

Type I - indicated by presence of Xanthorrhoea preissii, Dasypogon bromeliaefolius, Melaleuca seriata and Adenanthos obovata, characteristic of moist soils with dark grey humusoid surface and organic deposition horizon at depth, occurring within the transition zone and the Bassendean Dune System.

Type J - indicated by presence of Hypocalymma angustifolium, Pultenaea reticulata, Xanthorrhoea preissii and Adenanthos obovata, characteristic of wet dark grey humusoid sands, usually over a desposition horizon, occurring throughout the region in flat swamp transition and in seasonal swamps.

Type K - indicated by Pericalymma ellipticum, Astartea fascicularis, Calothamnus lateralis, Regelia ciliata and Typha spp. characteristic of water saturated sands and peats, occurring in permanent swamps throughout the region.

ADDENDUM A-II

SUMMARY OF ROOT TYPES AMONGST NORTHERN SWAN COSTAL PLAIN SPECIES

The summary of Root Types amongst Northern Swan Coastal Plain Species is based on the classification scheme as proposed by Cannon, 1949. (Results extracted from Dodd et al., 1984). Root types for the tree species were followed but not published in Dodd et al., 1984. The tree species all had well developed lateral and deep roots (greater than 3m). Nuytsia floribunda had exceptionally large roots due to its parasitic activity on other shrubs.

Root Type 1: Least specialised, well developed primary and lateral roots, with neither system dominating over the other. Roots generally shallow, less than 1m in depth.

Acacia huegelii
Acacia pulchella
Aotus ericoides
Astartea fascicularis
Calytrix empetroides
Calytrix fraseri
Eriostemon spicatus
Euchilopsis linearis
Gompholobium tomentosum
Hibbertia aurea
Hibbertia helianthemoides
Hibbertia hypericoides
Hibbertia subvaginata
Hypocalymma angustifolium
Lechenaultia biloba
Oxylobium capitatum
Pericalymma ellipticum
Pithocapa corymbulosa
Regelia ciliata

Root Type 2: Characteristically shallow, laterally very extensive.

Hemiandra pungens

Root Type 3: Distinctly tap-rooted type, all sprouter species, depths greater than 3m recorded.

Daviesia juncea
Jacksonia floribunda
Petrophile linearis

Root Type 4: Similar to Type 3 in the presence of a deep tap-root, but differs in the development of extensive major laterals.

Acacia ? barbinervis
Adenanthos cygnorum
Allocasuarina humilis
Beaufortia elegans
Bossiaea eriocarpa
Calytrix flavescens
Eremaea pauciflora
Hibbertia huegelii
Jacksonia furcellata
Melaleuca scabra
Melaleuca seriata
Scholtzia involucrata
Stirlingia latifolia

Root Type 5: Specialised xerophytic root type which is typically shallow and characterized by pronounced branching and forking of roots.

Andersonia heterophylla
Astroloma xerophyllum
Conospermum incurvum
Conostephium minus
Conostephium pendulum
Leucopogon conostephioides
Leucopogon sprengelioides

ADDENDUM A-III

SUMMARY OF POTENTIAL DRAWDOWN EFFECTS OF NATIVE VEGETATION ON THE GNANGARA MOUND AREA

		Site-vegetation types Havel 1968	Vegetation complexes Heddle et al., 1980		Potential Impact Rating Havel, 1975; Heddle, 1980a
Unit Code	Description	Type Code	Complex No.	Description	
+Ja	Jandakot	G, H	43,44	Bassendean-North Central and South	Patchy-Mid slopes
+Ja-Steep	Jandakot	F, G	45,48	Bassendean-North, Transition Karrakatta-North Transition	Low
+G	Gavin	G, H	38,43,44	Yanga, Bassendean-North, Central and South	Low
+J	Joel	I, J	43,44,46	Bassendean-North Central and South and Bassendean-Transition Central and South	High
+Ws	Wetlands Seasonal (S)	K	54	Pinjar	High
+Wp	Wetlands Permanent (P)	-	53	Herdsman	Patchy, Lower slopes rather than wetlands
+Wy	Yeal Swamp Complex	K	43	Bassendean-North	High
+Pj	Pinjar	K	54	Pinjar	High
+DL	Drainage Lines	K	41,43	Moore, Bassendean-North	High
*Ky	Karrakatta yellow	B, C	47,49	Karrakatta-North, Central and South	Low
*Kg	Karrakatta grey	B, C	47,49	Karrakatta-North, Central and South	Low
*Kls	Limestone	A	51,52	Cottesloe-North, Central and South	Low
*Sp	Spearwood	D	47,49,51,52	Karrakatta-North, Central and South	Patchy-Lower slopes
				Cottesloe-North, Central and South	Low
*B	Beonaddy	E	47,49,53	Karrakatta-North, Central and South Herdsman	Moderate-Lower slopes
+W	Lakes and Swamps	-	53	Herdsman	Patchy, Lower slopes rather than wetlands
+Ya	Yanga	-	38	Yanga	Potentially High
+GG	Gingin Brook Complex	-	41	Moore	Potentially High

Landform and Soil Units
*McArthur and Bartle 1980;
+McArthur 1985

APPENDIX B

COMMERCIAL FORESTS OF THE NORTHERN SWAN COASTAL PLAIN

Report prepared by
McArthur & Associates
for
Dames & Moore
February 1986

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1.0 SUMMARY

An area of slightly over 20,000ha has been established with pine plantations on northern portions of the Swan Coastal Plain. This land has been set aside as early as the 1920s for long term renewable resource supply. As in most land development proposals, action was in response to circumstances observed, or expected in the future. The original land objectives were to produce saw-log timber for the Perth Metropolitan market. The State finds this area now has an additional long-term value: groundwater supply. Accordingly, since the 1970s, land management in this region has been accepted as having multiple values - but emphasizing water and timber production.

Water production from the Gnangara Mound can only be sustained if the water use can be controlled and monitored, and the water recharge of the reserves can be guaranteed. Much of the Gnangara Mound is forested - with a large proportion established as pine plantation; managed by the Department of Conservation and Land Management (CALM).

Research investigations have isolated Pinus pinaster as the most suitable species for timber production. Genetic trials have resulted in improved timber productivity characteristics, and further improvements are expected in the 1990s. With changes in land use emphasis, further genetic and species research is warranted, particularly for second-rotation forests.

As the groundwater abstraction programme is becoming more a reality, the forests' significance in water production has received close attention. There are two primary means of interaction - groundwater uptake and rainfall interception. It appears that pine forests, particularly on uplands, generally depend more on moisture in the soil profile than from the water table. Uptake from the water table can occur on lowland sites with low depth to water. Overstocked forests significantly reduce rainfall interception - the primary means of groundwater recharge.

Forest and hydrological research has culminated in the development of a land use management system, which will enable the achievement of water and timber production objectives from the land. A series of silvicultural programmes for the various soil types involve forest stand density reductions to levels equating those of the native forest, with the objective of maintaining the hydrological balance. Additionally, tree crown pruning and ground-fuel reduction (through the use of low intensity fires) can further improve the groundwater recharge.

Although the management techniques are sound, the programme is not without problems. Principal is the historical condition of the plantation, resultant from the unavailability of a market to utilise early and mid-rotation timber products from thinnings. The achievement of the dual land use objectives will necessitate a concerted effort by CALM to maintain the forest stands within narrow stocking density ranges.

A priority action thinning programme will be necessary as much of the plantation is currently outside the accepted specifications. It is preferable for thinning to be commercial, as the alternative is high cost non-commercial treatment. The State is faced with the need to encourage a small-wood market within the next five years, or be forced into a large expenditure programme for plantation management.

In a general sense, the land use management problem can be resolved between the two principal Government Departments, the Water Authority of Western Australia (Water Authority) and CALM. This is particularly the case for operations, however, there are other parties which must be considered. Some private plantations have been developed, and the opportunity for expansion or further establishment should not be discouraged. Regional and Local Authorities will also be involved because of potential restrictions and control mechanisms on land development. In addition, there is a growing workforce and its associated socio-economic multiplier which is dependent upon the forests.

As the productivity of the land is very sensitive to forest condition, it can be expected that land management must be more specific and controls may become necessary. As CALM have the major holdings, it is essential that forthcoming reviews of the General Working Plan (Forests Department, 1982) and Regional Plans further emphasise the importance of water production. Management Plans for specific areas should be prepared detailing this commitment. Additional controls can be considered through existing or proposed legislation, or through conditions of development enforced jointly by Local Authorities and the Water Authority.

Co-operative land management on the Northern Swan Coastal Plain has the potential to sustain a wide variety of land uses and activities over a long period (Forests Department, 1980). The solution of sustained water and timber production lies with the majority of the land remaining under State control, but with management directed to the maintenance of the primary land objectives.

2.0 FORESTS OF THE NORTHERN SWAN COASTAL PLAIN

2.1 REVIEW AREA

This study examines plantation forestry on the Northern Swan Coastal Plain. The boundaries are Gnangara Road in the south and Gingin Brook in the north (Figure 4).

2.2 TENURE

Commercial forest development on the Swan Coastal Plain (within the Gnangara Mound) north of Perth is limited to two portions of State Forest No. 65 - north of Gnangara Road (see Figure 4).

The Department of Conservation and Land Management (CALM) has authority over State Forest No. 65, as well as adjoining National Parks and vacant Crown Land.

2.3 PLANTATION SPECIES AND SITE SUITABILITY

The limited capacity of Western Australian indigenous forests to sustain timber production in the longer term has been recognized for some time. Commercial development possibilities were investigated during the 1930s and 1940s over portions of State Forest No. 65.

Pinus pinaster (Ait.) appeared the most suitable species. During the 1970s the problems of indigenous forest production and the small area of exotic coniferous plantations, stimulated research effort, particularly in the productivity of the Northern Coastal Plan under P. pinaster. Extensive phenotype selections and progeny testing resulted in breeding of a superior genotype orchard stock. A complete review of these projects may be found in Hopkins (1960), Perry and Hopkins (1967) and Butcher (1979). Concurrent with species trials, site suitability assessments on the coastal plain were initiated. Details of techniques and findings are provided in Havel (1967) and (1976).

Generally, both the Spearwood and Bassendean soil systems are suitable for pine planting, although there are specific restrictions.

The earliest pine plantings were established on the lower, moister profiles of the Bassendean System where the trees depend on the water table. These areas have a higher soil organic component due to heavy native vegetation growth. On elevated areas, the inherent highly leached soil condition and the lower availability of water has caused establishment problems.

The Spearwood System has younger, less leached and more fertile sands. The system is generally elevated and tree survival on these uplands is greatly dependent upon water retained in the soil profile - well away from the influence of the water table.

Plantation development to date has taken place south of Gingin Brook. Land is available north of Gingin Brook and trials are proceeding, however the greatest limitation appears to be climatic conditions, which imposes additional growing problems in the available Spearwood System soils.

2.4 FOREST ACTIVITY PLANNING

Activities in State forests are regulated by two official documents produced by CALM:

1. The General Working Plan (GWP) No. 87 (1982) provides policies and strategies for forest management for the period 1982-1986. Accordingly, the GWP is shortly due for renewal, and more importantly, the next review will incorporate any changes in philosophy as a result of the Forests Department's amalgamation into CALM.

   The current GWP embodies a broad philosophy of multiple land use management. Within that context, both wood and water production are recognized as two of the priority land uses. Other priorities are flora, fauna, landscape, scientific study and education, recreation, public utility and mining. As a factor of wood production, it is accepted that to achieve self-sufficiency in timber, it is important that a softwood forest resource is established at a rate of 4000ha/annum - of which the Government aims for 3500ha. For water production, the management objective is to manage forest catchments needed for water supplies so as to maintain or enhance water quantity and quality in accordance with the requirements of the water supply authorities.

The above two primary land uses are important on the Northern Swan Coastal Plain and in order to ensure planning and land management incorporates the principles of the GWP, a regional Land Use Management Plan has been prepared.

2. The second document is the Land Use Management Plan for the Swan Coastal Plain (North) (1981). CALM clearly sees strong and increasing demands for a variety of local resources from this region. There is acceptance that inappropriate land uses may have far-reaching and damaging effects.

Each part of State forest on the Swan Coastal Plain has been allocated a management priority based on the criteria of site potential, economic viability, operational feasibility and protectability. Further details on this planning may be found in the Forests Department (1980) Bulletin on Northern Jarrah Forest Management Priority Areas which resulted from the planning review. Figure 5 shows the various land use zones of the Study Area.

The Management Plan necessitates compromise between the current requirements of the various land users but provides opportunity for review of priority use as changes in land use demand evolve.

There are several activities which are incompatable with the management objective in the water production priority areas. These are activities which result in dense, deep-rooted vegetative cover throughout the area, or increase the risk of chemical or biological pollution (ie. activities which reduce the quantity and quality of groundwater). Generally, there are a range of compatable activities, including pine timber production. Specifically, State Forest No. 65, south of Gingin Brook will be managed primarily for the production of potable water.

Within the review area, no portion of State forest has a Timber Production (Pine) Priority. This allocation is only applicable where plantations are established outside declared water reserves.

In practical terms, the management strategy accepts that areas of suitable soil within the water priority area will be converted to pine plantations at a rate of 500ha/annum. The management of these forests is to optimise water and sawlog production.

2.5 SCALE OF PLANTATION FORESTRY

Planting on an extensive scale in the Northern Swan Coastal Plain has continued since the 1950s. Table 1 lists the areas of P. pinaster planting by year, soil type and plantation location. The total area up to 1985 is 21,760ha, of which the proportions are Gnangara 36.8%, Pinjar 34.1% and Yanchep 29.1%. It was not until the 1960s that planting was widespread in all areas. In addition, approximately 750ha of Pinus radiata have been planted, however, it cannot be considered to be a substantial resource.

Since 1972 all P. pinaster plantings have been from the pedigree orchard stock grown in State Forest No. 69. In terms of the commercial potential of the total P. pinaster forest, 46% are of pedigree stock which have been established with the objective of sawlog production. The management of these forests is reviewed in Section 3.

Figure 4 shows the planted area and proposed extensions to pine plantations in the Northern Swan Coastal Plain. At a planting rate of 500ha/annum, all first rotation planting in the area will be complete by 1988.

Based upon available soil types and applying advances in tree breeding and water recharge/pine silviculture knowledge, there is potential land suitable for plantation extension east of the central block of State Forest No. 65. This is vacant Crown Land with some portions vested in the Commonwealth for airfields and defence purposes. Soils are of the Bassendean System, and include low-lying and high dune areas. A portion of the area is in the Gnangara Water Reserve. To date there are no plantation expansion plans for these areas.

3.0 OPERATIONAL PLANNING

3.1 SILVICULTURE AND MANAGEMENT OBJECTIVES

Silviculture is the all encompassing term covering the art and the science of forest establishment and tending (McKinnell, 1982). Foresters have evolved forest management techniques applicable to tree species on specific soil types for particular commercial objectives.

TABLE 1

AREA OF PINUS PINASTER PLANTATIONS ON THE NORTHERN SWAN COASTAL PLAIN
(ha)

PLANTING YEAR	BASSENDEAN SOIL SYSTEM PLANTATION			SPEARWOOD SOIL SYSTEM PLANTATION		
	GNANGARA	PINJAR	YANCHEP	GNANGARA	PINJAR	YANCHEP
1926-30	102					
1931	41					
1932	120					
1933	50					
1934	24					
1935	10					
1936	16					
1937	14					
1938	29					
1939	108					
1940	17					
1941	62					
1942	39					
1943	7					
1944	-					
1945	-					
1946	46					
1947	32					
1948	-					
1949	115					
1950	65					
1951	440					
1952	592					21
1953	337					
1954	167					
1955	113				64	
1956	77				76	
1957	241				69	
1958	91				22	
1959	204				106	
1960	83				134	
1961	203				77	134
1962	110				106	74
1963	211				23	3
1964	290				149	
1965	412					78
1966	302					492
1967	488					611
1968	296					781
1969	498				193	542
1970	25					1016
1971	454				504	
1972	428				492	
1973	449					370
1974						57
1975	549				1186	
1976	10				985	
1977	15				805	
1978	7				502	
1979					517	
1980					463	104
1981	13				514	
1982					450	450
1983						616
1984						515
1985						457
Sub-Total	8002	0	0	0	7437	6321
TOTAL						**21760**

P. pinaster silviculture is currently in a second phase of development. The first, or species evaluation phase, considered the capability of P. pinaster on the Northern Swan Coastal Plain. It culminated in the selection of suitable phenotypes, and ceased by 1972 once bred-on orchard progeny was available for operational establishment. The second phase, which merged with the first, is silvicultural investigation. Early silvicultural research aimed at basic factors such as growth rate, diameter and branching responses from thinning and pruning. This phase is culminating now with the land management constraints being superimposed on basic silviculture. Until entire rotations have been completed under these regimes, this phase will continue. A final phase is the development of second rotation plantations within areas of appropriate land use priorities. To date, this has not progressed beyond the trial stage, as large areas have not been clear-felled. As second rotation plantings develop, considerable modification of silviculture practiced on first rotation stands can be expected.

A brief review of the rationale of past P. pinaster silvicultural approaches is given in Butcher and Havel (1976). More detailed summaries are available from internal CALM documents in the form of The Foresters Manual (Pine Plantation) and the Pinaster Management Model.

3.2 HYDROLOGICAL IMPLICATIONS

The potential for large scale utilization of the groundwater in the Northern Swan Coastal Plain was realised in the 1960s. As water demands and consumption increased in the 1970s, research was directed at the inter-relationships between pine plantations and the hydrological cycle.

Trials were carried out to isolate natural fluctuations of water table and site demands imposed by plantations. Seasonal cycles are readily observed and there are less obvious longer-term responses resultant from prolonged, unusually dry climatic conditions. The first impact of plantation development is immediately noticeable following clearing and establishment. Figure 6 compares the native woodland water table status during a period of reducing rainfall (GN 22) and a similar site following plantation establishment (GN 20). After six years, the plantation site is approaching the original water table levels. As the tree canopy cover increases, the water table declines. This takes place through rainfall interception and water uptake. Rainfall interception and subsequent evaporation reduces the amount of water reaching the ground, and hence contributing to groundwater recharge.

In this section, and later, the term basal area (BA) is introduced. This is the sum of the cross-sectional area of stems (measured at 1.3m above ground) per unit land area (McKinnell, 1982). Although related to both stocking and timber yield, it reduced the vagueness of stems per hectare and volume per hectare and as a measure of stand density is quantified in square metres per hectare (m^2/ha). Each site has a finite growth potential and basal area provides a clue as to whether the stand has further growth capacity. For P. pinaster, BA is maximised at approximately 30m^2/ha, with optimal growth maintained when stands are kept in the 10-20m^2/ha range.

Soil moisture withdrawal varies with tree species, season, stand density and root depth in the soil profile. Butcher (1977) found the native woodland water consumption increased as drought conditions progressed, but did not vary greatly at depth. This reflects the different levels of root penetration by the native vegetation. Pine plantations have a layered root system - one layer in the first metre of soil, and another between 3 and 6m. The pines appear to have the ability to reduce their water uptake as drought conditions are imposed. As stand density decreases, the water uptake reduces, because of less stress on the individual tree, but uptake is maintained during the drought period. Figure 7 compares the moisture withdrawal of native woodland with three different stands of P. pinaster. Figure 8 compares the moisture replenishment of those same stands.

According to Butcher (1977), there is an inverse relationship between stand density and groundwater recharge. Crown interception increased from 10% to 26% with basal area increasing from 7 to 25m^2/ha. The higher tree densities reduce the effective rainfall of the area, which contributes to a lower groundwater recharge rate. From Figure 8 it should be noted that under higher pine stocking rates, the wetting front does not penetrate as far, and the spring evapotranspiration quickly depletes the moisture.

The accepted priority of water production over the Northern Swan Coastal Plain has been the primary reason for modifications of the silvicultural regimes.

3.3 CURRENT SILVICULTURAL REGIMES

Plantations have been established on the Swan Coastal Plain with the original concept of timber production. As the importance of groundwater became more evident, silviculture has had to be reviewed. Although the management objective of timber production has remained, the strategy for achievement has been modified; guided by the need to hold stand density down so that water production is favoured.

For comparative purposes it has been considered that the base hydrological balance for the region occurs under native woodland. Any land use leading to lower recharge than the base level, must be viewed carefully. Havel (1968) found the basal area of the native woodland varied. For weakly leached soils (yellow-brown sands) in the Spearwood System, the BA ranged from 14-23m^2/ha, whilst on moderately leached soils (grey sands, over yellow sands) the BA ranged from 6-16m^2/ha. Accordingly, CALM has established a silvicultural model in which the basal area increases from 7m^2/ha to 17 m^2/ha; with an average of 11m^2/ha. Table 2 summarises operations and includes basal area growth.

The regime maximises water recharge by maintaining BA below 20m^2/ha. The objective of producing sawlogs will also be achieved by maintaining a low basal area. The combination of pruning and thinnings can produce a 15cm knotty core sawlog with diameters above 65cm over 40-45 years. The use of fertilizer ensures the growth rate is maintained. Approximately 2 tonnes/ha of fertilizer is applied over the rotation, in conjunction with the time of thinning.

3.4 EXISTING PLANTATION CONDITIONS

The plantations of the Northern Swan Coastal Plain can be sub-divided into three groups:

- Old growth stands (1926 - 1950 plantings).
- Mid-rotation stands (1951 - 1972 plantings).
- Young stands (1972+ plantings).

The old growth stands (entirely in the Gnangara Plantation) comprise a variety of P. pinaster provenances, which received silvicultural treatments reflecting more classical sawlog regimes. Most have been high pruned to 4-6m, and although stockings were generally high throughout the rotation, stockings now range from 75-150 stems per hectare (s/ha). These stands have been yielding sawlogs to the Metropolitan area for the past decade. Growth on these stands is slowing and there are inherent form and branching defects associated with the early provenances. The BA of these stands is greater than 15m^2/ha, and some older stands are occupying above average sites. The production of quality sawlogs in a reasonable time from these stands, will require clear felling and replacement with pedigree stock. The need for more information on second rotation trials is probably a major reason why this action has not been initiated.

TABLE 2

DETAILS OF PINUS PINASTER SILVICULTURAL REGIMES

		BASSENDEAN SOIL SYSTEM					SPEARWOOD SOIL SYSTEM				
AGE	OPERATION	AGE APPLIED	STEMS/ha INITIAL	STEMS/ha FINAL	BA INITIAL	BA FINAL	AGE APPLIED	STEMS/ha INITIAL	STEMS/ha FINAL	BA INITIAL	BA FINAL
	Establish	0	1000	-	-	-	0	1000	-	-	-
	Interrow Cultivate	1-2					1-2				
0-10	Interrow Cultivate	4					4				
	Low Prune	7		800			7		800		
	Fertilise 500kg/ha	8					8				
	High Prune (5.0m)	12		250			12		250		
	High Prune (7.5m)	14-15					14-15		100		
10-19	Thin	14-15	800	250	19	7	14-15	800	250	19	7
	Fertilise 500kg/ha	16					16				
	High Prune (10.0m)	17-19		50			17-19		50		
	Thin	20-21	250	100	17	7	20-22	250	100	17	7
20-29	Fertilise 500kg/ha	23					24				
	Thin	28-30	100	50	16	8	29-32	100	50	16	8
	Fertilise 400kg/ha*	31					32				
30-39	Fertilise 200kg/ha	34					35				
	Fertilise 200kg/ha	37					38				
	Clear Fall	38-42	50	0	16.5	0					
40+	Clear Fall						41-45	50	0	16.5	0

* Also addition of lupins

Mid-rotation stands generally have not received regular thinnings, and the BA of these stands exceeds 15m^2/ha. These stands are within the nominal rotational period, but received two types of management. Prior to 1970 traditional sawlog silviculture dominated, whilst the early 1970 plantings received a silvicultural programme dominated by early non-commercial culling. This regime evolved from a number of stimuli, with the principle objective of improving the productivity and condition of the P. pinaster forests. Butcher and Havel (1976) considered the main points were:

- Availability of local silvicultural data.
- Applicability of New Zealand silvicultural and economic studies.
- The realisation of problems associated with higher stocking rates and forest deaths (not necessarily with groundwater recharge emphasis).
- Poor marketing prospects for small - diameter logs derived from early thinnings.

These stands were established at 1988 s/ha, and were non-commercially thinned at age 6 to 740 s/ha, then further reduced to 247 s/ha at age 14 (with some marketing prospects). Many stands did not receive the second thinning due to unavailability of commercial markets, and accordingly now have high basal areas. The pre-1970 stands tend to have higher stocking rates, as early thinning rarely took place.

The younger stands are the product of research findings, observations and pressures of land use objectives. The seedling stock is genetically advanced, although further improved stock is expected by the mid 1990s. Plantings in the period 1972-1980 were dominated by an early culling silviculture regime. Since 1980 the silviculture has been modified for water production. Implementation of silviculture has been variable; depending on site type. Marginal sites have received the least attention. There are stands which are at, or approaching, thinning status. Basal areas are between 15-20m^2/ha and some stands have not received full silvicultural treatment.

An on-going assessment of the basal area of the plantations is carried out by CALM. This has been plotted and the distribution is shown in Figure 4. Basal area has been grouped as follows:

- Basal area over 20m^2/ha.
- Basal area between 15 and 20m^2/ha.
- Basal area between 7 and 15m^2/ha.

Although age in the rotation is important, the basal area provides a basis for planning thinning operations within an age group.

3.5 COMMERCIAL CONSIDERATIONS

Sawlogs are the ultimate product to which all silvicultural regimes have been directed. Because of the growth characteristics of pine, there is a secondary objective to maximise the intermediate yields through commercial thinnings.

Logs up to 15cm diameter can only be marketed in the solid (or round) form (suitable for perservative treatment) or as reconstituted products (chipwood, particle board or paper). The plantations of the Northern Swan Coastal Plain have had limited access to this market, for two reasons:

- o P. radiata is the preferred product for treatment logs.
- o The absence in recent years of a chip outlet in the Metropolitan area.

The 1970s culling prescription temporarily overcame the marketing problem by early culling; otherwise deaths occurred in the stands due to overstocking.

Logs of 15-30cm diameter are considered too large for preservative treatment (at the moment - i.e. the demand is low), however they are in the size range for chip production. A sawn product market has been available for this size range for the manufacture of fruit boxes, pallets and some rough-grade, limited life material. This market has been dramatically reduced in the past five years (by steel, aluminium, plastics and cardboard) and although the market still exists, the demand is significantly reduced. Because of the poor marketability of this size range, many stands have not been thinned. Certainly non-commercial culling has been considered, however, the tree sizes are such that the cost has discouraged implementation. Culling of 25cm trees would cost in the vicinity of $400/ha (assuming 500 s/ha). Intuitively, the prospect of a commercial operation, even if it was self-funding, seemed a better prospect. However, such operations have been deferred for up to 10 years in the expectation of the market situation changing. There is in excess of 100,000m^3 of small wood available at present in this form, and another 200,000m^3 will be available in the next decade (Murch, CALM, pers. comm.). A processing plant is currently under consideration. Any non-commercial thinning in the short term will jeopardise the viability of such a plant.

Logs above 30cm diameter are used as sawlogs. The demand for sawlogs is strong, and is not expected to reduce. Western Australia has the potential to increase timber consumption per capita up to the Australian average, plus increase total demand as the population grows. The reduced availability of native timber will increase softwood demand. Competition from New Zealand and Eastern States timber is not seen as a problem in the longer term.

The poor marketability of the size classes up to 30cm diameter has multiple impacts. Any thinning delays lower the rate of timber growth in a stand, and spread the slower growth onto more stems. The net result is a reduced sawlog yield in the 'normal' rotation period, or if the yield is to be maximised, the rotation period must be extended. Neither situation improves the economic viability of the plantations. The second, and equally important impact is on groundwater. Stands which increase in basal area reduce the area's effective rainfall and increase water uptake. Without commercial thinning capacity, the desired reduction in stand basal area to achieve water production and timber production objectives, will be very expensive. There is a likely stand density/tree diameter condition where a non-commercial thinning is practical - in comparison to the water resource cost plus the timber production forgone. The long term economic returns from the land could favour water supply, therefore forest silvicultural conditon may be dominated by non-timber objectives.

4.0 FUTURE FORESTRY OPTIONS

4.1 LAND USE MANAGEMENT

It is already accepted that land in the Gnangara Mound catchment has a dual land use priority - water plus sawlog timber.

Forestry and hydrological research have indicated that the two land uses are compatible under careful management. It must be realised that the majority of the pine stands were established before the water priority was established, and the silvicultural conditions of these stands reflect the absence of a sustained small wood market.

Accordingly, over much of the plantation, neither the water nor timber objective is being achieved. Sawlog yields will be lower due to higher stockings, or rotations will need to be extended, whilst maximum groundwater recharge is not possible at the higher stockings.

4.2 OPERATIONAL STRATEGY

Forest research has found that P. pinaster can be managed through basal area control. Stands can be permitted to reach $15m^2$/ha for limited periods, then thinned back to 6-$8m^2$/ha. The average for this period is $11m^2$/ha, which is considered equivalent to the basal area of native woodland.

4.2.1 Young Stands

These include future plantings and those up to age seven to eight years which are not yet due for thinnings.

There is no justification for these stands not to be managed through basal area control as per the applicable soil type prescription (Table 2).

By the time the young plantations are ready to yield smallwood commercial products (age 15-17 years), the availability of markets will be known. It is recommended that CALM maintain stand density within the acceptable basal area range. Non-commercial thinnings may be necessary as deferrals will be viewed as significant lost groundwater recharge capacity.

4.2.2 Mid-Rotation Stands

These include a variety of provenances and silvicultural regimes. However, in the main, basal areas are in excess of $15m^2$/ha, and stands have thinning material in the 15-30cm diameter range.

The marketability of the thinning products at the moment is quite restricted, however the proposed chipwood industry will need this resource.

If commercial thinning is possible, the problem is reduced to a priority action plan. This plan should identify isolated sites for appropriate basal area management, to maximise timber and/or water productivity.

In the absence of commercial opportunities, the problems are:

- how long can the undesirable stand condition be tolerated?
- what are the economics of treatment?
- which stands will yield the best sawlogs?
- which areas have greatest water production potential?

All solutions will require the injection of funds, and these must be directed to maximise the achievement of the dual objectives.

Poor site-quality stands are best thinned heavily - even accepting a longer rotation to achieve the sawlog yields.

Good site-quality stands which have high sawlog potential should not be held back. Growth must be directed to the most desirable stems (final crop-trees). It will be more economical to reduce stockings in one operation, although there may be situations where the diameter-height ratios are in the wind-throw danger zones. These areas would warrant a step-reduction over a period of four to five years.

Medium site-quality stands will require a variety of treatments. Final crop trees, should be designated and their release guaranteed. Care will be necessary to avoid co-dominants taking over, or continued competition from sub-dominants. It may not be economical to cull heavily, or funds may not be available for these stands.

4.2.3 Old Stands

These stands were established prior to 1940 and can be clear-felled as required. Generally the basal area will be above $15m^2$/ha, although stocking may be less than 100 s/ha.

The priority of action should be based upon current and potential productivity. The basic question will be: can this stand continue to grow to improve a sawlog product? In most cases the retention of the stand will not be justified except to maintain a flow of clear-fall sawlog product.

Stands which are of very poor quality on good sites should be immediately clear-felled and re-established under second rotation silviculture. Alternatively, the application of fertilizer may maintain growth over an extended rotation.

Medium and good site-quality stands should be thinned where possible to a basal area which optimises both wood and water production.

4.2.4 Second Rotation

Although not all second rotation problems have been isolated by research, many factors are well understood. Wherever possible, preliminary site preparation operations should be initiated. Such operations include:

- o sowing lupins and spreading fertilizer, and
- o crushing of thinning slash.

Some 1300ha could be ready for second rotation planting within five years (Table 1). This is a small area in comparison to the total area, but if neither the water production, nor the timber growth is optimal under current management, second rotation must be considered.

Second rotation problems seem to be isolated to establishment. With improved genetic stock, use of fertilizer and basal area control, growth should not be a problem. It is desirable that CALM research into second rotation establishment should be treated with a high priority.

4.3 TIME LIMITATIONS

The current silvicultural strategy leaves a seven to eight year growing period between thinnings. During this period, basal area increases from 7-8 to 16-18m^2/ha. Accordingly, the basal area will rise above 11m^2/ha for two to three years before being reduced but the average basal area should be maintained at 11m^2/ha.

Operations may not always be able to be completed within the prescribed time frame. This may be due to log flow plans or finance availability. It is not desirable, however, for deferrals to go beyond five years, or for stands to be maintained above 20m^2/ha basal area.

4.4 WATER ABSTRACTION ZONES

Groundwater pumping will cause water table levels to be lowered in the immediate proximity of the abstraction wells. Forest research indicates that plantation survival should not be significantly affected by water table changes. In the Spearwood Dune System the trees depend upon upper profile moisture, and exhibit physiological shut-down in summer. In the Bassendean Dune System, reductions in the water table may in fact increase the plantable area where inundation is presently a constraint. Some reduction in pine productivity may occur over small areas of lowland plantings which rely on the water table.

As the rainfall interception effect applies over a broad area, there is little reason to reduce stocking adjacent to the well lines alone. However, from the point-of-view of uptake it may be desirable to maintain stands near to the bores within a lower basal area range (5-12m^2/ha) to avoid potential tree deaths during drought periods.

4.5 DENSITY REDUCTION TECHNIQUES

Commercial thinning is the desired method of lowering stocking.

Non-commercial operations can include selective culling, or in some cases, row culling. The latter should be avoided as unthinned bays (between rows) will not respond without in-bay thinning.

Culling aims to remove suppressed, sub-dominant and competing co-dominant stems. If a partial operation is intended, the priority is crop-tree release, and removal of non-productive stems.

Chemical killing of trees may be possible, however, the implication of such chemicals in association with the water resource would require very careful evaluation.

Culling will cause protection problems. Ground debris, or standing dead trees may encourage disease (particularly insects), and the fire hazard will be greatly increased. Slash treatment by crushing may be essential to minimise the fire hazard. This should be emphasised in areas of high recreational use.

5.0 SECONDARY ASPECTS OF PINE FOREST MANAGEMENT

5.1 STATE FORESTS

Plantation forests have additional important values other than wood and water. Until recently the criteria for plantation development has been dominated by pine productivity. With the development of planning by Land Management Priority, other values have been recognised. Although a multiple-use concept is central to the planning system, pine plantations do not offer as wide a scope for diverse activities or values as indigenous forests.

The ground preparation and pine stand canopy development under past and current management techniques virtually eliminates native vegetation, and restricts natural regeneration. Specific areas of significant conservation value have now been retained along with significant ecological buffer zones (Figure 3). These conservation areas amount to approximately 20% of State forest in the study area.

Within five years of establishment, pine plantations come into conflict with many of mans' activities - principally from the risk of uncontrolled fire. This type of fire in plantations at any age is disasterous, and records reveal fire risk increases with human activity. Fortunately the risk of fire can be reduced in Pinus pinaster forest. As the stand matures, the live crown is higher from the ground, and bole bark-thickness increases. Thus individual tree protection increases. Additionally, ground fuel (grass, needle litter) quantities can be reduced through low intensity fires. This is possible because of thick bark development early in the Pinus pinaster rotation, giving sufficient protection from low-intensity fires, and CALM's knowledge in the use and control of fire.

Once stands have been thinned, the fire hazard remains high for 1-2 years whilst slash (downed foliage and small diameter woody material) remains in a highly inflammable condition. Once this hazard reduces, a controlled fire can be initiated to reduce the ground fuel quantities. Removal of slash and litter by control burning also decreases interception and hence increases recharge. As stand stocking is lowered and ground fuel hazards are minimised, other human recreational activities are possible eg. off-road driving, horse-riding and to a lesser extent, picnicking. The plantations offer few specific attractions except as areas where there is minimal overlap with passive recreational activities.

CALM has developed several sites specifically for certain activities, and it is expected demands for sites will increase with population growth and greater available recreational time. Sites can be considered according to stand-stocking, tree size and ground-fuel loadings. Areas where low stocking favours groundwater management have potential for greater recreational use. Although there may be pressure to reticulate water for facilities or landscaping, this can be controlled at all times.

In any extension of plantation areas, it is important not to introduce dieback disease (Phytophthora cinnamomi). All equipment must be subjected to strict hygiene standards. Phytophthora has exhibited long term spore viability, and therefore it is imperative to avoid a potential inoculum store in plantation areas. The dieback disease has its maximum impact in native banksia woodland. Disease introduction is possible from adjacent clearings or from subsequent activities.

Throughout State forest, other activities are permitted which strengthen the multiple use concept. Several leases exist for minerals, grazing, sporting groups and other services (sewage, radio transmission, power substations, utility and road routes). Honey production is permitted widely across the forests, particularly adjacent to native vegetation zones.

Pine plantations provide considerable direct and indirect socio-economic benefits. In 1985, 50-60 people were employed in pine forest management and contracting. The multiplier effect extends this benefit into service industries and district population. The plantation maintenance programme is in arrears for thinning and pruning, probably requiring 10-20 further contractors over the next five years. Although a reduction in employment can be expected beyond five years, the commencement of a sustained logging programme, the maintenance of an up-to-date silvicultural condition, and expanded second rotation programme should see the employment maintained above 70 people. These estimates do not include the research and inventory support required for the area, or the senior level administration associated with land management.

Other industries which derive benefit from the plantations include fertiliser producers, aviation contractors, farm and logging equipment suppliers, transport contractors, saw and secateur suppliers and general maintenance groups.

5.2 PRIVATE FORESTS

Within the study area, there are a number of established private pine plantations. The total areas is not known, but is likely to be less than 2000ha and mostly younger than 10 years of age.

These private forests were established with Pinus pinaster or Pinus radiata and planned under the influence of CALM's 1970s philosophy. There has not been a consistent approach to forest maintenance, although at this young age, it has not become critical. Unfortunately, most private plantations have not received regular silvicultural review, and thinning opportunities have been low. This situation may have been anticipated by many of the investors, as non-commercial culling has been common. Basal area status of these plantations is not available.

In the future, these plantations can be managed either in the same way as State plantation silviculture, or as other horticultural water-users. Silvicultural control is the most practical method of managing rainfall interception and water uptake.

Existing plantations were established with minimal controls, however future management can be monitored through private negotiation, legislation or licence controls. In any case, controls which restrict the investment capacity of the plantation will be opposed. Silvicultural control, combined with reasonable access to timber markets can be attained through the endorsement of professionally prepared and executed Management Plans. Such plans would be the responsibility of the land owner, but be subject to review by CALM (for logging products scheduling) and approval by the Water Authority for evaluation against acceptable silvicultural regimes.

Plantations established in the future can be controlled more directly through statutory provisions. These may form conditions of a land-planning scheme (dependent upon regional and local authorities), legislation (considered impractical for such a small land use - unless control of plantations, irrespective of ownership is contemplated), land use permit or licence under existing or proposed legislation, or through the preparation of enforceable contracts to maintain or thin plantations. These aspects require careful considerations, however it should be borne in mind that private plantations should not be discouraged. The State has a timber deficit, and although a large private plantation area increase is not expected, further prohibitive restrictions are to be avoided.

Private plantations also depend upon employment, contracting and equipment available in the district. Due to the smaller areas, work is more seasonal, but likely to increase.

6.0 CONCLUSIONS

This investigation has examined pine plantation on the Northern Swan Coastal Plain generally, and although some private plantations are scattered over the area, the zone is dominated by State-owned plantations, which should simplify liaison and management.

6.1 VALUES

Pine plantations have developed in response to a projected sawlog deficit in Western Australia, combined with desires to have a sustained, balanced timber industry. The reality of this situation has become apparent only in this decade with the necessity to significantly reduce the timber cut from indigenous forests. Pine plantations, whether private or State-owned, have the potential to eleviate the deficit.

The value of plantations include tangible and intangible benefits. The benefits are the supply of wood and water and the employment plus associated socio-economic multipliers. In addition the forests offer a range of opportunities to individuals and organisations which would not be possible under private ownership, or if maintained as indigenous woodland. From the water production point of view, there is considerable opportunity for co-ordinated planning through one organisation (CALM) in State forest.

The Northern Swan Coastal Plain is becoming increasingly important in regard to its groundwater resources. The quality and availability of this resource in relation to the demand significantly affects the economics of water supply, especially compared with alternative sources which are generally some distance from Perth or involve expensive desalination.

Pine plantations are amongst the many activities practiced on the Swan Coastal Plain. Because of the broad-scale development of plantations over a large proportion of the Gnangara Mound, forest management and its impact on the groundwater resource warrants close examination.

6.2 SPECIES

Pinus pinaster has been shown to be the most suitable plantation species on the sands of the Northern Swan Coastal Plain. This has resulted from considerable research on species growth on the available soils and knowledge of timber market preferences. Although Pinus radiata is the preferred product, it does not sustain growth on most coastal sites without heavy fertilizer supplements. P. radiata forests also place more demands upon a site, and would necessitate a totally different silvicultural system.

Intensive tree breeding of P. pinaster has developed a progency which has greatly improved the marketability of the species. Further improvements are expected in the mid-1990s and additional selection is recommended for early-rotation, low stocking regimes. The breeding programme should consider the second rotation implications and would benefit from an examination of other species.

6.3 SILVICULTURE AND OPERATIONS

Pine plantations have been shown to have an effect on the groundwater hydrological cycle. The stand removes water from the ground, largely from that held in the soil profile, rather than from the deeper water table. The trees have the capacity to limit their physiological activity during periods of stress. The greatest impact on the hydrological cycle is rainfall interception associated with a heavily stocked forest. With plantations developed on a broad scale over much of the Gnangara Mound intake area, there is great concern that if plantation stockings are not kept within an acceptable range, the water recharge capacity will be significantly affected.

The recharge to an area under forest is proportional to tree crown density. Stand basal area is seen as a practical measure of stand condition, and therefore hydrological status. The native woodland has basal areas of 10-18m^2/ha and a P. pinaster silvicultural programme has been developed to maintain basal areas close to that range. This programme will enable the timber and water objectives of the land to be jointly optimised.

Groundwater recharge can be improved by general maintenance of the forest stands. Crown pruning reduces the crown area and periodic low intensity fuel reduction burns decreases the understorey and needle-bed effects on rainfall interception.

In order to meet the timber objectives, individual trees require above and below ground space to expand. Thinning the stand progressively, leaving the best stems for the final sawlog yield is the best management tool available to enable this objective to be met. Similarly, maintaining the stand at a low-medium drought stress, reduces rainfall interception and decreases the groundwater uptake.

Unfortunately, the past marketing expectations of CALM have not been achieved, particularly for the small-wood sizes. A mid-rotation product market is absolutely essential for economic removal of thinnings, which is so important for the vigour of the forest and to optimise groundwater recharge.

The inter-relationship between plantations and groundwater has now placed a different perspective on forest management. Although a small-wood market is close to reality, forest conditions must be viewed seriously in relation to the primary objective - water. The cost of 'non-commercial' thinning should be offset against the value of water lost by excessive interception.

The State is faced with an operational challenge. Plantations can achieve timber and water objectives with careful management. If a small-wood market is forthcoming, the solution is a matter of sequential priority programming. If this market is not realised, the priorities may be dominated by stand condition rather than product flow considerations. These operations would be non-commercial and would lead to high fire risk zones due to the number of trees felled and the prohibitive cost of any mechanical treatment to crush the fuel.

The maintenance of a well-thinned forest must commence early in the rotation. Non-commercial culling before age 10 will minimise problems without adding to the fire risk. Young stands are easier and cheaper to manage. The cost of management in older stands depends on the value of the sawlog product available or the productive value of the occupied land which is not being adequately utilised. The mid-rotation stands, which form the bulk of the resource, have a wide range of genetic strains, site quality and silvicultural backgrounds. Action in these stands will require a review of current conditions and necessitate projections on forest growth and market demands.

An action plan is essential and a basal area control system is recommended as the monitoring parameter. Basal areas should be maintained between acceptable upper and lower site tolerances. There must be a commitment by CALM that thinning will be initiated within a reasonable time; a three to five year period is suggested. Thinning on a precise date is unrealistic because of many operational constraints and minor extensions will not be detrimental to the water objectives.

6.4 FOREST MANAGEMENT CONTROLS

It is suggested that there are up to four levels at which forest management can be controlled. The Water Authority has legislation which licences the removal of groundwater and controls the use of land in water catchments generally. Although pine plantations will not fall into existing water use categories, it may be possible to adapt and incorporate silvicultural concepts - stocking, basal area and time to manage plantation basal areas and hence effects on groundwater. This may be applicable to State or private land.

Control through Regional or Local Authorities may be possible for future plantations. Land development for forests could be subject to conditional management - essentially the same provisions as Water Authority licences. These two methods may only be enforceable together.

The bulk of the plantations are under State control, and therefore it is imperative that CALM have the primary water production objective endorsed for the State forest over the Gnangara Mound. This will require embodiment into the new General Working Plan and must be further exemplified in the Regional Land Use Plan. Ultimate control is recommended through Management Plans which outline zones for operational implementation. The Management Plans are seen as the mechanism of commitment and control, and can be directed to specific areas or to specific age forests. The Plans should further outline the multiple land use philosophy; particularly water, timber and recreation.

Crown Land in the Northern Swan Coastal Plain should be subject to similar endorsement. This is essential for land outside the control and management of CALM.

Private plantations can be controlled by a variety of means. Existing pines are a problem because of limited establishment controls and the imposition of a system which may deviate from that planned by the developer. The recommended silviculture should account for most plantations, but the solution probably lies with private negotiations and assistance in marketing intermediate thinnings. Future plantations can be controlled through a licence or Management Plan System.

The State needs to sustain a balanced timber industry, as well as meet market demands. Plantations require a spectrum of markets and if production targets are to be met, the intermediate product range requires development. The State has much to lose if these products cannot be marketed. The land productivity is reduced, raising the question of economic land use, plus the expenditure of public money. If this situation is maintained, the forestry sector as a whole will decline with local effects on the economy. The State should pursue small-wood markets, not just in the traditional area, but be active in reviewing interstate and overseas situations. Western Australia may be isolated from the bulk of the Australian population, and hence potential markets, but it is well placed for Middle-east and South-east Asian markets. The State has a further obligation to market development as the private sector has been influenced by Government Policy and action. Early achievement of these objectives will encourage others to participate in development, marketing and processing within the industry, which will reduce the Government role. The Government has the option, to act as a catalyst and large resource supplier, or follow the South Australian approach and become actively involved at all levels.

6.5 CHALLENGES

Land management on the fringes of large urban centres proceeds through a series of developmental phases. In the vicinity of Perth, it is fortunate that so many options remain. The portions of the Northern Swan Coastal Plain which have been converted to pine plantations offer a wide range of options.

There is a significant difference between productive and non-productive pine forests. Fortunately, it has been revealed that good management improves forest productivity and the same management is beneficial to the maintenance of a substantial groundwater resource.

It is recommended that the Water Authority and CALM develop a series of joint Management Plans which permit operational flexibility, but optimise water as well as wood production. The pine plantations offer the Water Authority the greatest opportunity to preserve and manipulate the groundwater supply. With private development, the water consumption and control system would be much more difficult.

Careful land management on the Northern Swan Coastal Plain provides the greatest opportunity for the production of two valuable commodities, wood and water, plus the added benefit of tangible socio-economic inputs to the region. Effective land management rests largely with CALM but requires the co-operation of the Water Authority and the State generally.

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APPENDIX C

THE GNANGARA MOUND GROUNDWATER AREA
LANDFORMS, SOILS AND VEGETATION

Report prepared by
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for
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1.0 INTRODUCTION

On the Northern Swan Coastal Plain, the geological formations provide the main basis for sub-division into soil mapping units. Thus the three dune systems - Bassendean, Spearwood and Quindalup - are characterised by distinctive geomorphology and soils and these are clearly separate from the alluvial landscape to the east and north. Detailed mapping was carried by stereoscopic interpretation of colour air photos at a scale of 1:20,000 or 1:25,000. Mapping units were checked from field traverses. The area to the west of Wanneroo Road, corresponding to the Metropolitan North-West Corridor, is covered by a previous publication (McArthur and Bartle, 1980).

Information sources are McArthur and Bettenay (1960), Churchward and McArthur (1980) and McArthur (unpub. data, 1985).

The distribution of vegetation on the Northern Swan Coastal Plain is determined by the underlying landforms, soils, depth to water table and climatic conditions. Consequently it was possible to summarise the vegetation for each landform and soil unit. This was achieved by reference to previous publications and selective field checking (Riggert, 1966; McComb and McComb, 1967; Havel, 1968; Smith, 1973; Congdon and McComb, 1976; Heddle, 1980 and Heddle, et al., 1980).

Landforms, soils and vegetation of the Gnangara Mound are presented on Figure 1.

The Bassendean Dunes generally have low relief but minor variations in topography, which translate into variable depths to water table, are the basis for division into mapping units. It is stressed that the landscape comprises a continuum from permanent open water to ridges with more than 20m relief and the divisions recognised are arbitrary. The hills and ridges (Jandakot - Ja) generally have more than 5m relief with an area of exceptionally high ridges mapped as Jandakot-Steep. The flat or gently undulating terrain (Gavin - G) has less than 5m relief.

Special attention has been given to the various wetlands because these are likely to be first affected in the event of groundwater drawdown. Wetlands are generally developed in depressions in the landscape and have been classified according to degree of wetness and nature of the substrate. Thus there are swampy areas (Joel-J), seasonally inundated areas (Seasonal Swamps - Ws) and areas of permanent water (Permanent Lakes and Swamps - Wp).

Several extensive, flat areas (Pinjar-P) have been separated because of soil differences. Drainage lines (DL) which carry surface water from the mound are also identified. The area around Yeal Swamp consists of a pattern of low sandy rises and small swamps. This area (Yeal Swamp - Wy) has not been divided into its component parts.

The Spearwood Dunes are divided mainly on the depth of soil over the limestone substrate and the incidence of karst features. Limestone is exposed or covered by shallow soils (Limestone - Kls) on the hills and ridges. In lower positions the sand may be several metres thick and is mapped as the Karrakatta unit. The sand may be yellow almost to the surface (Karrakatta - yellow - Ky) or grey in the surface layers (Karrakatta - grey - Kg). In the karst depressions the slopes are mapped as Spearwood (Sp). The depressions often have permanent lakes (W) with poorly drained areas, mapped as Beonaddy (B) around the edges.

The Quindalup Dunes, which occur only west of the Wanneroo Road, have been described by McArthur and Bartle (1980).

The Alluvial Terrain has not been treated in detail for this study. It is sufficient to note that, in the north and northeast, water from the Gnangara Mound discharges into Gingin Brook. Water enters the Brook through a complex of drainage lines mapped as the Gingin Brook Complex (GG). To the east, the discharge is into Ellen Brook and the Swan River and these broad drainage zones have been mapped as the Yanga unit (Ya).

2.0 DESCRIPTION OF MAPPING UNITS

2.1 BASSENDEAN DUNES

2.1.1 Jandakot (Ja)

This is a landscape of low hills and ridges with relief in excess of 5m and commonly 10-15m. It occurs mainly as separate ridges in the southern part but, in the north, tends to become continuous. The soil is an iron podzol with a grey surface, an almost white subsurface, and a yellow subsoil at 1-2m. In the central part of the mound area, just northeast of Lake Pinjar, is a complex system of high steep dunes (Ja-Steep) which come within the Jandakot class but are separated because of possible different hydrological relationships.

These steep dunes are the result of relatively recent redistribution of Bassendean sand as shown by the buried soils and clay bands encountered in bore holes. Within the Jandakot unit, in both normal and steep phases, variations in topography have significance in this study; in particular some lower sites show hydromorphic properties, approaching conditions in the Gavin unit, and this is reflected in the vegetation communities.

Vegetation is dominated by a low open forest and woodland of Banksia attenuata - B. menziesii - Eucalyptus todtiana. Other tree species include Eucalyptus marginata (in the south), Allocasuarina fraseriana (in the south), Nuytsia floribunda and the occasional Banksia ilicifolia. Understorey species, which range in height up to 1m, include Scholtzia involucrata, Eremaea pauciflora, Melaleuca scabra, Astroloma xerophyllum and Petrophile linearis. The only remaining areas of native vegetation in the Jandakot landform and soil unit occur to the north of Gnangara Road in the areas of State Forest No. 65, on vacant Crown Land to the northeast of Lake Pinjar and in the Moore River National Park.

In the central part of the mound area, the series of steep high irregular dunes (Ja - steep) support a low open woodland of Banksia attenuata - B. menziesii - Eucalyptus todtiana on the drier slopes with understorey species which reflect the underlying layers of grey and yellow sands. On the yellow sands these species include Stirlingia latifolia, Jacksonia floribunda, Conospermum stoechadis (Havel, 1968). Astroloma xerophyllum, Scholtzia involucrata, Eremaea pauciflora and Melaleuca scabra are deep grey sand indicators. On the intervening swales and hollows there is a distinctive area of open forest of Eucalyptus marginata - E. calophylla, which in moister sites is replaced by Melaleuca preissiana, Banksia ilicifolia and Eucalyptus rudis. This area is significant in that it includes the northern most major stand of Jarrah (Eucalyptus marginata) on the Northern Swan Coastal Plain.

2.1.2 Gavin (G)

Gavin (G) is a landscape of very low relief, generally less than 5m, and occurring most commonly in and just south of the Gnangara pine plantation. It also occurs sporadically as low sandy rises on the fringe of the mound on the alluvial plain. The soil is an iron-humus podzol with a dark grey surface, a grey subsurface, and a dark brown, sometimes indurated subsoil; there may also be iron concretions.

Minor variations in topography have influence on vegetation communities; the higher sites tend towards conditions similar to the Jandakot unit while the lower sites tend to be swampy and so merge with the Joel unit.

The vegetation consists of a woodland of Eucalyptus calophylla - Banksia spp. with the occasional Jarrah (Eucalyptus marginata) south of the Gnangara Road and Eucalyptus todtiana north of Gnangara Road. Other tree species include Banksia grandis, B. attenuata, B. menziesii, Allocasuarina fraseriana and Nutysia floribunda. In many respects the vegetation on the upper slopes has affinities with the Bassendean plant communities. Associated species include Kunzea ericifolia, Beaufortia elegans, Macrozamia riedlei, Xanthorrhoea preissii, Jacksonia spp., Viminaria juncea and Dasypogon bromeliifolius. In moister locations the vegetation is replaced by stands of Paperbark (Melaleuca preissiana) and the occasional Banksia ilicifolia. In many respects this area therefore has vegetation affinities with the Joel unit further west. To date this unit has been largely cleared for agricultural and forestry (pine) undertakings, so any small remnants of relatively undisturbed vegetation are significant from a conservation point of view.

2.1.3 Joel (J)

Joel (J) occurs as small separate depressed areas within both Jandakot and Gavin landscapes. These depressions may be swampy during winter but do not have free water for any length of time. The soil is a humus podzol with a very dark surface, a grey subsurface, and a dark brown often indurated subsoil at 1-2m. The water table is usually within 2m of the surface.

This landform and soil unit supports a variable vegetation, ranging in height, foliage cover and species composition. Dominant tree species include Eucalyptus marginata and Banksia ilicifolia on the lower moist slopes where the water table is within several metres of the soil surface; and Melaleuca preissiana, M. rhaphiophylla, Banksia littoralis and Eucalyptus rudis on the slightly moister areas. Understorey species are also variable and include Hypocalymma angustifolium, Pultenaea reticulata, Xanthorrhoea preissii, Adenanthos obovatus, Dasypogon bromeliifolius and Pericalymma ellipticum. This unit occurs on the moister lower slopes in State Forest No. 65, vacant Crown Land (northeast of Lake Pinjar) and on the Yeal Nature Reserve and Wabling Management Priority Area - MPA. To date the evidence of Heddle (1980) indicates that this is a unit that could be markedly affected by a lowering of the water table.

2.1.4 Seasonal Swamps (Ws)

Seasonal Swamps (Ws) occur as small separate depressed areas and are most common in the central part of the mound. These depressions usually have shallow water during winter and, in the late summer, as the water table declines, the surface dries completely or perhaps only the lowest sites remain moist. The substrate may vary and include peat, organic stained soil, and diatomite. No attempt is made to identify these various substrata but, in future studies, it may be relevant to do so. The soils around the margins of the depressions are usually humus podzols.

The swamps support a variety of vegetation. This range includes dense stands of Melaleuca preissiana and M. rhaphiophylla, heaths dominated by species from the families Myrtaceae and Leguminosae and mosaics of reeds and sedges of families Cyperaceae, Juncaceae and Restionaceae in the seasonally wetter areas. These areas are scattered throughout the Northern Swan Coastal Plain within the Bassendean landform and soil unit. Significant areas include the swamps in Melaleuca Park, a flora and fauna conservation area and the series of reserves and vacant Crown Land to the north of the Commonwealth Bombing Range. This unit too is likely to be markedly affected if the water table is lowered (Heddle, 1980).

2.1.5 Pinjar (P)

This unit occurs as extensive flat areas which apparently were lakes or swamps but subsequently were covered by a veneer of blown sand altering the surface hydrology. The main areas are Lake Pinjar and Tick Flat which occur at the junction between the Bassendean and Spearwood Dune Systems. Another large area, just to the northeast of Lake Pinjar and enclosed within the zone of steep dunes is also tentatively classed with this unit. The surface is generally sandy, perhaps with an admixture of diatomite, and with an organic hard pan within 2m of the surface. Sporadic low sandy rises may have formed as lunettes during earlier times. Small areas are seasonally flooded and the water table remains within 2m of the surface in summer.

The Pinjar landform and soil unit is dominated by woodlands of Eucalyptus rudis and Melaleuca spp, interspersed with sedges and reeds from the families Restionaceae and Cyperaceae (eg. species of Leptocarpus, Baumea and Lepidosperma). This unit is of particular interest in the proposed extension to the water scheme on the Northern Swan Coastal Plain, in that it includes the extensive Lake Pinjar area.

In recent decades this area has been cleared for agricultural purposes and consequently the native vegetation remains as pockets on the drier fringes and more extensive reed cover in the central seasonally wetter areas. Shrub species present include Acacia saligna, Hakea varia and H. trifurcata. The sporadic low rises support a range of low shrubs which include Jacksonia furcellata, Viminaria juncea, Exocarpus aphyllus, Melaleuca spp. and the occcasional emergent eucalypt.

Further north another substantial area of this unit occurs at Tick Flat, which is a blown over swamp with large trees of Melaleuca preissiana and Eucalyptus rudis on the former swamp fringes and scattered Banksia littoralis in the formerly wetter swamp floor (Heddle, 1980). Other species now extending their range onto the drier swamp floor include Banksia attenuata, B. menziesii and B. prionotes. Lake Pinjar is largely private land, while the majority of Tick Flat has been reserved for food supply for the koala population at Yanchep National Park. In recent recommendations by the Environmental Protection Authority (DCE, 1983) it was proposed that Tick Flat be added to the Wabling Management Priority Area for Conservation of Flora and Fauna. Both these areas provide a diversity of seasonally moist and wet habitats for flora and fauna. Heddle's 1980 work indicates that this unit could be markedly affected by a lowering of the water table.

2.1.6 Permanent Lakes and Swamps (Wp)

This unit is developed in depressions where the groundwater table comes above the surface and, though the area of water may be reduced during the summer, the water table remains near the surface. The substrate is generally peaty but often has an admixture of diatomite. In the zone of water fluctuation around the fringes, the soils are humus podzols grading to iron-humus podzols on the slopes. Towards the north, some lakes have a bare steep sandy fringe.

This landform and soil unit supports a range of community types. This includes the heaths of Melaleuca spp. on the fringing slopes, fringing woodland and tall shrublands of Melaleuca preissiana and M. rhaphiophylla on the water's edge. Reeds and sedges occupy the inundated areas. This unit is likely to be affected by a lowering of the water table, particularly in the shallow lakes within the Bassendean sand dune system (eg. Lake Gnangara, Lake Jandabup). These areas support various land uses, thereby providing a diversity of management problems.

Fence lines that are now inundated with water, indicate that these lakes were drier in the past. Lake Jandabup is reserved for conservation of flora and fauna and Lake Gnangara is reserved for recreational activities which may afford some protection to the remnant native vegetation.

2.1.7 Yeal Swamp Complex (Wy)

This is a pattern of low sandy rises and many small seasonal swamps, the incidence of which varies considerably. They predominate in the vicintiy of Yeal Swamp and the sandy landscape near Gingin Brook. In future investigations it may be necessary to subdivide this unit into its component parts. The soils on the rises vary considerably with humus podzols or iron podzols occurring according to relief. The swamps apparently have a surface layer of diatomite overlying sand; Bindiar Swamp, the largest in this complex, has about 1.5m of diatomite.

This landform and soil unit varies in relation to the proportion of swamps and lower slopes. Near Yeal Swamp, the vegetation is dominated by heaths of Myrtaceous and Leguminous species, with substantial trees of Melaleuca preissiana, M. rhaphiophylla (which forms dense thickets in places), Eucalyptus rudis and Banksia littoralis occurring on the fringes and swamp floors. In the moister diatomite soils the understorey is dominated by the reed Lepidosperma scabrum. As this range of vegetation is dependent on moist soils on the lower slopes and swamp floors, it is likely to be affected if the water table is lowered. The drier sites support vegetation similar to the Joel and Jandakot units.

2.1.8 Drainage Lines (DL)

These are broad, shallow channels which carry surface water from the mound area during the winter months. Several of these channels carry water into Lake Pinjar. The channels often begin as connecting swamps but eventually form a continuous feature which connects to adjacent streams. The central part of the channel is often peaty and, though surface flow is seasonal, the water table maintains moist conditions. Humus podzols occur along the fringes.

The vegetation on this unit includes woodlands of Eucalpytus rudis on the fringes of the drainage lines, dense thickets of Melaleuca preissiana and M. rhaphiophylla along the watercourses and Baumea articulata in the wetter areas. The occurrence of Pteridium esculentum in several locations along these watercourses is worthy of review. Recognizing that any abstraction of water from the Gnangara Mound might influence the availability of water for these courses, it is important to monitor their plant communities. Several channels occur within the area of vacant Crown Land to the northeast of Lake Pinjar and the reserves north of Yeal Swamp, which drain northwards to Gingin Brook. Their interrelations with other units and their conservation value should be assessed.

2.2 SPEARWOOD DUNES

2.2.1 Karrakatta - Yellow Phase (Ky)

This is a landscape of low hills with gentle slopes and includes some broad shallow depressions; it occurs mainly in the western part of the Spearwood Dunes. The soil consists of grey-brown surface sand which passes into bright yellow sand with limestone generally within 2m of the surface. The soil tends to be shallow on the tops of rises becoming deeper in the hollows.

The vegetation consists of a low open forest of Banksia attenuata-B. menziesii with the occasional emergent tree of Tuart (Eucalyptus gomphocephala), E. marginata (south of Yanchep), Allocasuarina fraseriana and E. calophylla. The understorey consists of a dense shrub layer dominated by Xanthorrhoea preissii, Macrozamia riedlei, Stirlingia latifolia, Jacksonia furcellata, J. sternbergiana, J. hakeoides, Hakea costata and Allocasuarina humilis. This community is unlikely to be affected by any lowering of the regional water table, as the depth to water table is substantial (see Appendix D of this ERMP). This unit occurs in Yanchep National Park, Wabling MPA, Ridges MPA and Caraban MPA, all of which are for the conservation of flora and fauna.

2.2.2 Karrakatta - Grey Phase (Kg)

This is a landscape of low, hilly to gently undulating, terrain occurring mainly in the eastern part of the Spearwood Dunes. The soil is an iron podzol with a grey surface, an almost white subsurface, and a yellow subsoil; limestone is generally deeper than 2m. The unit has affinities with the Jandakot Unit but is separated because of the limestone substrate.

The vegetation consists of a low open woodland of Banksia attenuata and B. menziesii. Scattered emergents include Eucalyptus marginata in the south and E. todtiana in the north. Understorey species include Jacksonia sternbergiana, Calothamnus quadrifidus, Petrophile serruriae, P. brevifolia and Hibbertia hypericoides. This unit has affinities with the Karrakatta - yellow phase but differs in the proportion of Banksia attenuata and species which occur on the grey surface sands over yellow sands at depth. This vegetation has a similar distribution to that on the Karrakatta - yellow phase and is also unlikely to be affected by lowering of what is already a deep water table. It too is represented in Yanchep National Park and the Wabling, Ridges and Caraban MPA's.

2.2.3 Limestone (Kls)

These areas are characterised by a high proportion of outcrop with shallow siliceous or calcareous sands in pockets in the limestone. There is usually a higher incidence of outcrop on the rises and ridge crests.

The vegetation is dominated by limestone heaths which include Melaleuca huegelii, M. cardiophylla, Grevillea thelemanniana, G. vestita, Hakea spp., Conospermum triplinervum var. linearis and Dryandra sessilis (particularly after the passage of fire). The plant species reflect the limestone near the surface and form characteristic breaks in the landscape. Because the water table is deep here, this unit is also unlikely to be influenced by the abstraction of water from the surface aquifers. Major occurrences occur in Ridges MPA, Yanchep National Park and Caraban MPA.

2.2.4 Spearwood (Sp)

This unit is developed on slopes of karst depressions and is characterised by shallow soils and some limestone outcrop; there are often low cliffs, some with cavern openings, and the slopes are generally irregular due to solution and collapse. The soil has a brown sandy surface and a yellow-brown subsoil with limestone usually within 1m of the surface.

The vegetation consists of a woodland of Eucalyptus gomphocephala, E. marginata, E. calophylla and Banksia spp. with a dense understorey similar to that described for Ky, but with a higher proportion of Xanthorrhoea preissii, Macrozamia riedlei, Stirlingia latifolia and Melaleuca scabra.

As this unit extends to the lower slopes near the series of wetlands, it is likely that any lowering of water levels will influence some areas. However recognizing that the topography and water table depth change rapidly in this unit, then any changes would be localized patches or strips. This unit is represented in Yanchep National Park, Neerabup National Park and Caraban MPA.

2.2.5 Beonaddy (B)

This occurs on the floors and lower slopes of depressions adjacent to lakes and swamps. The soil has a dark surface passing into pale brown sand below; water generally occurs within 1m of the surface.

This unit supports a range of fringing vegetation near the swamps and a series of lakes in the Spearwood Dune system. The vegetation ranges from woodland of Eucalyptus rudis, Banksia littoralis and Melaleuca spp. to Typha species near the waters' edge. Recognizing the close proximity of the water table to the surface, a change in plant community composition and structure may be expected if the water regime is altered substantially. Although this unit occurs in several small reserves near Yanchep, the most substantial area is in the Yanchep National Park. To date, evidence indicates that clearing associated with market gardening has had a large influence on the water levels in this area. In fact it appears that any changes which could be associated with the proposed water abstraction scheme are likely to be only minor in comparison.

2.2.6 Lakes and Swamps (W)

These are areas of permanent water in karst depressions within the Spearwood Dunes. They are separated from the wetlands of the Bassendean Dunes because of generally deeper water and a calcareous substrate. Detailed descriptions of these features are given by Riggert (1966) and McComb and McComb (1967). The seasonal changes in water quality and quantity in Lake Joondalup, which is representative, have been discussed by Congdon and McComb (1976); some seasonal swamps are shown as (Ws).

The vegetation of these lakes have been discussed by McComb and McComb (1967). Plant communities range from sedges and reeds of the families Cyperaceae and Restionaceae to aquatic plants. The low lying areas between the lakes support stands of Melaleuca spp. and Eucalyptus rudis. These lakes and swamps are represented in a series of reserves, including Yanchep National Park. The likely effects of water abstraction on the native vegetation are similar to the previous Beonaddy unit.

2.3 ALLUVIAL TERRAIN

2.3.1 Yanga (Ya)

This is an almost flat, swampy landscape associated with Ellen Brook; the unit includes areas mapped as Beermullah by Churchwood and McArthur (1980). The dominant feature in both Yanga and Beermullah is poor drainage. The Yanga Unit has a very low gradient and the resultant restricted drainage has allowed a buildup of salts. The soils are very variable and include sand over heavy clay, sand over limestone and deep sand; bare saline patches occur sporadically and some soils have a heavy ferruginous pan.

The vegetation on these series of swamps and wetlands east of the Gnangara Mound consists of a dense heath of Melaleuca spp. (e.g. M. hamulosa, M. lateritia, M. viminea) with the occasional Actinostrobus pyramidalis. Casuarina obesa occurs on saline, solonetzic areas. Other species include a range of species from the families Cyperaceae and Restionaceae. Large sections of this unit have been cleared for agriculture, despite the recognised importance of the habitat for the rare and endangered short-necked tortoise. As the effects of the proposed groundwater abstraction proposal are not predicted to extend to this part of the Gnangara Mound, it is unlikely that there would be further alteration of the water regime in these swamps.

2.3.2 Gingin Brook Complex (GG)

This is a flat, poorly drained landscape interrupted by broad low sandy rises; there are many seasonal and permanent swamps associated with sluggish drainage zones. Soils are variable and include shallow sand over ferruginous pan, red loam over limestone, and black clay over limestone on the poorly drained areas; the low sandy rises have humus or iron-humus podzols.

Vegetation varies according to soil characteristics and depth to water table. The low sandy rises support a low open woodland of Banksia spp. and Eucalyptus todtiana, similar to the Jandakot and Joel units further south. The poorly drained areas support a mixture of heaths dominated by Melaleuca spp., Verticordia spp. and the occasional Actinostrobus pyramidalis. The drainage lines support a fringing woodland of Eucalyptus rudis and Melaleuca rhaphiophylla. The unit includes significant numbers of shallow permanent water lakes. If the drainage pattern northwards is affected by the proposed groundwater abstraction then it is possible that there would be a further alteration of the water regime in these wetlands to the north.

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LEGEND

LANDFORMS, SOILS AND VEGETATION

BASSENDEAN DUNES

Jandakot (Ja) — Low hills and ridges with more than 5m relief; iron podzols; Banksia spp. low open woodland with a dense shrub layer.

(Ja-Steep) — Ridges with more than 10m relief; iron podzols; Banksia spp. low open woodland with sparse shrub layer.

Gavin (G) — Flat or gently undulating landscape; iron - humus podzols; Banksia spp. low open woodland with scattered emergent Eucalyptus calophylla and Melaleuca preissiana; dense shrub layer.

Joel (J) — Poorly drained depressions; humus podzols; scattered M. preissiana, E. rudis and Banksia ilicifolia with a dense shrub layer.

Seasonal Swamps (Ws) — Depressions with free water in winter; humus podzols and peats; dense M. preissiana, M. rhaphiophylla and E. rudis around the edges with reeds and sedges in the centre.

Pinjar (P) — Extensive flat swampy areas; sandy surface with some admixture of diatomite in the surface and organic hard plan below; E. rudis, B. littoralis and M. preissiana around edges; sedges and reeds with scattered M. teretifolia in centre; Jacksonia furcellate and Viminaria juncea on low sandy rises.

Permanent Lakes and Swamps (Wp) — Depressions; humus podzols and peats around the edges often with some diatomite; zoned vegetation with heath on upper slopes, Melaleuca spp. and E. rudis at waters edge, reeds and sedges in shallow water.

Yeal Swamp Complex (Wy) — A pattern of low sandy rises and many small seasonal swamps; rises have iron-humus or iron podzols and Banksia spp. low open woodland; swamps have surface layer of diatomite over sand; dense Melaleuca spp. and E. rudis around fringe with sedges in central parts of swamps.

Drainage Lines (DL) — Broad, shallow channels; peaty soils; fringe of Melaleuca spp. and E. rudis; reeds and sedges in central zone.

SPEARWOOD DUNES

Karrakatta-yellow (Ky) — Low hilly to gently undulating terrain; yellow sand over limestone at 1-2m; Banksia spp. woodland with scattered emergent E. gomphocephala and E. marginata and a dense shrub layer.

Karrakatta-grey (Kg) — Low hilly to gently undulating terrain; iron podzols; Banksia spp. woodland with E. todtiana and depauperate E. marginata; dense shrub layer.

Limestone (Kls) — Low hills and ridges; bare limestone or shallow siliceous or calcareous sand over limestone; dense low scrub dominated by Dryandra sessilis, Melaleuca huegelii and species of Grevillea.

Spearwood (Sp) — Irregular banks of karst depressions; some limestone outcrop; shallow brown soils; Banksia spp. woodland with emergent E. gomphocephala and E. marginata; dense shrub layer.

Beonaddy (B) — Flat terrain fringing water in base of karst depressions; light grey sand with water table within 2m; E. rudis, B. littoralis and Melaleuca spp; Typha sp. near waters edge.

Lakes and Swamps (W) — Permanent water in base of karst depressions; Melaleuca spp. and E. rudis in zone of water level fluctuation; sedges and reeds in shallow water. Seasonal swamps are shown as **Ws.**

ALLUVIAL TERRAIN

Yanga (Ya) — Flat, poorly drained complex landscape; soils include shallow sand over limestone or ferruginous pan, deep leached sand, and saline soils; dense Melaleuca spp. along drainage lines.

Gingin Brook Complex (GG) — Flat poorly drained landscape interrupted by broad low sandy rises; soils include shallow sand over ferruginous pan, red loam over limestone and black clay over limestone; Banksia spp. woodland on sandy rises; Melaleuca spp. with scattered Actinostrobus pyramidalis on swamp; Melaleuca spp. and E. rudis along drainage lines and fringing permanent water.

APPENDIX D

GNANGARA MOUND REGION
ECOSYSTEMS, SENSITIVE SPECIES AND CONSERVATION RESERVES

Report prepared by
A.S. Weston
for
Dames & Moore
February 1986

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1.0 INTRODUCTION

The Northern Swan Coastal Plain area between the coast, Moore River, Gingin Brook, the Swan River, Chandala Brook and Ellen Brook has a mounded water table called the Gnangara Mound (Allen, 1981). This groundwater mound is an unconfined aquifer which is directly recharged by rainfall. Discharge of groundwater from the superficial formations of sand, limestone, silt and clay in the mound occurs by evapotranspiration, by outflow westward to the ocean, by leakage into underlying aquifers and by baseflow into the rivers and brooks that define the northern, eastern and southern boundaries of the mound.

In a few areas where the groundwater is under pressure there may be discharge by minor artesian flows, as in small mound springs in the headwaters of some of the Ellen Brook tributaries. It is estimated that over 80% of rainfall recharge to unconfined aquifers on the Swan Coastal Plain is discharged by evapotranspiration.

The Gnangara Mound is one of the major sources of groundwater supplying the Metropolitan area. The Water Authority of Western Australia is developing a series of schemes for abstracting Gnangara Mound water for Metropolitan use. The first three schemes, Gwelup, Wanneroo and Mirrabooka, are already in operation. The next one proposed for development is the Pinjar Scheme.

The vegetation of the Gnangara Mound area is described in reports by McArthur and Mattiske (Appendix C) and Mattiske & Associates (Appendix A). The reports also describe the landforms and soils of the region, indicate distribution, condition and reservation status of each major landform/soils/vegetation unit and discuss possible effects upon them of abstraction of Gnangara Mound groundwater.

This report adapts and summarises information presented by Mattiske and McArthur about vegetation and ecosystem condition, distribution and representation in conservation reserves. In addition, it tabulates and elaborates upon existing and proposed conservation reserves in the Gnangara Mound area generally and in the vicinity of the Pinjar Scheme in particular. It also discusses rare, geographically restricted and poorly known flora and fauna in the area. Finally, it refers briefly to possible effects of groundwater abstraction upon ecosystems and biota of the area, effects which are described in greater detail and more specifically elsewhere in this set of reports (McArthur and Mattiske - Appendix C; Mattiske & Associates - Appendix A.

2.0 ECOSYSTEMS

Any ecosystem comprises all of the plants and animals of a given habitat or area plus the interactions occurring among them and the physical features of the habitat that impinge upon them (Mason and Langenheim, 1957). An ecosystem is much more than an assemblage of plants and animals; it is also a network of patterns and interactions. A change in one component of an ecosystem may affect other components. Changes in habitat factors, species and vegetation units in terms of numbers, relative abundances, types and condition may affect the ecosystem as a whole.

An ecosystem is commonly named after its dominant vegetation, such as banksia woodland, or a distinctive habitat feature, such as ephemeral swamp. Because the broadly circumscribed ecosystem units of the Gnangara Mound area roughly correspond to the land system units described by McArthur and Mattiske (Appendix C), their land system names are used for the ecosystems and the two systems are considered, for the purposes of this report, to be equivalent.

The Gnangara Mound ecosystems and their map symbols are listed in Table 1 along with notes on their ranges, abundance, conservation status and representation in existing and proposed reserves in and near the Gnangara Mound area. The reserves that are in the Pinjar Scheme project area are indicated with asterisks. Most of the information in the table is summarised from McArthur and Mattiske (Appendix C), Department of Conservation and Environment (1983) and discussions with W.M. McArthur.

Ten of the 17 ecosystem units listed in Table 1 occur either in depressions in the landscapes or in wetlands as defined by the Wetlands Advisory Committee (1977; Department of Conservation and Environment, 1980). These ten are Joel (J), Seasonal Swamps (Ws), Pinjar (P), Permanent Lakes and Swamps (Wp), Yeal Swamp Complex (Wy), Drainage Lines (DL), Beonaddy (B), Lakes and Swamps (W), Yanga (Ya) and Gingin Brook Complex (GG). Several of these units encompass a great deal of variation, and many, if not most, of them would be sensitive to rapid or long term lowering of water tables. Seddon (1972) observed that of all the resources of the coastal plain none have been affected more by European occupation than the wetlands. However, even Banksia woodland ecosystems situated higher in the landscape have been observed to suffer if sudden, dramatic lowering of the water table occurs (Mattiske & Associates - Appendix A).

TABLE 1

ECOSYSTEM REPRESENTATION IN EXISTING AND PROPOSED CONSERVATION RESERVES OF THE GNANGARA MOUND REGION

Map Symbol	Ecosystem[1]	Abundance and Range	Conservation Status[2]	Reserve Representation[3]
	Bassendean Dunes			
Ja	Jandakot	Becoming uncommon (through clearing); widespread	Poor to moderate	Moore River National Park (C2)[4], Gingin & Boonanarring Brook (C9)[4]
Ja-Steep	Jandakot-Steep	Restricted to survey area, in Pinjar/Dune area	Very poor	Modified M5
G	Gavin	Uncommon (much of it cleared); widespread southwards	Poor	M5
J	Joel	Small occurrences; mostly uncleared in survey area but cleared elsewhere; widespread	Poor to moderate; sensitive	M5,M9,C13
Ws	Seasonal Swamps	Small occurrences (many cleared); widespread on coastal plain	Poor to moderate; sensitive	M9
P	Pinjar	Few, small occurrences; restricted to survey area	Very poor; sensitive	M5,*M8
Wp	Permanent Lakes and Swamps	Small, uncommon occurrences; widespread	Poor to moderate; sensitive	*M8
Wy	Yeal Swamp Complex	Scattered small occurrences; restricted to survey area	Poor; sensitive	M5
DL	Drainage Lines	Not common; widespread	Poor to moderate; sensitive	M5,*M8,M9,C13
	Spearwood Dunes			
Ky	Karrakatta - yellow	Common; widespread	Moderate	M3, C12, C13
Kg	Karrakatta - grey	Common; widespread	Moderate	M3, C12, C13
Kls	Limestone	Common as fire climax (mostly with Dryandra sessilis); true climax rare; widespread	Moderate	M3, C12, C13
Sp	Spearwood	Uncommon (largely cleared for market gardens and urban development); widespread	Moderate	M3, M6, C12
B	Beonaddy	Rare but widespread	Poor to moderate	M3 and others
W	Lakes and Swamps	Uncommon; not widespread	Poor to moderate	M17
	Alluvial Terrain			
Ya	Yanga	Common (mostly cleared); widespread	Poor to moderate	M17
GG	Gingin Brook Complex	Uncommon; restricted to drainage at northern end of survey area and north of it	Poor	C9[4]

* In Pinjar Scheme area.

1. The broad ecosytem units used here equate with the landforms, soils and vegetation units named and described by McArthur and Mattiske (Appendix C) except that native vegetation is considered to be the essential and principal defining feature of each ecosystem unit. The symbols are also from McArthur and Mattiske (Appendix C).

2. Adequacy of conservation in existing reserves and throughout range of ecosystem. The term 'sensitive' refers to ecosystems potentially most sensitive to effects of drawdown.

3. Existing and proposed reserves (Department of Conservation and Environment, 1983) in or near survey area in which ecosystem units occur.

4. Proposed and existing reserves outside the survey area.

3.0 SENSITIVE SPECIES

The term 'sensitive species' as used in this report refers to species that are:

- o Rare or geographically restricted
- o Particularly susceptible or vulnerable to environmental changes, especially ones caused by humans, either directly or indirectly
- o Diminishing in abundance or geographical range due to clearing and other environmental changes associated with agriculture, mining, recreation, urbanisation and provision of services
- o Poorly represented in secure conservation reserves.

The term 'sensitive' is used in this report instead of 'vulnerable', 'threatened', 'depleted' or 'endangered' because terms such as the latter ones are either too limited in their scope or implications or, as Leigh et al., (1984) put it, "have become highly emotive through popular usage, making it difficult to develop objective criteria for use in ascribing species to various categories". Leigh et al., (1984), Holloway (1979), Ride and Wilson (1982b) and Koopowitz and Kaye (1983) discuss appropriate terminology in more detail.

In addition to their intrinsic importance, sensitive species are important as components of the ecosytems in which they occur, as potential sources of food and economic products and for aesthetic reasons. They may also be important as environmental indicators, and their occurrence is often associated with types of ecosystems that are also sensitive. Main (1982) eloquently discusses reasons why rare species are important for the study of ecosystem evolution and the design and management of reserves.

At least 16 relevant sets of lists and discussions of rare, geographically restricted or otherwise sensitive plant associations and species of flora and fauna have been produced since the first comprehensive list of Western Australian rare plant species was published in 1974 (Specht et al., 1974). All of these productions include associations or species that probably occur in the Gnangara Mound area or nearby. Seven publications list or discuss sensitive fauna (Ride and Wilson, 1982a; Frith, 1979; How, 1978; Kitchener et al., 1978; Storr et al., 1978a; Storr et al., 1978b; Sarti and Allen, 1978), and another discusses vegetation (Specht et al., 1974). The other publications and lists are concerned with species of vascular plants that are rare, geographically restricted, endangered, threatened, vulnerable or poorly collected (Specht et al., 1974; Hartley and Leigh, 1979; Marchant and Keighery, 1979; Dames & Moore, 1979; Rye and Hopper, 1981; Leigh et al., 1981, 1984; Patrick and Hopper, 1982; Rye, 1982).

Many lists of rare biota suffer from a common, unavoidable deficiency. Namely, the intensity and uniformity of collecting and systematic surveying have been insufficient to distinguish between species that are genuinely rare (and restricted) and species that are reasonably common but appear to be rare (or restricted) because, they have been poorly collected. Furthermore, most lists refrain from including undescribed species, some of which are also rare. Other sources of ambiguity in assessing sensitivity are provision of insufficient locality information with specimens, inaccurate determinations of specimens and the treatment of groups of species as single species. So little is known about the abundance, distribution and taxonomy of the smaller and more obscure invertebrate animals and nonvascular plants that few species of these groups are included in lists and discussions of rare biota.

Certain gazetted rare and endangered or otherwise sensitive fauna and flora are protected by law[1]. Lists of these species are revised from time to time; species which are found to be less restricted or more common and less in need of protection are deleted from the lists, and other species that are found to be rare, geographically restricted or otherwise in need of special protection are added. Unnamed species and hybrids that are not stabilised and self-perpetuating are not eligible for gazettal.

3.1 FLORA

Surveys of the plant collections in the Western Australian Herbarium by Marchant and Keighery (1979), by Barrett (pers. comm.) and during the preparation of this report, have identified 13 sensitive species of vascular plants which may occur in the Gnangara Mound area or nearby. Although some of the species qualify for protection as rare flora, only one of them has as yet been gazetted: Stachystemon axillaris.

The 13 sensitive species are listed in Table 2 in alphabetical order, with species and family names conforming to Green (1985). The principal habitats and distribution are also given for each species, along with the months during which it flowers, the type of roots it has and the number of collections it is currently represented by in the Western Australian Herbarium. A species' habitats and rooting pattern may give some indication of the plants susceptibility to lowering of unconfined groundwater (Dodd et al., 1984; Mattiske & Associates - Appendix A).

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1. Lists of gazetted rare species are printed in the Western Australian Government Gazette from time to time. The most recent such fauna list was printed in November 1985. The most recent gazetted flora list was printed in March 1982; another one is due soon.

TABLE 2

RARE, GEOGRAPHICALLY RESTRICTED AND POORLY COLLECTED SPECIES OF VASCULAR PLANTS THAT MIGHT OCCUR IN OR NEAR THE GNANGARA MOUND REGION

Scientific Name	Family	Habitat	Roots[1]	Flower[2]	Distribution[3]	No.[4]	Reserves[5]
Cartonema philydroides	COMME	Low-lying sandy soils in open jarrah/marri woodland	Shallow	7, 10-11	Kemerton - Kalbarri (E of Yanchep)	9	Yes
Conospermum huegelii	PROTE	Sandy/gravelly soil; often around granite rocks or on swampy or moist ground	Medium	7-10	Gleneagle-Serpentine Falls-Mogumber (Bullsbrook airfield)	29	Yes
Conostephium minus	EPACR	Sandy soil; Banksia woodland	Shallow; Root Type 5	7-10	Cataby - Perth (Gnangara)	12	?
Darwinia sp. A (D. aff. neildiana)[6]	MYRTA	Swampy or moist sandy ground	Shallow?	?	Muchea area (Mound Spring)	3?	No
Eremaea purpurea	MYRTA	Subswamp; low open Banksia woodland	Deep; Root Type 4	10-1	Gingin - Upper Swan (Perry Road, N of Pinjar)	13	?
Lhotskya brevifolia	MYRTA	Sandy/gravelly soil	?	9-12	Kings Park - Moore River (Bindoon)	4	Yes
Lycopodium serpentinum	LYCOP	Moist ground	-		Mound Spring, South Coast and eastern states (Mound Spring the only non-south coast site in WA)	1? (locally)	No
Lysinema elegans	EPACR	Sandy soil; Banksia scrub	Shallow; Root Type 1	10-11	Thompsons Lake - Regans Ford (Jandakot)	3	Yes
Restio stenostachya	RESTI	Sandy; swampy	Shallow, fibrous	6, 9-10	Gnangara - 12 km south of Gingin (Gnangara)	4	?
Stachystemon axillaris	EUPHO	Sandy soil	?		Near Wanneroo - Arrowsmith River (Melaleuca MPA)	10	Yes
Stylidium utricularioides	STYLI	Flat, swampy areas	?	10-12	Pinjarra - 31mi. peg, GNHighway (Gnangara)	15	?
Tetratheca pilifera	TREMA	Banksia woodland	Shallow ?	8-10	Yanchep/Lancelin - Wooroloo (Wanneroo)	7	Yes
Thelymitra sp. A (Th. aff. carnea)[7]	ORCHI	Swamp edges	?	9-10	Wanneroo, Cannington, Jandakot (Wanneroo)	3	?

1. The root type information is contributed by E M Mattiske. Root Types 1, 4 and 5 are briefly defined in Addendum II of Appendix A in this set of documents and are described in more detail by Dodd et al., (1984).
2. Times of flowering are based on inspection of labels on Western Australian Herbarium collections. The numbers refer to the months, e.g. 9 = September, in which specimens were collected in flower.
3. Distribution information is also based upon Western Australian Herbarium collection labels. The name in brackets is the location in or closest to the survey area in which the species has been recorded.
4. The numbers indicate the number of collections of each species in the Western Australian Herbarium.
5. Species protected in National Parks or Conservation Reserves.
6. The forthcoming flora of the Perth Region being prepared by the Western Australian Herbarium assigns the temporary, informal name 'Darwinia sp. A' to this undescribed species.
7. The Perth regional flora assigns the name 'Thelymitra sp. A' to the local orchids that have been called 'Thelymitra carnea'. The plants are, apparently, not proper species but hybrids.

The number of collections of a species held by the Western Australian Herbarium may give some indication of the rarity of a species, although species believed to be rare tend to be collected more frequently, especially if they are conspicuous. The flowering times given in Table 2 suggest the month when a survey for the species could be undertaken most productively. In the case of these 13 species, October would be the best month because most of them have been collected in flower then.

Eight of the 13 species have been recorded in wetland habitats, and the other five have been recorded in Banksia woodland and scrub vegetation. Plants of wetland habitats are, according to Aplin (1976), more likely to suffer from drastic variations in water table levels than plants growing higher in the landscape[2].

One sensitive species, Conostephium minus, is known to occur in the Pinjar Scheme area (Mattiske, pers. comm.) and all of the others except the Lysinema and the Lhotskya have been collected nearby, mostly in the Gnangara Mound area and mostly in the vicinity of Gnangara and Wanneroo. The rarest vascular plant species listed in Table 2 are an undescribed orchid recorded from only three sites and an undescribed Darwinia that survives in only one or two sites. All of the sites are low-lying and wet. Hoffman and Brown (1984) refer to the orchid as Thelymitra carnea and regard it as one of the rarest species in Western Australia. The undescribed Darwinia has been recorded from a site between Gingin and Muchea and from two of the lots in the proposed Mound Springs nature reserve. The lots are now cleared and being grazed, and the Darwinia now survives in only one of them (Keighery, pers. comm.).

3.2 FAUNA

Fifteen of the species of vertebrate fauna reported for the Northern Swan Coastal Plain between the Moore River and the Swan River (Western Australian Museum, 1978) are regarded as having become rare, at least locally, or otherwise sensitive (Department of Conservation and Environment, 1983; Ride and Wilson, 1982a; Frith, 1979; How, 1978; Kitchener et al., 1978; Storr, et al., 1978a; Storr, et al., 1978b; Sarti and Allen, 1978).

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2. Mattsike & Associates - Appendix A discuss potential impacts in more detail.

These species, most of which have been recorded in the Northern Swan Coastal Plain during the last 15 years, are listed in Table 3. Many of them have been recorded in the Gnangara Mound area during that time, and some can be expected to still occur in the Pinjar Scheme area.

Most of the recent sightings recorded in the Western Australian Museum reports of 1978 were made during the museum's 1977-78 surveys. Regular surveying was carried out in seven terrestrial study areas and in four aquatic study areas in the Gnangara Mound area (How, 1978). None of the regularly surveyed study areas, with the possible exception of Yanchep National Park, was in the Pinjar Scheme area. Consequently, some of the species listed in Table 3 may be more abundant or widespread locally than the surveys indicate. The general paucity of records suggests, however, that these species are indeed locally rare.

The various causes of decline of these once-common or abundant species include disease, success of introduced predators and competitors, loss of tall forests and wetlands and changed aquifer characteristics (How, 1978). Increased frequency of burning (Kitchener et al., 1978) and replacement of native shrub vegetation by suites of alien grasses and forbs may also be instrumental in the decline of native species.

There are additional, unlisted species, especially of birds and other species that depend upon wetlands, which are still common or not yet rare but are declining in range and abundance due to destruction of habitat and increase of introduced predators and competitors (Kitchener et al., 1978; Storr et al., 1978b; Sarti and Allen, 1978). Such species include the Brown Bittern, the Blue-winged Shoveler and the Musk Duck. There are also species, such as the Red-eared Firetail-finch and the Yellow-plumed Honeyeater, which were once common or abundant in the area and are now absent. Most of the birds that have declined in abundance or have become extinct in the Gnangara Mound area are species that inhabit wetlands or infrequently burnt dense heath and scrub vegetation (Storr et al., 1978b; Dell, pers. comm.). Because reproduction of the amphibians recorded for the area, with the exception of the frog Myobatrachus gouldii, is dependent upon unpolluted surface water, all of these species would be vulnerable to reduction or deterioration of wetland habitats (Storr et al., 1978a).

TABLE 3

RARE, GEOGRAPHICALLY RESTRICTED, ENDANGERED AND VULNERABLE VERTEBRATE ANIMALS THAT DO OR MAY OCCUR IN THE GNANGARA MOUND REGION

Scientific Name	Common Name	Habitats and Distribution[1]	Status[2]	Source[3]
Mammals				
* Dasyurus geoffroii fortis	Chuditch (Western Quoll)	South-western Western Australia; very scarce or extinct in Gnangara Mound area. Recorded in Yanchep National Park in 1972.	?SV	SKDT
Pseudomys albocinereus	Ashey-grey Mouse	Sandplain from Kalbarri to Israelite Bay; principally unburnt heath.	LUV	EK
Cercartetus concinnus	Mundarda (Western Pygmy-possum)	Mallee heath and dry sclerophyll forest; southern W.A. and South Australia. Not recorded in mound area since 1966.	?LSV	KS
Tarsipes rostratus	Noolbenger (Honey-possum)	Sandplain from Sharks Bay to Israelite Bay. One male recorded in 1977 in low unburnt heath south of Burns Beach.	?LSV	KS
Birds				
* Stictonetta naevosa	Freckled Duck	Freshwater lakes and swamps; south-western Western Australia and eastern states. Observed in 1977 at Lake Bambun.	?DVE	RFJBW
Turnix varia varia	Painted Button-quail	Forests, woodlands and heaths with leaf and twig litter; Sharks Bay to Cape le Grand and eastern states. Observed at Mussell Pool in 1975.	?LS	EBJW
Chlidonias hybrida javanica	Whiskered (Marsh) Tern	Australian lakes and rivers. Rare visitor at Lake Joondalup in 1977-78.	?LS	BJW
Pachycephala pectoralis	Golden Whistler	Densely wooded country and coastal vegetation of southern and eastern Australia. One male seen in 1978 at north end of Loch McNess.	?LS	BJ
Myiagra inquieta inquieta	Restless Flycatcher	Open forests and fringing flooded gum and paperbark vegetation; south-western Western Australia and the eastern states.	?LSV	BJW
Malurus elegans	Red-winged Fairy-wren	Dense, often sword-sedge vegetation, especially along streams and lakes; south-western Western Australia. Seen near source of Gingin Brook in 1975.	?UV	BJW
Strepera versicolor plumbea	Grey Currawong	Forest, woodland, mallee and heath; south-west Western Australia. Seen in Pinjar Scheme area in 1985.	LSD	BJW
Reptiles				
* Pseudemydura umbrina	Western Swamp Tortoise	Restricted to a few seasonal swamps along Ellen Brook.	RSE	ERFH
Aclys concinna	legless lizard	Sandy heath and woodland on coastal plain north of Perth.	LC	HC
Drysdalia coronata	Crowned Snake	South-western, especially coastal, Western Australia.	LC	HC
Leiolopisma trilineatum	Swamp Skink	Damp, often swampy places in south-western Western Australia. Specifically distinct from south-eastern Australian populations. Recorded in Melaleuca MPA.	LC	EMHC
Galaxiella munda	Mud Minnow	Coastal streams, ponds, swamps, and ditches between Albany and Margaret River, and Ellen Brook.	LR	A

* Gazetted species

1. The HABITATS AND DISTRIBUTION information is compiled from the references indicated in the Column 5 SOURCES.

2. The STATUS symbols refer to abundance, geographical range and vulnerability: C= Probably common to very common in Gnangara Mound region (Harold pers. comm.); D = Declining; E = Endangered; L = Locally; R = Restricted; S = Scarce or Rare; U = Uncommon; V = Vulnerable; ? = Occurrence in Gnangara Mound study area questionable.

3. The SOURCES of information in Columns 3 and 4 are: A = Allen (1982) and Sarti and Allen (1978); B = Blakers et al., (1984); C = Cogger (1983); D = Archer (1978); E = Environmental Protection Authority (Department of Conservation and Environment, 1983); F = Frith (1979); H = Storr et al. (1978b); J = Storr (1978a); K = Kitchener et al., (1978); M = Storr et al. (1981); R = Ride and Wilson (1982); S = Strahan, (1983): T = Archer (1979); W = Serventy and Whittell (1976).

There are many snakes and lizards which are abundant or common in the nearby Darling Range but are naturally scarce, rare or absent in the study area because suitable habitats are also scarce or rare (Storr et al., 1978a). One such snake is the gazetted Carpet Python (Morelia spilota).

Several kinds of crustaceans appear to be unique to the Gnangara Mound area, where they have been found in caves in Yanchep National Park, as discussed by Harold - Appendix E.

4.0 CONSERVATION RESERVES

Sixteen System 6 national parks and nature reserves within the Gnangara Mound area (Figure 3), recommended by the Environmental Protection Authority, are listed in Table 4, along with the vesting bodies, brief descriptions of ecosystem features and notes on which recommended areas include existing reserves. There is at least one additional area which is managed as a nature reserve that is not in the Environmental Protection Authority report, the grounds of the Western Australian Wildlife Research Centre at Woodvale. The table and figure do not indicate recommendations for strictly coastal reserves (M2 and M10), a Swan River reserve (M19) and reserves south of Beach Road and its eastward extension (M35-60), all of which are small and none of which will be affected by development of the proposed Pinjar, Lexia, Yeal or Barragoon groundwater abstraction schemes. Three other small recommended sets of reserves near Gingin Brook, C14, C15 and Gingin Stock Route Reserve 34761, might be influenced by the Barragoon Scheme.

The four recommended reserves that are in the Pinjar groundwater scheme area are indicated with asterisks. These four are Yanchep National Park (M3), Ridges Management Priority Area (M4), Yeal Nature Reserve (M5) and the Wanneroo Wetlands - Eastern Chain (M8). The first two reserves are existing; the third and fourth exist only in part. Only a relatively small, narrow strip of Yanchep National Park near the park's eastern boundary is included within the Pinjar Scheme boundaries. Few of the System 6 recommendations for the Gnangara Mound area have been implemented.

TABLE 4

CONSERVATION RESERVES IN THE GNANGARA MOUND REGION
EXISTING AND AS RECOMMENDED BY THE ENVIRONMENTAL PROTECTION AUTHORITY (DCE, 1983)

EPA Locality Number	Name	Tenure/Vesting	Action Taken[2]	Comments[3]
C12	Caraban Management Priority Area (MPA 15.4)	CALM/ILDA/LSD	None	Virtually undisturbed tuart and banksia woodland; 1461ha of State forest.
C13	Wabling Management Priority Area (MPA 15.3)	CALM/NPNCA	None	Limestone outcrop to leached sand dune and seasonal semi-swamp vegetation. Some adjustments to boundaries planned. Includes 1436ha of State forest and 112.96ha Reserve 24436 for protection of flora.[4]
C25	Mound Springs (Muchea)	SC/VCL/PF/ Various	None	Wetland vegetation supported by artesian flows from the Gnangara Mound. Very rare Darwinia sp. nov. and locally rare clubmoss.
M1	Two Rocks Open Space	PF	None	Tuart-banksia woodland with Melaleuca acerosa open-heath and prickly-bark and limestone marlock woodlands.
* M3	Yanchep National Park	NPNCA/PF	Some	Noteworthy caves, wetlands and diverse vegetation. Possibly some increase in area. Existing reserved area is 2799ha[4].
* M4	Ridges Management Priority Area (MPA 15.2)	CALM	None	1260ha of State forest: supplement and buffer to Yanchep National Park.
* M5	Yeal Nature Reserve	VCL/NPNCA	None	Vegetation and soil types, including an unusual swampy tract, not represented in other reserves. Includes Reserve 31241 of 337.04ha[4]. The area proposed for reservation shown in Figure 3 is substantially larger than the System 6 recommendation
M6	Neerabup National Park	NPNCA/Various	None	Remnant woodlands of jarrah, she-oak, prickly-bark, tuart and banksias. Possibly some decrease in size of area has been recommended. Includes 1111.5ha National Park and 116.41ha Fauna Sanctuary Class A Reserve 24581[4].
M7	Lakes Joondalup and Goollelal	NPNCA/CW/MRPA/ Various	None	Supports great numbers and variety of water birds and important summer drought refuge. Includes Reserves 21708 (4.04ha)[4] and 31048 (465.38ha)[4].
* M8	Wanneroo Wetlands - Eastern Chain	CW/Various	None	Important water bird habitats. Minor changes in recommended area anticipated due to submissions. Includes 232.28ha Reserve 7349[4].
M9	Melaleuca Management Priority Area (MPA 15.1)	CALM	None	Important for Bassendean Dune System vegetation, diverse fauna and the relatively rare swamp skink; 3208ha of State forest.
M11	Warwick Woodland	MRPA(CW)	None	Jarrah(-marri)-banksia woodland. Planned development for active recreation.
M12	Reserve A20091, Marangaroo	Unvested	None	Jarrah-banksia woodland. Class A reserve.
M13	Whiteman Park (Mussel Pool)	MRPA/PF	None	Rich diversity of flora and fauna, which includes the locally rare painted button-quail and ashey-grey mouse; high recreation potential. Seasonally flooded vegetation of particular interest.
M15	Pearce Aerodrome	CA	None	Marri, wandoo, jarrah, flooded gum, she-oak and paperbark woodlands and open forests. Important as catchment for Ellen Brook.
M17	Ellen Brook and Twin Swamps Nature Reserves	NPNCA	None	Unusual clay swamp with other swamps, lowlands and sandhills rich in species. Only known location for western (short-necked) swamp tortoise. Existing Class A reserves total 155.27ha[4].

* In Pinjar Scheme area.

1. The table excludes recommendations for strictly coastal reserves (M2 and M10), a Swan River reserve (M19) and reserves south of Beach Road and its eastward extension (M35-60), all of which are small and none of which will be affected by development of the Lexia and Pinjar groundwater abstraction schemes. Potential impacts on three recommended reserves C14, C15 near Gingin Brook, and Gingin Stock Route Reserve 34761, should be considered prior to development of the Yeal and Barragoon Schemes.
2. Changes in size and shape of area recommended by EPA (DCE,1983) and implementation of additions to reserve system recommended by EPA (DCE,1983) as of January 1986. In the majority of cases no positive action has been taken, and many of the recommended areas have suffered severe degradation since the recommendations were made.
3. Most of the comments have, unless otherwise indicated, been taken from Environmental Protection Authority (DCE,1983).
4. Nature reserve and/or vested in NPNCA and with stated area as of January 1986 printout from CALM.

Abbreviations:

CA Commonwealth of Australia
CALM Dept. Conservation & Land Management
CW City of Wanneroo
ILDA Industrial Lands Development Authority
LSD Lands and Surveys Department
MPA Management Priority Area
MRPA Metropolitan Regional Planning Authority
NPNCA National Parks & Nature Conservation Authority
PF Private Freehold
SC Shire of Chittering
VCL Vacant Crown Land

National parks and other conservation reserves are as vulnerable to changes in groundwater regimes as natural ecosystems outside the reserves. Impacts of groundwater drawdown cannot be restricted or controlled the way surface developments or access can[3]. However, the fact that an area is a reserve, or is recommended to be one, is indicative of its conservation value, and groundwater management should reflect this value. Development of the unconfined groundwater resource and management of its abstraction should take a cautious, conservative approach in relation to conservation areas in order to ensure that their conservation values are not affected by unnatural changes in the groundwater regime.

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3. Impacts and measures to avoid them are discussed in more detail by Mattiske & Associates - Appendix A. Proposed monitoring programmes are described by Mattiske & Associates - Appendix A and in the ERMP.

5.0 REFERENCES

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APPENDIX E

FAUNA OF THE GNANGARA MOUND

Report prepared by

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for

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November 1985

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1.0 INTRODUCTION

The proposed Pinjar Scheme is one of several potable water sources that the Water Authority of Western Australia is investigating for future water supply to the population of the North-West Corridor.

This report is essentially a summary of the faunal studies undertaken by the Western Australian Museum during 1977-78 on the Northern Swan Coastal Plain, and provides an indication of the terrestrial fauna and wetland ecosystems in the area.

2.0 TERRESTRIAL FAUNA

2.1 MAMMALS

After a search of the Western Australian Museum records and relevant literature, Kitchener et al., (1978) concluded that 33 native mammal species have been recorded with certainty from the Northern Swan Coastal Plain. An additional four are also listed, though these are considered to be of doubtful validity due to vague locality data on the original specimens. An annotated list (including history, past and present distributions, abundance and habitat preferences) of all mammals listed for the region can be found in the above reference.

The Northern Swan Coastal Plain was extensively surveyed for mammals during 1977-78 by the Western Australian Museum. Prior to this, the only other organised mammal collecting was undertaken by Shortridge (undertaken from 1904 to 1907) (Shortridge, 1909) and the Western Australian Museum at Mussel Pool in 1975. The 1977-78 survey consisted of a total of 315 man days and 24,443 trapnights and was carried out in the following areas:

Moore River National Park
Gingin Proposed Reserve
Melaleuca Park
Martyn/Twin Swamps Reserve
Yanchep National Park
Neerabup National Park/Burns Beach
Mullaloo

These areas were selected for intensive trapping as they were relatively undisturbed, reasonably large and contained representatives of the majority of vegetation associations and soil types found on the coastal plain.

The survey confirmed the presence of only 12 native species. They are:

Short-beaked Echidna	Tachyglossus aculeatus
Southern Brown Bandicoot	Isoodon obesulus
Common Brushtail Possum	Trichosurus vulpecula
Honey Possum	Tarsipes rostratus
Western Brush Wallaby	Macropus irma
Western Grey Kangaroo	M. fuliginosus
Lesser Long-eared Bat	Nyctophilus geoffroyi
Goulds Wattled Bat	Chalinolobus gouldii
King River Eptesicus	Eptesicus regulus
Water Rat	Hydromys chrysogaster
Ashey Grey Mouse	Pseudomys albocinereus
Bush Rat	Rattus fuscipes

Furthermore another three were also considered to be possibly still extant in the region.

Western Quoll	Dasyurus geoffroii Last collected in 1972.
Western Pygmy Possum	Cercartetus concinnus Last collected in 1966.
Chocolate Wattled Bat	Chalinolobus morio Last collected in 1951.

All of the above 15 species inhabit heath, shrubland or woodland habitats with the exceptions of the Southern Brown Bandicoot, Water Rat and Bush Rat, which prefer swamps and lakes.

The Honey Possum (Tarsipes rostratus), is known to occur in Yanchep National Park and at Mindarie, east of Burns Beach, where it depends on a year round supply of flowering plants.

2.2 REPTILES AND AMPHIBIANS

The Northern Swan Coastal Plain supports a relatively rich herpetofauna with 42 genera and 70 species distributed amongst 11 families (Storr et al., 1978a). They are:

Ground Frogs	(Leptodactylidae)	7 genera, 11 species
Tree Frogs	(Hylidae)	1 genus, 2 species
Side-necked Turtles	(Cheluidae)	2 genera, 2 species
Geckos	(Gekkonidae)	4 genera, 6 species
Legless Lizards	(Pygopodidae)	6 genera, 8 species
Dragon Lizards	(Agamidae)	1 genus, 2 species
Skink Lizards	(Scincidae)	10 genera, 19 species
Monitor Lizards	(Varanidae)	1 genus, 3 species
Blind Snakes	(Typhlopidae)	1 genus, 2 species
Pythons	(Boidae)	2 genera, 2 species
Front-fanged Snakes	(Elapidae)	7 genera, 13 species

In the above reference the Northern Coastal Plain was divided longitudinally into three zones corresponding approximately to the Spearwood/Safety Bay sands (western zone), Bassendean Dune System (central zone), and the Guildford Formation (eastern zone). The western zone, primarily due to the presence of outcropping limestone, possessed a greater diversity of geckos (Gekkonidae) than the eastern zone which was noted to be much richer in ground frogs (Leptodactylidae) and poorer in skink lizards (Scincidae) than the other zones. Otherwise, the zones only differed marginally.

The importance of unpolluted surface water to the amphibian fauna is illustrated by the fact that all but one species (The Turtle Frog - Myobatrachus gouldii) use swamps, lakes and streams etc., for larvae development. Additionally a number of reptiles prefer surface water or moist places, namely the Long-necked Turtle (Chelodina oblonga), Short-necked Tortoise (Pseudemydura umbrina), the skink lizards Egernia luctuosa and Leiolopisma trilineatum and the Western Tiger Snake (Notechis scutatus occidentalis).

Seventeen of the above species and sub-species listed in Storr et al., (1978a) are considered to be scarce or rare, primarily due to a lack of suitable habitat on the coastal plain though they are more common elsewhere in the south-west. Four of the seventeen are at the respective limits of their distributions. A further twelve species are endemic or nearly endemic to the west coast and coastal plains from North West Cape to Geographe Bay, though none are restricted to the Northern Swan Coastal Plain.

2.3 BIRDS

The avifauna of the region was documented by Storr et al., (1978b) who compiled an annotated list which included local distribution, relative abundance, faunal status (ie. visitor, resident etc.), habitat preferences and breeding season. Data were derived from the literature, W. A. Museum catalogues, journals of local naturalists and survey work undertaken by W. A. Museum staff during 1977-78. A summary is reproduced below. Figures in brackets refer to species which formerly occurred on the Swan Coastal Plain but for which no definite records exist.

NON-PASSERINES	PASSERINES	TOTAL	
Residents	52(3)	48(7)	100(10)
Breeding Visitors	14	5	19
Non-breeding Visitors	73	10	83
Vagrants	12	2	14
Established Exotics	5	2	7
TOTAL	156(3)	67(7)	223(10)

Of the birds that have declined or become locally extinct, Storr et al., (1978b) noted that most were either wetland or forest inhabiting species.

Of the woodlands on the coastal plain, the best have been felled for timber and cleared for various agricultural activities. Consquently, birds such as the Scarlet Robin (as a breeding species), Yellow Robin, Crested Shrike-tit, Rufous Tree Creeper, Yellow-plumed Honeyeater, White-naped Honeyeater, Dusky Wood-swallow and Grey Currawong are either no longer found in the region or are rare. The increasing rarity of the Western Rosella and more recently of the Regent Parrot have probably been caused by the increase in numbers of the Ringnecked Parrot. The Bush Stone Curlew has declined since the introduction of the Red Fox and the Brown Falcon became scarce due to the use of DDT in the south-west.

A number of species have benefitted by man's clearing practices and growing of exotic trees. This has enabled some species to colonize the Perth area, eg. the Great Egret, Straw-necked Ibis, Sacred Ibis, Wood Duck, Black-shouldered Kite, Banded Plover, Crested Pigeon, Regent Parrot and the Galah. Also, open country birds have been favoured, including White-faced Heron, Richards Pipit, Magpie Lark, Black-faced Woodswallow, Magpie and Australian Raven. Others such as Carnabys Cockatoo, Silver Gull and Grey-breasted White-eye have benefitted from an increased food supply and consequently become much more common. The additional food sources include pine plantations, rubbish disposal areas and cultivated fruit trees.

Part of the survey of 1977-78 concentrated on the lakes of the region and Storr et al., (1978b) note that the waterfowl most threatened by a lowering of the water table are the inhabitants of deeper waters, ie., the Musk Duck, Blue-billed Duck, Freckled Duck, Blue-winged Shoveller and Great Crested Grebe. Most of the wetland species that have declined depend greatly on the fringing swamp and lake vegetation. The combined effects of drainage and land fill, fire, cutting for fence posts and clearing for summer grazing would have eliminated shelter and nest sites for many species over large areas of the coastal plain. Birds greatly affected by the deterioration of the wetlands included the above mentioned species plus, Black Bittern, Brown Bittern, Barking Owl, Red-winged Fairy Wren, Golden Whistler, Restless Flycatcher, Red-eared Firetail, Marsh Harrier, Painted Snipe, Whiskered Tern, and Southern Emu Wren. To this list can be added the Ground Parrot and Bristlebird, which are today locally extinct and are not represented in Museum collections, but were reported by local naturalists in earlier days. Both relied upon dense swamp vegetation.

Unlike some of the southern Metropolitan lakes, those north of the Swan River do not provide a major habitat for wading birds (Storr pers. comm., Johnstone pers. comm.). This appears to be for two main reasons. The western linear lakes have steep sides and rarely dry out sufficiently to allow waders to feed. The lakes of the shallow eastern chain do dry out, but still do not support large wader populations, probably because the sandy lake substrates do not support the organisms on which the waders feed on the southern lakes.

3.0 WETLAND ECOSYSTEMS

Concurrent with the terrestrial vertebrate surveys conducted by the W. A. Museum in 1977-78, attention was also given to aquatic fauna. Papers were written on invertebrates (Hembree and George, 1978) and fishes (Sarti and Allen, 1978).

3.1 INVERTEBRATES

In their studies on the aquatic invertebrate fauna of the coastal plain, Hembree and George (1978) recognized two major habitat divisions, the pelagic and the benthic. Both were sub-divided as follows:

Pelagic Zone

- Open water fringing Baumea (B. articulata and B. juncea) - Open reed swamps provided the principal habitat for fishes and crustaceans with the reed stems housing sedentary invertebrates such as turbellarians and gastropods. It was also an important breeding area for fishes, molluscs and other aquatic organisms.

- Open water fringing Typha (T. domingensis and T. orientalis) - The peripheral margins of these closed reed swamp areas supported similar populations of animals as the Baumea swamps. Most activity however was confined to the outer regions due to the closed compact nature of the Typha.

- Open water fringing overhanging Melaleuca (M. teretifolia and M. rhaphiophylla) - Crustaceans and gastropods were provided with habitats and resources from fallen leaf litter and submerged branches.

- Open water - provided habitat for pelagic fishes, crustaceans and insects.

Benthic Zone

- Sand and Submerged Vegetation - Most of the lakes on the coastal plain are situated in sandy areas and consequently sand comprises part or all of the major aquatic substrates. This substrate together with benthic flora provides an important habitat for fishes, crustaceans and molluscs.

- Mud and Submerged Vegetation - While only one lake (Lake Chandala) was observed to have a bottom comprised only of mud, the majority had a mixture of sand and mud. In some lakes these areas were clearly defined zones whilst in others they occurred as stratified layers.

- Flocculated Organic Detritus - This material is comprised of rotting vegetation and occurs as a suspension on the lake bed. Several of the coastal plain lakes were found to have a layer of black detritus, ie., Lake Joondalup, Lake Beermullah and especially Loch McNess where the layer was up to 2m deep in some areas.

The aquatic invertebrate studies by Hembree and George (1978) carried out on most of the lakes on the Northern Swan Coastal Plain, showed the importance of the littoral zone and its associated habitats to the species richness and abundance of invertebrates in the lakes investigated. The littoral open water/sedge community interface being the richest, while the poorest habitat was the flocculated organic detritus. When compared to some lakes in eastern Australia, and probably those in the wetter south-west, the local lakes were found to have a low species diversity with a similarity of faunal types throughout the area.

The dominant faunal types were crustaceans and insects. Species more tolerant to fluctuating environmental conditions were most common. No species were found to be particularly uncommon or restricted to the Perth area and indeed most were thought to range throughout the south-west and some to occur Australia wide. Species diversity and abundance was shown to increase following winter rains, declining again when lake levels dropped during summer. The study also revealed that the more saline lakes had fewer species, lower numbers and reduced habitat diversity. The crucial effects of a reduction of the water table were deemed to be the degree and time period of the water drawdown and the effects on both water chemistry and vegetation. The invertebrate fauna was considered to be tolerant of moderate water level reductions and the above mentioned factors, due to their adaptations to cope with naturally occurring fluctuating environmental conditions. Those species which do not produce drought resistant eggs may be detrimentally affected. Hembree and George (op.cit) recommended that "as threshold levels of most organisms are not well known, water level fluctuations should be in accordance with natural environmental conditions as much as possible and every effort should be made to preserve vegetation habitat structures in the littoral zone".

Several kinds of crustaceans appear to be unique to the Gnangara Mound region, where they inhabit caves in Yanchep National Park. The most prominent of these crustaceans are the variously coloured forms (white, red, blue, brown and intermediate shades) of gilgies (Cherax quinquecarinatus) in the cave system (Muir, pers. comm.). Although the unusual, cave-dwelling gilgies may not be taxonomically distinct from their widespread surface-dwelling relatives, their interesting range of colour forms and other adaptations to their dark environment make them not only unique, but also important for scientific research. Other types of crustaceans do, however, appear to be represented in the Yanchep Caves, by endemic species of subspecies or cave-adapted animals. These amphipods and isopods include some forms that are white and completely eyeless, features often associated with cave-dwellers (Austin, pers. comm.).

3.2 FISHES

During the fish studies on the Northern Swan Coastal Plain, representative watercourses and lakes, representing a wide range of habitats, were sampled periodically by Sarti and Allen (1978). They concluded that the freshwater fish fauna is represented by 13 species belonging to 10 families. Of this total, two are introduced and seven are endemic to the south-west of Western Australia, though none are restricted to the Perth area. On face value 13 species out of a total of 23 (56%) for the entire south-west appears impressive, though during the 1977-78 survey, only seven were found with any regularity, the remainder being restricted to either the Moore River or Ellen Brook.

The impoverishment is quite probably due to the introduced Mosquito Fish (Gambusia affinis) which exists on the coastal plain in prodigeous numbers and out-competes native species for living space and food resources. The area considered by Sarti and Allen (1978) to be of most importance is Ellen Brook and its tributaries as they contain the richest fish fauna on the coastal plain with eight species, and only low levels of Mosquito Fish infestation. Additionally it supports a "possibly relict population of Galaxiella munda, a species which is otherwise restricted to coastal streams between Margaret River and Albany" (Sarti and Allen, 1978). They recommend that this stream be monitored closely to determine the effects of a lowered water table and an increasing Mosquito Fish population.

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APPENDIX F

REPORT OF A SURVEY FOR ABORIGINAL ARCHAEOLOGICAL SITES AT THE PROPOSED PINJAR SCHEME INCLUDING COMMENTS ON THE EFFECTS OF DRAWDOWN WITHIN THE GNANGARA MOUND

Report prepared by
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for
Dames & Moore
November 1985

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1.0 INTRODUCTION

The Pinjar Groundwater Scheme is one of several potable water sources that the Water Authority of Western Australia (Water Authority) is investigating for future water supply development. The proposed project is located on the Swan Coastal Plain some 40km north of Perth. The wellfield comprises a total of 28 wells in two lines located approximately four kilometres apart (Figure 9).

A Notice of Intent (NOI) has been prepared by the former Metropolitan Water Authority (MWA) for this groundwater scheme and submitted to the Environmental Protection Authority (EPA). The EPA has subsequently recommended that an Environmental Review and Management Programme (ERMP) be prepared for the Water Authority's utilization of groundwater from the Gnangara Mound.

This report, therefore, contains two sections. The first describes a survey for archaeological sites within the impact areas of the Pinjar Scheme. The second section reviews and discusses the possible broad scale effects of a long term lowering of the water table and the implications of this on the archaeological record of the Gnangara Mound.

Specialist contributions to the ERMP include mapping of landforms, soils and vegetation (McArthur and Mattiske - Appendix B), effects of drawdown on native vegetation (Mattiske - Appendix A) and the location of rare and endangered flora and fauna (Weston - Appendix D). The Archaeologist carried out a field reconnaissance with these specialists and refers to their contributions in Section 2 of this report. Computer simulated preliminary drawdown contours for the Pinjar Groundwater Scheme were supplied by the Water Authority as a component of their NOI to the EPA (Metropolitan Water Authority, 1985).

2.0 PINJAR GROUNDWATER SCHEME

2.1 DESCRIPTION OF SURVEY AREA

The project area lies to the west of the Darling Fault in the Perth Basin (Biggs and Wilde, 1980). The proposed Pinjar Scheme wellfield (and Gnangara Mound) is developed largely within the oldest aeolian unit of the Swan Coastal Plain, the Bassendean Dune System (Churchward and McArthur, 1980). While the Dunes have low relief, three topographic mapping units have been defined.

These are hills and ridges (Jandakot), level or gently undulating terrain (Gavin) and depressed areas which are swampy in winter (Joel). Permanent water and seasonal swamps are also identified as well as a high dune unit to the north (Figure 1). The vegetation of the Jandakot unit is Banksia spp. low open woodland, the Gavin unit is typified by large scattered Eucalyptus spp. and Melaleuca spp. or Banksia with a very dense shrub layer. The low lying Joel units are characterised by peaty soils, large Eucalyptus spp. and Melaleuca spp. and sometimes a dense growth of reeds and rushes.

The proposed wellfield, illustrated in Figure 9, is located almost entirely within State Forest No. 65 (see Figure 4). Only one small area of vacant Crown Land is traversed. The wellfield location is constrained by a number of factors including the unsuitability of the coastal strip as a groundwater supply, the vulnerability of the lakes and wetlands to the west and south as identified in the System 6 report (Department of Conservation and Environment, 1983) and hydrological/engineering considerations (Metropolitan Water Authority, 1985).

Therefore, all but several kilometres of the route to be disturbed by trenching and drilling, are located within pine forest of varying degrees of maturity. The ground has obviously already been subject to gross disturbance which would have affected archaeological site integrity.

2.2 SURVEY METHODS AND RESULTS

All of the proposed wells and pipeline routes are located directly adjacent to existing sealed or limestone roads and tracks. As these pass through pine forest, the land is either cleared for fire breaks or has pine stands with different levels of groundcover development. A right-of-way of no less than 20m width was inspected on foot and by vehicle traverse. The landscapes actually intersected by the wellfield configuration are generally flat to gently rolling (apart from the extreme north) and features such as immediate lake margins and major drainage courses are avoided. Where several small water holding depressions (less than 10m in diameter) were encountered, a systematic survey of no less than 200m radius from the feature was made.

No cultural material was located during the survey.

While archaeological sites have been recorded in the region (ie. 14 registered with Western Australian Museum in the Wanneroo Shire) comprising artefact scatters and the Orchestral Shell Cave to the east of Lake Neerabup, the somewhat featureless landscape traversed by the wellfield and the fact it does not intercept any major drainage lines or lake margins may partly explain the lack of cultural material. It is relevant to reiterate the rationale used by the Water Authority in avoiding direct disturbance to the lake systems in the proposed groundwater scheme. While cultural material has been identified in surveys of pine forest in other parts of Australia (Geering, 1982; Veth, 1984) the disturbed integrity and stratigraphic context of these sites means they are of limited scientific value.

3.0 EFFECTS OF DRAWDOWN WITHIN THE GNANGARA MOUND

3.1 BACKGROUND

The integrity of archaeological sites within drawdown contours similar to those illustrated for the Pinjar Scheme would be determined primarily by the long term effects of a reduced water table on vegetation patterns. These, in turn, would influence the stability of soil units mapped in total for the Gnangara Mound (W. McArthur and E. Mattiske, pers. comm.). It is therefore relevant to discuss previous vegetation monitoring programmes and the potential impacts on vegetation patterns predicted by specialist participants in the Gnangara Mound ERMP.

A number of monitoring programmes on changes in soil moisture and vegetation have been carried out on the Northern Swan Coastal Plain since 1966 by the former Forests Department and subsequently the Water Authority (Metropolitan Water Authority, 1985). These were located in the vicinity of Lake Gnangara, Lake Jandabup, Melaleuca Park, to the north of Yeal Swamp and at Lake Joondalup. Published literature includes discussion of the effects of a lowered water table on the natural vegetation of the Swan Coastal Plain (Aplin, 1976; Muir, 1983) and tree/shrub vulnerability (Dodd and Bell, 1982). In addition, as part of the present ERMP, Mattiske and McArthur have identified areas where vegetation may be sensitive to changes in the water table based on detailed mapping of landform with the relationship of native vegetation to these.

3.2 EFFECTS

To date, (Metropolitan Water Authority, 1985) the monitoring programmes have identified the following trends:

- While soil moisture levels have dropped in the 1970s and 1980s, fluctuations are part of a normal cyclic pattern.

- The plants which responded adversely included the older trees on wet and moist sites. Loss of vigour and death was off-set by an increase in younger seedlings and saplings.

- Trees favouring drier conditions increased in numbers.

- Species with a shallow root system fluctuated in numbers.

Aplin (1976) suggests that a lowered water table would result in a shift of vegetation towards the xeric end on the vegetation continuum. This would involve replacement of tree and shrub species on moister soil with species tolerant of drier conditions. A shift in swamp vegetation would also occur.

Muir (1983) and Dodd and Bell (1982) both suggest tree mortality may occur, with subsequent shift and replacement of species. These effects are only likely to occur, however, in the immediate vicinity of wells.

Mattiske and McArthur (pers. comm.) emphasise that where regional effects of drawdown are likely to be most significant (ie. lakes, swamps, depressions with water near or at the surface) shifts in vegetation are likely to occur, rather than critical and total mortality. In 'higher' landscape units such as the Jandakot unit, the effects of drawdown are likely to be minimal on a regional basis.

Therefore, the predicted effects on the more vulnerable moister sites will involve gradual change in vegetation towards partial or total replacement by species with higher drought tolerance.

On the basis of data presently available there are no predicted deleterious effects of a minor reduction in the water table level to the stability of soil units within the Gnangara Mound. The integrity of archaeological sites should therefore not be affected.

4.0 RECOMMENDATION

The vegetation monitoring programmes, mentioned above, will continue. The Water Authority is to consider the establishment of transects in locations appropriate for monitoring vegetation response to scheme operation (Metropolitan Water Authority, 1985). While there are no identifiable ill-effects of previous drawdowns to archaeological site integrity, the results of future monitoring programmes should be made available and assessed by an archaeological consultant or consulting body.

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APPENDIX G

SOCIAL ENVIRONMENT AND LAND USE STUDY

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1.0 INTRODUCTION

Peoples' concerns with the Water Authority of Western Australia (Water Authority) proposal to use the Gnangara Mound as a water supply source for the increasing urban population north of Perth are many and varied . They range from the need to provide water for a rapidly expanding urban community, through maintenance of groundwater availability for private rural users, to preservation of the local wetlands.

The Gnangara Mound is situated north of Perth and is bounded by the coast, Gingin Brook in the north, Ellen Brook in the east and the Swan River in the south. Existing schemes utilizing groundwater from the mound are Gwelup, Mirrabooka and Wanneroo. These schemes, in conjunction with surface water sources in the Darling Range, supply water to urban users north of the Swan River. New water sources will be required to fulfil the water supply needs of the urban development of the North-West Corridor. The Water Authority is examining the water management implications of further utilizing the groundwater of the Gnangara Mound, with the progressive development of the Pinjar, Yeal and Barragoon Schemes in line with this urban growth.

The following sections describe the existing social environment and land use of the region relevant to the groundwater schemes, and investigate sociological and land use trends. The groundwater schemes will be located within the Shires of Gingin, Chittering and Swan as well as the City of Wanneroo. The affected areas within the Local Government Authorities are virtually unpopulated, being either vacant Crown Land or State Forest No. 65. Therefore the discussion centres on the City of Wanneroo. Specific attention will be paid to the impact area of the Pinjar Scheme as it is the next proposed development.

2.0 REGIONAL STUDY AREA

2.1 POPULATION TRENDS AND URBAN DEVELOPMENT

The vast majority of people who will be affected by the groundwater developments live in the Wanneroo region. Hence, for the purposes of this sociological study, the Local Government Area of the City of Wanneroo has been regarded as the regional study area. The estimated resident populations for the City of Wanneroo from 1966 to 1984 are presented in Figure 10. This figure shows the population to have increased exponentially from 2,440 people in 1966 to 114,300 in 1984. This represents a mean average annual growth rate (AAGR) of 26.1%.

The majority of this increase can be attributed, particularly in recent years, to rapid urban development of the North-West Corridor. Since the late 1970s the growth rate has levelled off but is still significant with a mean AAGR from 1976 to 1984 of 10.8%. This compares with an AAGR for the State over the same period of 2.1%.

The North-West Corridor runs along the coast, covering an area of approximately 240km^2 and is bounded by Hepburn Avenue in the south, State Forest No. 65 and Yanchep National Park in the east and the City of Wanneroo boundary in the north (Figure 11). Most of the Corridor is presently undeveloped, though this is changing rapidly. Population growth in the Corridor has markedly exceeded original Metropolitan Region Planning Authority (MRPA - now part of the State Planning Commission - SPC) estimates. The 1978 North-West Corridor report projected a population of 70,000 by 1985 and 130,000 by 1993, however the former figure was far exceeded and current projections indicate that there will be 256,000 people in the North - West Corridor by the year 2001 (State Planning Commission, pers. comm.). The areas of proposed urban development within the Corridor are shown on Figure 5.

Population projections by the State Planning Commission estimate the population of the City of Wanneroo to have reached 260,000 by the year 2001 and 470,000 by the year 2021 (Figure 10). These projections are based on Treasury estimates for the State and Perth Statistical Division with small area forecasts also taking into account factors including existing trends and proposed land use (SPC, pers. comm.). The Water Authority projections utilized for estimating demand are derived from the State Planning Commission information (Town Planning Department, 1980) and also from Treasury estimates (Western Australian Treasury, 1982) (Water Authority, pers. comm.).

These projections are provisional and subject to revision (SPC, pers. comm.). The limitation of both sets of projections is that they are based on the theoretical development of the North-West Corridor. The corridor system of development for Perth was proposed in 1971 in 'The Corridor Plan for Perth' (MRPA, 1971), a detailed land use plan submitted to the Government by the MRPA. Subsequent documents including, the 'Planning Structure for the North-West Corridor' (MRPA, 1977) have been produced as the Plan was further refined. The longer the projection, the less accurate it becomes. In addition, the State Planning Commission are initiating a two year review of the existing corridor plan which could result in an amended development strategy (State Planning Commission pers. comm.).

However, as the Water Authority's planning process is on-going, the development of the Metropolitan area's water supply is reviewed prior to each stage. Thus, while maximum growth rate is allowed for in long term planning, any alteration in population growth and distribution is catered for by review of the short term plans based on 'most likely' population projections.

2.2 LAND USE AND ZONING

There are seven basic land zones within the Gnangara Mound: urban, urban deferred, industrial, rural, special rural, parks and recreation and State forest.

The majority of the mound lies within the boundaries of the Metropolitan Region Scheme (MRS) except for sections of the Shire of Gingin and Chittering which are covered by their respective Town Planning Schemes (TPS). The MRS is a statutory plan of the broad scale land zoning of an area. The MRS is currently under review by the State Planning Commission.

All local authorities within the Perth Region are obliged to prepare a Town Planning Scheme which is submitted to the State Planning Commission for examination. Most of the land administered in the Gnangara Mound is subject to a Regional Planning Scheme under the co-ordination of the State Planning Commission, except for the Shire of Gingin.

Figure 5 outlines the various land zones on the Gnangara Mound. For further detailed information on the land use of a Local Authority, the reader is referred to the Town, District or City Planning Schemes (PS) on Table 1.

These Town Planning Schemes are available for perusal at Shire, Town and City Council Offices and at the State Planning Commission (Head Office), Perth.

The main population increase in the City of Wanneroo has been within the North-West Corridor. Development of the North - West Corridor has been guided by the Structure Plan of the North-West Corridor outlined by the Metropolitan Region Planning Authority (MRPA, 1977).

The Structure Plan is a non-statutory plan which aims to portray the preferred, development of the North-West Corridor. The Structure Plan, outlining the various zonings, is also currently being reviewed by the State Planning Commission.

TABLE 1

TOWN PLANNING SCHEMES CURRENTLY IN OPERATION

LOCAL AUTHORITY	CURRENT SCHEME IN OPERATION	APPROVED BY MINISTER
Shire of Chittering	*	
Gingin	TPS No. 2	April 1972
Swan	TPS No. 9	December 1985
Peppermint Grove	TPS No. 3	May 1985
City of Bayswater	TPS No. 13	September 1972
Belmont	TPS No. 6	October 1972
Nedlands	TPS No. 2	April 1985
Perth	CPS	December 1985
Stirling	DPS No. 2	September 1985
Subiaco	TPS No. 3	March 1984
Wanneroo	TPS No. 1	August 1972
Town of Bassendean	TPS No. 3	December 1982
Claremont	TPS No. 3	May 1985
Cottesloe	TPS No. 1	November 1976
Mosman Park	TPS No. 1	May 1972

* The Shire of Chittering does not have a gazetted Town Planning Scheme at present but one is currently before the Minister for Town Planning.

2.2.1 State Forest

Almost all of the northern coastal area of State forest is located within or adjacent to the Perth Metropolitan area and therefore is subject to strong and increasing demands for the resources it provides.

A multiple use policy was adopted in 1976 by the Forests Department (Forests Department, 1981), now part of the Department of Conservation and Land Management - CALM. The management objectives which influence land use in the area include timber production, groundwater yield, protection of water quality, recreation, conservation of flora and fauna, scientific investigation, mining, and protection of the forest from insects, fire and disease.

Within the Gnangara Mound, State forest exists as two separate major units:

- Gnangara Area - Bounded by Commonwealth Reserve (RAAF bombing range) and vacant Crown Land to the northeast, State Planning Commission holdings to the south and private property adjacent to the remainder.

- Yanchep and Pinjar Area - Bounded by Yanchep National Park in the west, Commonwealth (RAAF) land in the east and private property on the remaining boundaries.

Except for a small area of land to the west of Lake Joondalup (State Forest No. 69), all land administered by CALM in the Gnangara Mound area is State Forest No. 65, dedicated in 1959 under the Forests Act 1918 (Forests Department, 1981) or conservation reserves.

State Forest No. 69 covers an area of approximately 12ha and is the main local seed orchard for Pinus pinaster on the Northern Swan Coastal Plain.

Pine plantations currently cover approximately 20,000ha of the Gnangara Mound and extensive areas of Pinus pinaster have been grown mainly on the Spearwood and Bassendean Dunes, where suitable sites are defined by depth to limestone or the water table (Havel, 1975). Pine plantations provide quick growing timber for many uses including building and panelling, particle board and fence posts. A detailed analysis of the pine plantations of the Northern Swan Coastal Plain is contained in Appendix B of this ERMP.

2.2.2 Rural and Special Rural

Within the Gnangara Mound area agricultural pursuits include market gardening, wholesale and retail nurseries, poultry (including chicken and egg production), viticulture, orchards and general farming activities including sheep, cattle and pig husbandry and cropping. Specialist pursuits undertaken include flower, mushroom, strawberry and gourmet pheasant production.

In addition, numerous special rural zones have been established in the City of Wanneroo, one in the Shire of Gingin and three within the Shire of Swan. The Shire of Gingin's development (Woodridge) is located adjacent to Lancelin Road, south of Moore River and is some 18km by road from Guilderton. The lot sizes range from 2 to 5ha with in excess of 300 lots being created. The three special rural zones within the Shire of Swan are located on the western side of West Swan Road within the locality of West Swan and Henley Brook. The special rural zone within the proposed Pinjar Scheme lies in the southwest corner of the scheme and is bounded by Wanneroo Road and Flynn Drive.

The objective of these special rural zones is to create lots, within predominantly rural areas, suitable for a specific purpose eg. hobby farm, rural retreat, horse breeding. Provision for the retention of the rural landscape and amenity is a major objective. Each lot is approximately 2ha in area and its utilisation should be compatible with low water use ($1,500m^3$/lot/yr). This quantity of water is sufficient for normal domestic requirements; including a domestic garden, some stock watering and a small irrigated area (usually less than 0.1ha).

The rural wedges, lying outside the four Perth urban corridors, are subject to increasing pressure as Perth's urban population increases. The conflicts arising from competing land use in the rural zone are being reviewed by the State Planning Commission in an attempt to protect the groundwater aquifer and agriculturally viable and productive areas from incompatible developments.

2.2.3 Urban Areas

Section 2.1 outlines the population trends and urban development within the City of Wanneroo. Urban development in the study area imposes constraints on the surrounding land. Also, as the land changes from say rural to urban pursuits, there is a resultant alteration in water usage.

The North-West Corridor has developed at a rate that has surpassed the State Planning Commission's population estimates. The North - West Corridor has certain perceived attributes that will continue to attract people to the area, like proximity to the coast, in conjunction with adequate public infrastructure.

Regional Centres have been developed within the project area to service both the urban and rural components of the population with the necessary goods and services (eg. Joondalup).

As shown in Figure 5, a large portion of land to the west of Lake Joondalup is deferred urban and will eventually be released to the public for urban development.

Public utilities service the urban areas of the Gnangara Mound, but in doing so they become a land use in their own right. Table 2 outlines the authorities responsible for the construction and maintenance of these services.

TABLE 2

AUTHORITIES RESPONSIBLE FOR PUBLIC UTILITIES
ON GNANGARA MOUND

UTILITY	AUTHORITIES RESPONSIBLE
Roads	MRD, CALM, Water Authority, Local Government Authorities
Powerlines	SECWA
Water pipelines/Wells	Water Authority
Gas Pipelines	SECWA
Airstrips	CALM, Commonwealth of Australia
Telephone Lines	Telecom, CALM
Radio Transmitters	CALM, Water Authority

Key: CALM - Department of Conservation and Land Management
MRD - Main Roads Department
SECWA - State Energy Commission of Western Australia
Water Authority - Water Authority of Western Australia

Source: Forests Department, 1981

2.2.4 Mining, Extractive Industries and Industrial Zones

2.2.4.1 Limestone Resources

The importance of the Tamala Limestone as a resource is evidenced by the fact that the known reserves in the Gnangara Mound are virtually all subject to mining tenements under the Mining Act (1978-1983).

Numerous mineral leases granted under the Mining Act occur in State Forest No. 65, the most common being limestone extraction for lime manufacture, building stone and for roadworks.

The extent of the limestone resource within State Forest No. 65 is known from assessment surveys by the Geological Survey of Western Australia and from investigations by two major cement companies: Swan Portland Cement and Cockburn Cement. Total proven reserves of high quality limestone (ie. greater than 80% calcium carbonate - $CaCO_3$) within State Forest No. 65 are in the order of 66 million tonnes ($\times 10^6$t) (Department of Mines, pers. comm.). At present there is no extraction of limestone within the State Forest No. 65 boundary.

The area west of Lake Pinjar is the only sizeable reserve of high grade limestone to the north of the Perth Metropolitan area that is currently being worked. It is largely controlled by Swan Portland Cement and Cockburn Cement. Total reserves of high quality limestone are in the order of 70 $\times 10^6$t. Lot 22 Flynn Drive (owned by the Industrial Lands Development Authority) has proven reserves of a further 14 $\times 10^6$t of roadbase grade limestone (65-80% $CaCO_3$). There is future potential for identifying further high grade limestone in the area according to the Geological Survey.

2.2.4.2 Sand Resources

Two geological units, the Tamala and Bassendean Sands have potential for commercial exploitation. The Geological Survey of Western Australia have indicated that the Pinjar area has the potential to supply large quantities of sand of all qualities and specifications.

To date neither of these two resources is being utilised in the Pinjar area but as workings at Landsdale and Wangara (to the north and south of Gnangara Road) come under increasing public pressure, access to other resources may become increasingly important.

At present, nine sand quarries operate within a 3.5km radius of Gnangara Lake with another three areas approved, but not yet operating.

2.2.4.3 Industrial Zones

As outlined in Figure 5 there are nine main industrial locations in the Gnangara Mound area.

These are located in the following areas:

- o Gnangara Road, to the southwest of Gnangara Lake
- o Wanneroo Road, opposite Walluburnup Swamp
- o Osborne Park
- o Malaga Park
- o Claisebrook
- o Balcatta
- o Ashfield Bayswater
- o Leighton/North Fremantle
- o Subiaco

Generally the major industrial zones are confined to distinct areas and are often located either close to basic raw materials or major transportation routes.

2.2.5 Parks and Recreation

The System 6 Study Report by the Department of Conservation and Environment (1983) recommended a number of reserves in the project area for conservation of flora and fauna, wetlands and recreational potential. These areas include existing National Parks, reserves vested in the Shires or other Government Departments and privately owned freehold land.

The major recreational outlets within the Gnangara Mound area cater for both passive and active recreational activities. Large areas of land have ben set aside as public open space. The most important open space and recreation areas include State Forest No. 65, coastal areas and National Parks, reserves, wetland areas and the Swan River foreshore (Figure 5).

2.3 GROUNDWATER USERS

2.3.1 Urban

The main urban development in the City of Wanneroo has been the North-West Corridor. The water supply requirement of the North-West Corridor is currently serviced by groundwater from the Wanneroo and Mirrabooka Schemes.

The further expansion of these existing schemes is limited by their ultimate yield and environmental and social factors. New supply sources must be found if the growth of the urban population continues. Given current growth estimates, 58 million cubic metres per year (58 x $10^6 m^3$/yr) will be required by the year 2001, and 75 x $10^6 m^3$/yr by the year 2008. The current peak supply capacity to the North-West corridor is 0.21 x $10^6 m^3$/day. It is anticipated that peak demand will exceed this level of supply by the end of 1989 (Water Authority, pers. comm.).

Groundwater in urban areas is also exploited by domestic wells. It has become increasingly popular over the last decade for urban dwellers to sink private wells to water their lawns and gardens rather than using scheme water. The Water Authority estimate an average one in seven houses have domestic wells in the existing urban areas of the North-West Corridor. Using State Planning Commission projections for the North-West Corridor, and an average household size of 3.0 (from Water Authority planning data, based on a nett occupancy rate for the North-West Corridor), this represents a further 8,705 domestic wells by the year 2001. Using Water Authority estimates of useage rates per well, this represents an increase in domestic groundwater demand from approximately 2.7 x $10^6 m^3$/yr to 7.1 x $10^6 m^3$/yr.

The other existing urban area in the City of Wanneroo is the actual township. The estimated population of the township is 4,000 people. Under existing zoning, expansion of the township is limited and the maximum capacity for the township will be approximately 5,100 people (State Planning Commission, pers. comm.). Using the same service level assumptions as for the North-West Corridor, this would result in an increase in domestic urban groundwater consumption in Wanneroo township from 0.77 x $10^6 m^3$/yr to 0.99 x $10^6 m^3$/yr.

2.3.2 Agriculture

The major agricultural activity in Wanneroo is intensive horticulture, predominantly for vegetable production. The City of Wanneroo is an important area for market gardening, due to its close proximity to the Metropolitan markets. During the 1982/83 season, 36% of the Metropolitan market garden area was in the City of Wanneroo. It is a particularly significant growing area for broadleaf vegetables and currently produces 58% of the total lettuce crop in Western Australia for example (Shire of Wanneroo, 1985a). Intensive agriculture is the largest private user of groundwater from the Gnangara Mound.

Other commercial agricultural activities all require a water supply, and private wells are a significant source of supply.

The irrigation requirement for vegetables has been estimated by the Department of Agriculture to be, on average, 15,000m^3/ha/yr, and 18,000m^3/ha/yr is desirable for broadleaf vegetables. The irrigation supplies required by market gardens are currently serviced by private groundwater wells. Given that approximately 718ha in the City of Wanneroo are irrigated for market gardening, an estimated 10.7 x 10^6m^3/yr of groundwater is required to maintain the existing level of vegetable production. The required increase in the area of market gardens in the City of Wanneroo to supply the population of Perth to the year 2018 is estimated, by the Department of Agriculture to be 200ha (Shire of Wanneroo, 1985a). This assumes a Western Australian population of 2,000,000 by the year 2000 and 'all things being equal'. To maintain the existing level of production will require an estimated 13.7 x 10^6m^3/yr of groundwater.

The City of Wanneroo has estimated that there are about 14,000ha of land potentially suitable for horticulture within the city boundaries. Although large portions of this land have already been alienated for other purposes, there is no shortage of land suitable for horticulture. Access to economic supplies of irrigation water is likely to be the limiting factor.

There is a particularly large potential market for export vegetables. Markets for other irrigated crops, such as flowers, are also opening up. The combined potential for irrigated horticulture on the Swan Coastal Plain may be 4000 to 5000ha over 10 years, of which perhaps 2000ha might be located in the Gnangara Mound area (Department of Agriculture, estimate). The development of these new markets and the distribution of production areas within the State is still uncertain however.

There have also been recent initiatives, prior to the recent extension of the Wanneroo Groundwater Area (WGA) for large scale irrigation of lucerne and turf farms in the Lake Carabooda area. One proposal alone has the potential to use up to 1.5 x 10^6m^3/yr of water.

Notwithstanding export and other developments, it has been estimated that an extra 200ha of irrigated development will be required in the Wanneroo area to supply vegetables to the population of Perth over the next 30 years (Shire of Wanneroo, 1985a). At an irrigation rate of 15,000m^3/ha/yr this would require an additional allocation of 3 x 10^6m^3/yr of groundwater over the next 30 years.

The rural subdivision policy adopted by the City of Wanneroo in 1978 proposed an area of about 1,100ha immediately south of Flynn Drive for market gardening. Although it is unlikely that the necessary groundwater supplies could be obtained from a concentrated area without adverse effects, the figure of 1,100ha can be regarded as an indication of the total new area of market gardens considered desirable by the City of Wanneroo.

The existing groundwater allocation policy recognises the importance of market gardening in Wanneroo and seeks to ensure that provision is made for it in the future. If an additional 1,100ha were developed in the WGA, for local and export markets, then an additional 16.5 x $10^6 m^3$/yr would be required. This is a 65% increase over the present estimated usage in the WGA. If 2,000ha were developed on the Gnangara Mound, the total demand for groundwater would be some 30 x $10^6 m^3$/yr, or about the same order as the public demand, producing a combined total in excess of the calculated safe yield.

This quantity can be compared with the currently unused portion of the groundwater allocation which amounts to 12 x $10^6 m^3$/yr. If this was used solely for market gardening, an additional 800ha could be irrigated.

Although these private demand figures are indicative only, they illustrate the large potential demand and the need for careful consideration and management of the various elements of that demand.

Further evaluation of the potential horticultural demand will be provided by a study recently commissioned jointly by the Water Authority and the Department of Agriculture.

2.3.3 Special Rural Zones

There is an increasing trend in the community for people working in the Metropolitan area to move out of the urban residential developments onto larger blocks of land. The reason is usually to achieve a perceived 'better quality of life' for themselves and their children whilst still retaining ready access to the Metropolitan area.

The 'Special Rural Zones' policy was formulated as an answer to the increasing pressure for rural living by people not wishing to be engaged in agricultural or other rural pursuits (Shire of Wanneroo, 1985a). The special rural zone was based on the following set of criteria:

- o Rural lots of approximately 2ha
- o These lots must satisfy demand and still maintain the rural character of the Corridor Plan's (1971) rural wedges
- o Zone sites must avoid mineral resources or land particularly suited for agriculture
- o Zones must not detract from any special native feature
- o Zones must be of a size to accommodate approximately 50 lots.

(Shire of Wanneroo, 1985a).

Currently a total of 483 lots have been approved in six special rural zones (Shire of Wanneroo, 1985a). Demand has been below expectation, with those lots near Wanneroo township being the most popular due to proximity to urban facilities.

Within the existing zoning policy, there is limited potential for further special rural zones. Approximately 1,100ha were proposed as 'special rural zone and market gardening' in the then Shire of Wanneroo's Rural Subdivision Policy (1978) and this includes approximately 147 of the abovementioned approved lots.

Groundwater allocation to each special rural lot is 1,500m^3/yr (Water Authority, pers. comm.). At this rate, current total groundwater consumption by special rural users would be approximately 7.2×10^5 m^3/yr if all approved lots were populated. This could eventually rise to approximately 1.5×10^6 m^3/yr within the existing zoning policy.

It should be noted however that there is some pressure to develop agricultural pursuits on these lots. Such development is constrained however by the limited allocation of groundwater.

2.3.4 Recreation and Tourism

A significant use of groundwater in the City of Wanneroo is the reticulation of playing fields for active recreation and sporting activities. Table 3 outlines the number of active recreational facilities in the City and their estimated groundwater usage per year based on water allocation estimates from the Water Authority. These playing fields provide facilities for a large number of community groups (Table 4) as well as being aesthetically pleasing additions to the urban environment. They are also important areas for passive recreation for the surrounding communities.

Based on the population projections for the North-West Corridor (Section 2.1), to maintain the existing level of service (Table 3), there will be a requirement for 407 ovals, 47 bowling greens, 245 tennis courts and 8 golf courses by the year 2026. This will require a total water allocation of approximately 8.2 x $10^6 m^3$/yr.

Parks and gardens are also reticulated throughout the City, to provide areas for passive recreation. They also add to the perceived 'quality of life' in the urban environment. There are currently 24 reticulated council parks and gardens covering approximately 450ha in the City of Wanneroo (City of Wanneroo, pers. comm.). Utilizing the same reticulation requirements as for ovals, this results in an annual water requirement of approximately 3.4 x $10^6 m^3$. Assuming the existing level of service is maintained, this requirement would increase to approximately 7.3 x $10^6 m^3$/yr by the year 2000 and 11.5 x $10^6 m^3$/yr by the year 2026.

Wetlands and their associated bushland form equally important recreation areas. They provide passive recreation areas for a cross section of the community. Community groups that may have specific interests in the wetlands include birdwatchers, naturalists, bushwalkers, conservationists, picnickers and people who simply appreciate the natural environment.

The forest is another important area for recreation. Both natural vegetation and pine plantations of State Forest No. 65 (Figure 4) are utilized for both active and passive recreation by members of the public. The predominant activities are bush walking and picnicking. Other activities in the forest are trial bike riding and wood gathering. There are specific areas in the forest set side for these purposes. Currently there is an area of 400ha set aside in State Forest No. 65 for trial bike riding and three designated domestic wood gathering areas to the north of Gnangara Road (CALM, pers. comm.). As roads in State forest are gazetted as public roads, off road vehicles are not permitted to use them. CALM have authority to limit road access in the forest and any car rally events must be approved by the Department (CALM, pers. comm.).

Yanchep National Park is a popular tourist attraction that focusses on natural features such as bushland, lakes and caves. Another natural attraction is Neerabup National Park. There are also a number of commercial recreational attractions set up in the City of Wanneroo including Atlantis Marine Park, Dizzylamb Park, the Wanneroo Lion Park, Botanic Golf Gardens and Wanneroo Raceway. These facilities while having a relatively small aggregate use, still rely on an assured source of groundwater to continue functioning.

The use of recreational areas in the City of Wanneroo is not confined to people in the local area. These features are close enough to Perth to encourage their use by the general public for a variety of sporting and passive recreational activities.

TABLE 3

EXISTING SPORTING FACILITIES
IN THE CITY OF WANNEROO
REQUIRING RETICULATION
1985

FACILITY TYPE	TOTAL NUMBER actual (cumulative)	WATER ALLOCATIONS (m^3/facility/yr)	TOTAL WATER ALLOCATION (m^3/yr)	LEVEL OF[1] SERVICE (No. of persons/facility)
Oval				
Football	39(39)	18,750	731,250	2,900
Cricket	14(53)	11,250	157,500	2,100
Baseball	2(55)	9,000	18,000	2,000
Rugby	4(59)	9,750	39,000	1,900
Soccer	4(63)	6,750	27,000	1,800
Lacrosse	1(64)	5,250	5,250	1,800
Hockey	2(66)	4,500	9,000	1,700
Junior Oval	37(103)	4,450	164,650	1,100
Teeball	1(104)	4,400	4,400	1,100
Outdoor Facility				
Bowling Greens	12	1,700	20,400	9,500
Golf Courses[2,3]	2	450,000	900,000	57,000
Tennis Courts	62	255	31,875	900
TOTAL				**2,108,325**

1. Derived from the total population of the City of Wanneroo divided by the cumulative number of facilities (shown in parentheses) that can be used for the sport. For example, Teeball can also be played on football ovals, so while there is only 1 Teeball oval, there are potentially 104 facilities for playing Teeball.
2. Calculations based on 18 holes.
3. Proportion of courts which are grassed is not known i.e. assuming 50% are grassed, 62 is the total number of tennis courts requiring reticulation.

N.B. This includes Education Department facilities.

Sources: Community Facilities Study. Shire of Wanneroo, 1985.
Wanneroo Groundwater Scheme Review '85.
Metropolitan Water Authority, 1985.
Department of Youth, Sport and Recreation.

TABLE 4

EXISTING CLUBS IN THE
CITY OF WANNEROO UTILIZING FACILITIES
THAT REQUIRE RETICULATION
1985

CLUB	NUMBER
Football	32
Cricket	15
Base/Tee/Softball	8
Soccer	12
Lacrosse	1
Hockey	5
Athletic	11
Tennis Clubs	10
Bowling	5
Golf	6
TOTAL	108

Source: Community Facilities Study. Shire of Wanneroo, 1985.

3.0 LAND USE SURVEY

3.1 INTRODUCTION

The next groundwater development being considered by the Water Authority in the Gnangara Mound, is the Pinjar Scheme. For the purposes of studying the land use and sociological impacts of this scheme, a Land Use Survey Area (LUSA) was defined. This area was regarded as the region where the social environment may be directly affected by the implementation of the Pinjar Scheme. The LUSA included the majority of rural and special rural properties east of the North-West Corridor and north of Clarkson Avenue, and excluded State Forest No. 65. The LUSA boundary was extrapolated to what were considered to be realistic and easily definable 'social boundaries' such as Wanneroo Road in the west and State Forest No. 65/Crown Land in the east. The LUSA coincided with the 1985 land use survey undertaken by the Water Authority (hence its title), and closely approximates the Pinjar/Carabooda area discussed in the main text.

3.2 LAND USE

A land use survey was undertaken in 1978/79 to assess current and future land use in the Pinjar Scheme area and to estimate both current and future water requirements for all land uses in the area. These data were assessed to substantiate the Metropolitan Water Authority's proposal for a Public Water Supply Area (PWSA), as well as providing an estimation of the existing and likely future pollution sources in the area proposed as the Underground Water Pollution Control Area (UWPCA). The survey was undertaken in conjunction with the Departments of Conservation and Environment, and Agriculture and the Shires of Swan, Wanneroo and Chittering.

The survey identified five major land zones in the Pinjar area: Crown Land, State Forest No. 65, Lake Pinjar, developed areas and wetlands. Land usage to the west of Lake Pinjar included industrial use (limestone quarrying), agricultural pursuits (market gardens, irrigated crops, chicken farms), and recreational venues (Lion Park, Golf Club, Motor Racing circuit and mini bike club).

The wetlands includes Lake Wilgarup, Carabooda, Nowergup and Neerabup. Major land usage in the wetland area includes market gardens, irrigated crops, chicken farms and stock husbandry (pigs and cattle). A summary of the land use survey is show in Table 5, reproduced from the Metropolitan Water Authority, 1985a.

A similar land use survey has been undertaken from air photo interpretation and a mosaic of photographs in 1985 (Water Authority, 1985). Although the survey area was not identical with the 1978 area (the 1985 survey excluded State Forest No. 65 and Crown Land), some interesting trends have developed. Utilising information gathered for the Land Use Survey conducted by the then Shire of Wanneroo in February 1985 (Shire of Wanneroo, 1985b) and the accompanying 1:10,000 maps, it was possible to ascertain the number of lots under various land use in the survey area (Table 6).

Tables 5 and 6 illustrate the emphasis on intensive market gardening in the Pinjar area. South of Flynn Drive, the lot sizes are smaller, with the market gardener growing a diverse array of crops, usually to supply the Perth Metropolitan area. Market gardens to the north of Flynn Drive, near Carabooda Lake have larger lot sizes (average 20ha) producing specialist crops, usually on a seasonal rotation basis.

Although the area surveyed was smaller by some 27,500ha, the groundwater demand in the intervening six years increased some 200% (from $3.062 \times 10^6 m^3/yr$ to $9.175 \times 10^6 m^3/yr$). This is shown in Table 7, and in Figure 12 (the 1985 total survey area was 11,000ha compared to 38,500 in 1978/79). These figures are based on estimates of water used by different crops, as follows:

- Vegetables/Avocados utilising $15,000 m^3$ water/ha/yr
- Lucerne/Turf Farm utilising $12,000 m^3$ water/ha/yr

3.3 GROUNDWATER USERS

3.3.1 Overview

The LUSA is basically rural, with the major land uses being agricultural pursuits, recreation or industrial activities. Existing industrial development is confined to quarrying for limestone, although there is a proposed industrial area north of Flynn Drive in the Shire of Wanneroo Rural Subdivision Policy, 1978 (Shire of Wanneroo, 1985a). The following recreation venues are located within the LUSA; a Lion Park, Dizzylamb Park, a golf course, a motor racing circuit and a mini bike club.

The lots within the LUSA are not all the same size. The above table has been included to illustrate that the Pinjar area is characterised mainly by uncleared blocks or market gardening.

Natural features of interest in the LUSA include the remaining native bushland, the chain of wetlands that run north/south to the west of Lake Pinjar, Lake Pinjar itself and the limestone caves to the north within Yanchep National Park.

Agriculture is an important activity in the LUSA, with approximately 50% of the privately owned lots being actively used for agricultural purposes. This equates to approximately 5.5% or 609ha of the LUSA. The remainder of the private lots are either bush or cleared but not being actively utilized at the present time.

TABLE 5

PINJAR LAND USE SURVEY (1978/79) - GROUNDWATER CONSUMPTION

LOCATION	AREA	RATE OF CONSUMPTION (m^3/yr)	ANNUAL CONSUMPTION	(m^3/yr)
EXISTING LAND USE				
Crown Land	15,500ha			
State Forest	13,300ha			
Lake Pinjar	2,950ha			
. Market Gardens	3ha	15,000	45,000	
. Private Wells	28	2,000	56,000	
Developed Areas (High Lands)	4,000ha			
. Market Gardens	44ha	15,000	660,000	
. Irrigated Crops	125ha	15,000	1,875,000	
. Golf Course	25ha	10,000	250,000	
. Chicken Farms	11 sheds	10,000	110,000	
. Private Wells	33	2,000	66,000	
			3,062,000	
Total abstaction within Provisional PWSA Boundary				3,062,000
Wetlands	2,350ha			
. Market Gardens	190ha	15,000	2,850,000	
. Irrigated Crops	14ha	15,000	210,000	
. Chicken Farms	7 sheds	10,000	70,000	
. Private Wells	92	2,000	184,000	
			3,314,000	
Total abstraction within Survey Area				6,376,000
ANTICIPATED LAND USE				
An additional 130ha of market garden/irrigated crop, to the year 2000	130ha	15,000	1,950,000	
Total Anticipated Demand by the year 2000				8,326,000

Source: Metropolitan Water Authority, 1985a

TABLE 6

LAND USE BREAKDOWN
BY BLOCK WITHIN
LUSA

LAND USE OF LOTS	NUMBER OF LOTS	PERCENTAGE
Bush	131	33.0
Cleared	63	16.0
Fruit Trees	1	0.5
Horses	32	8.0
Market Gardens	88	22.0
Nursery	4	1.0
Poultry	9	2.0
Rural Areas	63	16.0
Vines	1	0.5
Pigs	3	1.0
TOTAL	395	*100.00

*Data may not total 100% due to rounding factor

Data extracted from 1:10,000 maps - Shire of Wanneroo, 1985b

3.3.2 Agricultural Groundwater Users

The agricultural groundwater users in the LUSA all require groundwater for irrigation and domestic purposes. A recent survey of the LUSA by Water Authority and Deparment of Agriculture personnel, indicated that an estimated 8.8 x $10^6 m^3/yr$ of groundwater was required to maintain the existing level of agricultural production from approximately 609ha of irrigated rural land. Table 7 outlines the area under irrigation for the production of vegetables, lucerne, poultry, avocados, citrus fruit, pasture, wildflowers and turf grass.

Lake Pinjar itself is a seasonal lake which is utilized for dry pasture in the summer months. Very little intensive agriculture is carried out due to flooding in winter. Under existing subdivision policy, the majority of the land in the LUSA north of Flynn Drive is proposed rural lots with a minimum size of 20ha. There are smaller lots around the chain of lakes and these are sought after by market gardeners, due to the soil and moisture content being suitable for vegetable growing. Much of the land in the LUSA is not currently utilized.

No estimate is available for the future extension of market gardening, but if all of the estimated increase in market garden area for the City of Wanneroo to the year 2018 (200ha) occurred in the LUSA, the groundwater demand would increase from its current $9.0 \times 10^6 m^3/yr$ to $12.0 \times 10^6 m^3/yr$.

3.3.3 Special Rural Users

There is presently one approved special rural area in the LUSA. This consists of 147 lots, although currently only approximately 100 lots are developed. The area will have an estimated total groundwater requirement of $2.2 \times 10^5 m^3/yr$ based on the Water Authorities allocation of $1{,}500 m^3$/lot/yr. The existing area is part of a special rural zone proposed in the Shire of Wanneroo's Rural Subdivision Policy, 1978 (Shire of Wanneroo, 1985a).

TABLE 7

ESTIMATED GROUNDWATER USAGE BY
AGRICULTURAL ACTIVITIES IN THE LAND USE SURVEY AREA (LUSA) 1985

AGRICULTURAL ACTIVITY	AREA (ha)	% OF LUSA*	% OF IRRIGATED	GROUNDWATER DEMAND AGRICULTURAL AREA ($x10^6 m^3/yr$)
Vegetables	416.4	3.8	68.4	6.2
Lucerne	80.4	0.7	13.2	1.0
Avocados	69.6	0.6	11.4	1.0
Turf Farm	21.8	0.2	3.6	0.3
Poultry	-	-	-	0.2
Other (eg.citrus, wildflowers, nurseries and pasture)	20.5	0.2	3.4	0.2
TOTAL	608.7	5.5	100.00	9.0

* % of the total area surveyed. The rest of the area is currently either uncleared, non-irrigated, cleared land or a golf course.

Sources: Water Authority of Western Australia
Department of Agriculture

3.3.4 Recreational Groundwater Use

Groundwater use by active recreational facilities in the LUSA is relatively low, due to the few facilities in the area. There are only seven ovals in the entire rural area of the City of Wanneroo, and none of these are within the LUSA (Shire of Wanneroo, 1985; Water Authority, pers. comm.). There is however, one golf course in the LUSA. This covers an area of approximately 48ha and has an estimated groundwater requirement of 360,000m^3/yr. It is not possible to predict the future increase of recreational facilities requiring reticulation in the LUSA.

The LUSA is bounded by the chain of linear lakes and wetlands that run north/south, to the west of Wanneroo Road. This chain has important sociological value as well as environmental value. The wetlands provide a breeding habitat for many species of native fauna, particularly birds. For this reason, plus the inherent aesthetic appeal of inland water bodies, the wetlands are areas of interest for many groups in the community including birdwatchers, conservationists, naturalists, bushwalkers and picnickers. In addition, the wetlands play an important role in the aesthetic character and ecological makeup of the Swan Coastal Plain and as such, are of interest to members of the public who value their existing regional environment.

4.0 IMPACTS OF THE DEVELOPMENT ON THE SOCIAL ENVIRONMENT

4.1 URBAN GROWTH AND GROUNDWATER USE

Future urban growth in the City of Wanneroo is based in the North-West Corridor. There is a primary water supply requirement if this or any other major urban development to the north of Perth is to proceed. The population of the North-West Corridor is projected to grow to approximately 256,000 people by the year 2001 (State Planning Commission, pers. comm.). The Water Authority estimates that a water supply of approximately 58 x $10^6 m^3$/yr will be required to service that population.

The Water Authority proposes to meet that water supply requirement by utilising groundwater from the Gnangara Mound. Existing urban areas in the North-West Corridor are already supplied by groundwater from the mound via the Wanneroo and Mirrabooka Schemes.

An assured water supply is a prerequisite for urban development. Hence, without the groundwater developments, there are two options; to restrict development of the North-West Corridor, or to obtain a water supply from other sources. The first is an area of Government policy outside the brief of this document. The second option is feasible, depending on the willingness of the community to pay for alternative developments. An assessment of the alternatives is presented in Section 4.0 of the main text of the ERMP.

The need to protect the groundwater resource will continue to constrain urban development on the Gnangara Mound. Fortunately, urban growth is planned for the coastal corridor where it will not conflict with groundwater management objectives.

The other potential impact of the Gnangara Mound development in urban areas is on domestic wells. These wells are used primarily for watering private lawns and gardens. It is estimated that by the year 2001 there will be approximately 14,200 domestic wells in the North-West Corridor requiring $7.1 \times 10^6 m^3/yr$ of groundwater. This assumes continuation of the existing level of service. The North-West Corridor is down-flow of the proposed Gnangara Mound developments. As the developments will largely utilize groundwater which is presently used by evapotranspiration, they are not expected to affect urban wells. However, the on-going investigation and monitoring associated with the Gnangara Mound development may reveal a need for more conservative management of the groundwater resource.

The depth to groundwater in domestic wells along the coastal corridor is not expected to be affected by the Gnangara Mound development, as the zone of drawdown due to the project does not coincide with the urban area. No impact is expected on domestic wells in Wanneroo township, due to their remoteness from the proposed wellfields.

4.2 GROUNDWATER USE IN RURAL AREAS

In the rural areas of the City of Wanneroo groundwater supplies irrigation and domestic needs. Both market gardening and horticulture require intensive irrigation. The expansion of market gardening and other irrigated agricultural activities in the City of Wanneroo is dependent on the availability of water. There is an oversupply of suitable land, given enough water.

On-going investigation and monitoring on the Gnangara Mound may indicate the need for more conservative management as more groundwater users draw on the resource. This management, while vital in ensuring the long term security of the resource, may include steps such as monitoring of wells and managing groundwater allocation to new developments, including agriculture. This may impact agricultural producers who wish to expand their interests and perceive such management strategies as an intrusion and constraint on their activities.

Specific management strategies may be required in sensitive areas, for example near wetlands, where changes in the level of the water table will have impacts on the natural environment. This could include limiting groundwater abstraction, as has occurred in the Wanneroo PWSA around Lake Jandabup. While necessary to protect the environment, this can impact the local landowners who wish to utilize more than their allocation for the agricultural activities that contribute to their livelihood.

The abstraction of groundwater by the Water Authority is expected to cause some localized drawdown of the water table, principally in the vicinity of the production wells. Computer modelling has produced a series of probable drawdown contours for the Pinjar Scheme. The impact of this drawdown on agricultural groundwater users could be a drop in the groundwater table. This impact, in the majority of cases, would not be significant as only users close to the production wells who draw water from close to the top of the water table would be affected. Most users would have their abstraction point well below the water table to allow for localised drawdown and seasonal variations. It is expected that the drawdown coinciding with agricultural users will be approximately 0 to 2m and any impacts will be confined to those users in the LUSA.

Lake Pinjar is a seasonal lake, which is used for summer pasture due to its susceptability to flooding in winter. The impact of the Pinjar Scheme on the lake would be to lower the water table in the vicinity between 0.5 and 2.5m, thus reducing the degree of flooding. This may benefit landowners in the winter but may deprive them of natural summer pastures.

4.3 SPECIAL RURAL ZONES

As special rural users are already limited to a groundwater allocation of approximately 1,500m^3/lot/yr and their total abstraction is relatively low, it is unlikely that the Gnangara Mound developments will have any additional impact on their water supply. This limit will be maintained however.

If any special rural users abstract groundwater close to the top of the water table they may have to increase the depth of their wells if water tables drop. This impact will be confined to those users in the special rural zone in the LUSA, where the drop in the water table is estimated to be less than 1.0m. No estimate of the number of people likely to be affected is available. Only 147 special rural lots are approved at present. The impact is likely to be low as the majority of users would have their wells constructed such that the abstraction point is well below the water table.

4.4 RECREATION

Reticulation of playing fields for sporting activities and parks and gardens for passive activities are the two major uses of groundwater for recreation in the Wanneroo region. These uses benefit the community by contributing to the perceived 'quality of life' of the urban environment. However, if there is a requirement for more conservative management of the groundwater resource, these uses may be impacted by the controls placed on groundwater availability. These controls could take the form of a stricter reticulation regime and overall reduction in the amount of water used.

As the abstraction of groundwater from the Gnangara Mound may influence water table levels, there is a potential impact on the lakes and wetlands in the vicinity. This impact is significant from a social as well as ecological viewpoint. The wetlands are important areas for passive recreation and are regarded as significant natural features by a cross-section of the community. Any factor which results in ecological change ultimately has a social impact.

The response to impacts of this nature can be gauged from the reaction in the adjacent Wanneroo PWSA. An apparent drop in water levels in lakes of that area, particularly Lakes Gnangara and Jandabup, has been a point of concern for local residents and other wetland conservation groups in the Metropolitan area.

Whilst the actual cause of the drop has not been defined, the groups perceive it to be due to groundwater abstraction. A more detailed analysis of community attitudes is presented in Section 5.0 of this appendix.

The wetlands which might potentially have been impacted by the Pinjar Scheme are those in the LUSA which run north/south, west of Wanneroo Road. The proposed Pinjar Scheme has been modified to avoid these lakes. Computer modelling now indicates that the lakes will experience minimal impact due to the project. Careful monitoring and management will be required to ensure any impact is kept to a minimum. Fortunately, these linear lakes are unlikely to be severely affected by minor water level fluctuations because they are deep and relatively steep sided. They are much less vulnerable than the shallow circular lakes, like Gnangara and Jandabup. A more detailed discussion of these potential impacts is contained in Appendix A of this ERMP.

5.0 COMMUNITY ATTITUDES STUDY

One of the aims of the present study was to assist the Water Authority in the development of an overall concept for development and management of the groundwater resources of the Gnangara Mound.

Consequently, an integral part of the analysis of the social environment was a Community Attitudes Study. This study was developed with the following two objectives:

- To seek input from the public concerning the perceived importance of environmental issues and values that are relevant to the project.
- To inform the public on the need for the project, its nature, likely impacts and safeguards.

In order to fulfill the first objective of the programme, a Public Awareness and Attitudes Survey (PAAS) was conducted. The second objective was partially met by displays in the Wanneroo area and will be fulfilled when the ERMP document is placed on public exhibition.

The PAAS was aimed at documenting the perceived issues and public aspirations so that the State Government would be aware of them, could keep them under review and make decisions with them in mind. There were two basic components of the study:

- o Personal Interviews
- o Public Questionnaire.

5.1 PERSONAL INTERVIEWS

5.1.1 Methodology

A series of personal interviews were conducted with individuals and small groups who were identified by City of Wanneroo and Water Authority personnel as representative of concerned groups. The interviews were conducted by Dames & Moore personnel usually with a suitable representative from the Water Authority present to answer any technical queries. Lists of people and groups contacted as well as State Government Departments are presented in Table 8. Questions were asked on an open-ended basis and the discussion was not prompted by a formal questionnaire. The issues raised by the personal interviews were further investigated in the public questionnaire.

TABLE 8

CONCERNED GROUPS CONTACTED DURING THE PAAS

PEOPLE & GROUPS CONTACTED	STATE GOVERNMENT DEPARTMENTS CONTACTED
City of Wanneroo Staff	Environmental Protection Authority
Wanneroo City Council	Dept. of Conservation and Environment
Conservation Council of W.A.	Dept.of Conservation and Land Management
Wanneroo Ratepayers Association	Dept. of Agriculture
Shire of Swan	Dept. of Mines
Shire of Chittering	State Planning Commission
Shire of Gingin	
Ms Jackie Watkins (MLA)	
Mr Bert Crane (MLA)	
Mr Peter Wells (MLC)	
Mr Graham Edwards (MLC)	
Mr Bill Stevens (Vegetable Growers Association)	
Mr Edgar Griffiths (Wanneroo Groundwater Advisory Council)	
Mr Malcolm Hollick (Research Group on Groundwater Management)	

5.1.2 Results of the Personal Interviews

Probably the most significant finding of the personal interviews was that preservation of the environment was considered to be a priority in the development of a management strategy. Embodied in this finding was the need for more efficient land use and consequent use of water resources. For example, many of the agencies aligned with conservation viewed the use of finite groundwater resources for the development of pine plantations to be inefficient when the natural bushland vegetation was better adapted to the type of climate. In contrast, others felt that the use of groundwater for irrigation purposes to grow vegetables and the supply of water to urban development were viewed as legitimate users.

Other important results of the personal interviews were recommendations addressing what should be included in an education programme concerning the conservation of groundwater resources. The important components were:

- To improve access to information about water conservation and the water cycle.
- The need to develop paths of communication between public authorities, especially closer liaison between bodies responsible for land use planning and the Water Authority.
- To provide better and more accessible information about the limits of the resource so that there is clearer understanding for potential purchasers of agricultural and rural-residential land.

The importance of conservation education and protection of the natural environment which came out of the interviews, implied that all of the groups recognised the need for management of groundwater resources. The type of management (water charging, quotas, time restrictions, etc.) was not discussed during the interviews and would form an important component of further community studies.

A complete summary of the concerns expressed is presented in Table 9.

TABLE 9

SUMMARY OF CONCERNS EXPRESSED BY PERSONAL INTERVIEWEES OVER THE PROPOSED GNANGARA GROUNDWATER DEVELOPMENTS

MAJOR AREA OF CONCERN	SPECIFIC CONCERN*
Conservation of the Environment	o For aesthetics and lifestyle, natural environment and wetlands are important o Has been heavy degradation of System 6 areas o Have been tree deaths, perceived due to Water Authority abstraction o Pines are not important o Preservation of the environment is important o The use of pine plantations is not supported, they use too much water. Natural banksia woodland is preferred.
Groundwater Use	o Community resource, all should have access not just Water Authority o Need to conserve water in all uses o Need to preserve groundwater for private use o Urban development requires water and is a legitimate user o Waste of water by overwatering, watering during the day etc. o Water for irrigation is most important, but retain lakes if have the option o Water quality is an issue o Water table should not drop, should only use what falls on the land ie. 'harvest' water not 'mine' it o Whose water is it? That is, is it owned by those who own the land above it or by the whole community?
Management	o Community should be prepared to pay more for water to afford conservation ie. use other sources such as Ord River o Compensation issue - drop in land values etc. o Conservation will cost. Who pays? May need well restrictions, native gardens, high rates etc. o Demand Management (need for controlled usage within the public water supply) by education of urban users to conserve water o If can't avoid a lowering of the water table, should consider artifically maintaining wetland levels by pumping water back into them o Land is not worth much without water. Leave all people with some allocation o Look at other alternative water supply sources o Locate wells as far away from wetlands as possible

TABLE 9 (cont.)

MAJOR AREA OF CONCERN	SPECIFIC CONCERN*
Management Cont.	o Management is necessary but needs to be fair, meters are okay o Monitoring is essential o Need a trade-off between moving horticulture from proximity to markets and importing water o Need compensation for those whose livelihood is being impacted by water restrictions - who pays? o Need management of the groundwater resource o Need shared water restrictions (Water Authority as well) o No meters o Other sources - Ord River etc. o Perhaps a winter pumping strategy - use groundwater in winter and conserve Hills water for summer, or pump back groundwater in winter to fill dams o Planning of rural activity in the North-West Corridor is not on, due to wrong soil types o Population control is an alternative o Private allocation > public draw - should it be used by public? o Some obligation to rural as well as urban people o There are choices to be made - need a balance between wetlands, population, wild rivers and green lawns o Water Authority is responsible for total management of the resource not just for public water supply o Water Authority to use groundwater from aquifers north of Gingin Brook, not Gnangara Mound o Water management for all users (not just Water Authority) o Water where people need it most - market gardens etc.
Public Education	o More opportunity for public input into decisions on groundwater o Need public access to all Water Authority information o Need to educate people in conserving groundwater o Need to inform the public that the resource is not limitless o Needs to be on-going discussions between Government authorities and public o People are claiming reduced utility due to water restrictions as a means of getting lower rates

TABLE 9 (cont.)

MAJOR AREA OF CONCERN	SPECIFIC CONCERN*
Public Education Cont.	o People didn't know about groundwater limitations when they bought properties, now they can't develop them due to lack of water o Public purchasing land need to be informed of groundwater restrictions before buying o Rates and charges are a problem - too high o Urban and rural people have different aspirations hence different priorities for groundwater o Water Authority need to be honest to public about the amount of groundwater abstracted by production wells and their effect
Rural Areas	o Golf courses in rural areas - use a lot of water o Hobby farms - keeping horses on irrigated land uses too much water - few horses, large water usage o Market gardens and other rural activities in Wanneroo have good proximity to Metropolitan markets o Special rural and unlimited subdivision uses too much water o Special rural areas - net recharge due to restrictions o Special rural requires trees and lawns etc, uses too much water o Restrictions are an intrusion on rural activities o Wanneroo is desirable for special rural areas due to its proximity to Perth o Wanneroo vegetable growing areas are vital to complement other regions and provide a wide range of produce throughout the year o Worry about future of rural activities and market gardens in Wanneroo
Wetlands	o Lake levels are dropping, of particular concern - Lakes Gnangara, Jandabup and Neerabup o Lake Pinjar is seasonal, could be better utilized for agriculture by draining o No impact on wetlands is an acceptable impact o Seasonal wetlands are also important, they are links in the wetland chain o Wetlands are important natural features to be conserved o Wetlands are important scenic and passive recreational venues.

* The concerns have not been ranked at all, all points are listed alphabetically.

5.2 PUBLIC AWARENESS AND ATTITUDES SURVEY

Following the personal interviews, a Public Awareness and Attitude Survey (PAAS) on groundwater use was circulated in conjunction with a public display of the proposed groundwater development. These were set up at the Wanneroo Agricultural Show, Wanneroo City Council Offices and the Wanneroo Shopping Centre. The displays were manned by Water Authority personnel and were designed to inform the public of the proposed groundwater developments. Dames & Moore staff were in attendance to distribute and collect the self administered questionnaire. The locations of the display were chosen to reach a larger cross-section of the community, and were advertised in the local media.

Over 130 responses to the survey were received. Responses were collated and analysed by computer, and conclusions to the above questions were drawn from the resultant individual and cross tabulations. There was a deadline for postal returns and, while any responses received after that date were not able to be included in the computer analysis, the comments of the respondents were noted.

Addendum I of this appendix contains a copy of the original survey questionnaire. The results and discussion of the analysis are presented in the following sections.

The purpose of the survey was to address more specifically the objectives of the Community Attitude Study rather than simply generate perceptions about issues. The survey was structured so that it was possible to answer the following management questions.

- How important is the groundwater issue when compared to other common issues of community concern?
- Are there differences in the issues raised between residents of the region (ie. entire Gnangara Mound) and residents of the Wanneroo township and rural area (known as the Wanneroo locality).
- Within both the broader region and the Wanneroo locality, are there any differences in perceptions between urban and rural areas?
- Is there any relationship between the length of residence in an area and a person's perception of groundwater as an issue?
- Is there any particular socio-economic group which would be associated with a particular concern about the use of groundwater?
- What are the implications of the results for development of a management strategy?

For each of the questions in the survey there was a range of responses which corresponded with degrees of regulation of groundwater and consequent management strategies; for example, a highly regulated management strategy would be associated with answers which showed concern for protection of the natural environment and conservation of the resource. A more unregulated system of management with unlimited private access to groundwater resources would be associated with responses which showed concern for private use and unlimited access to the resource.

Due to the relatively broad nature of the survey, the study area for the public questionnaire was larger than for other sociological aspects. The region was defined as residents of the entire Gnangara Mound and the Wanneroo locality was defined as the area occupied by Wanneroo township and rural dwellers. This allowed comparison of the existing community attitudes and perceptions of people already affected by groundwater management with those in the rest of the area.

5.3 RESULTS OF THE SURVEY

5.3.1 Introduction

As discussed above, the PAAS was administered to members of the general public who attended a groundwater display centre at three locations in the study area. Consequently, the level of confidence in the results cannot be estimated for the general population. However, based on the tabulations of age, occupation, location and sex the results are considered to give a valid impression of the attitudes of the population of Wanneroo and its environs, that consider the use of groundwater to be a community issue.

A discussion answering the above management questions with selected cross-tabulations is presented in Section 5.3.2. The management implications of the results are then discussed in 5.3.3. Tabulations of the answers to each question in the survey are also presented in Section 5.3.4.

5.3.2 Discussion

o **Importance of Groundwater Compared to other Community Concerns**

Compared to other community concerns, groundwater was not considered very important. Access to groundwater was rated as the fifth most important community feature that should be improved. Rates and charges, public transport, pollution and recreational facilities were viewed as being more important to improve. When these results were cross-tabulated with location, a highly significant relationship was observed between the two. In urban areas the major concerns were rates and charges, public transport and pollution whereas in rural areas access to groundwater was observed to have a higher priority.

o **Regional and Wanneroo Locality Differences**

In order to consider whether there were significant differences between the regional and Wanneroo locality groundwater concerns, a statistical chi-square analysis was conducted on the questions, probing both regional and Wanneroo locality groundwater concerns. As the chi-square analysis showed a very highly significant relationship between the two, it was concluded that there were no significant differences. This result suggests that planning a management strategy based on the experience already gained, should provide the appropriate data base for development of a regional strategy. As discussed below, within the region there were statistical differences observed between urban and rural responses on questions about groundwater generally. However, in contrast on questions specifically about groundwater in Wanneroo, statistical differences were not apparent.

o **Internal Differences - Regional Perceptions**

Internal regional differences were explored by cross-tabulating the location of the response (Q1) with the important aspects to have in the region (Q7). This tabulation revealed a highly significant relationship between what was considered important in the area and whether the respondent was urban or rural. In the urban areas people were concerned primarily with the conservation and protection of natural bush and lake areas. In contrast, in rural areas opinion was more divided with access to groundwater slightly ahead of environmental conservation. It is important to point out, however, that these urban-rural differences were not observed with quality drinking water. This was an obvious priority, regardless of location (see Table 10).

There were also differences between the urban and rural responses when considering the best uses for groundwater within the region (Table 11).

The clear cut differences between the urban and rural areas were as would be expected. Urban respondents viewed the use of groundwater for urban household wells and for Council use on parks and gardens as a priority. Rural responses favoured hobby farm and rural uses, and farm irrigation. It is also interesting to note that the use of groundwater for market gardens did not show the same extent of differences between the urban and rural responses. The data also again suggests the overall concern for the environment with a significant number of responses preferring the maintenance of lake levels. These responses were equally distributed between the various locations.

- **Internal Differences - Wanneroo Locality Perceptions**

Internal differences within the Wanneroo locality were analysed in similar fashion to the above with location (Q1) cross tabulated with Q7 (most important land use - Wanneroo) and Questions 9 and 10 (specific groundwater concerns - Wanneroo).

In this case there were no significant differences between urban and rural responses. For the best land use in Wanneroo, market gardens were viewed as by far the most important, regardless of the respondent's location (see Table 12). The most particular concern regardless of location in the Wanneroo area was lakes and swamps drying up. This was verified by responses to both the multiple response question (Q9) (Table 13) and the open-ended question (Q10), which has not been reproduced. The other two issues of concern that were rated highly were water restrictions and higher water charges. Water restrictions did show up as a particular concern for rural respondents even though there were no clear statistical differences for the table as a whole.

- **Differences Due to Length of Residence**

Another important question raised was whether there was any statistical relationship between the concerns that people had concerning groundwater, both regionally and locally, based on the length of time they had lived in the area. This was possible by cross-tabulating length of residence (Q2) with the regional concerns and land use questions (Q4 and Q6) (Tables 14 and 15) and also with the questions specific to Wanneroo (Q7 and Q8). For all four cross-tabulations no statistical differences were observed. The latter two cross-tabulations have not been reproduced in this document.

TABLE 10

LOCATION OF RESIDENCE BY
IMPORTANT ASPECTS TO HAVE IN AREA - 1ST PREFERENCE

	LAKES WITH OPEN BUSH	NATURAL BUSH AREAS	WELL KEPT PARKS	GREEN DOMESTIC LAWNS	LOW WATER RATES	ACCESS TO BORE WATER	QUALITY DRINKING WATER	ACCESS TO SCHEME WATER	OTHER	DON'T KNOW	ROW TOTAL (%)
WANNEROO TOWNSHIP	5	4	1	2	6	5	15	1	1	1	41 (31.8)
WANNEROO RURAL	10	10				12	4	2			38 (29.5)
OTHER SUBURB	6	8	3	4	2		15	2		1	41 (31.8)
OTHER RURAL AREA	1					1		1	1		4 (3.1)
ELSEWHERE			2		1		1	1			5 (3.9)
COLUMN TOTAL (%)	22 (17.1)	22 (17.1)	6 (4.7)	6 (4.7)	9 (7.0)	18 (14.0)	35 (27.1)	7 (5.4)	2 (1.6)	2 (1.6)	129 (100.0)

TABLE 11

LOCATION OF RESIDENCE BY
BEST USES FOR GROUNDWATER - 1ST PREFERENCE

	URBAN HOUSE-HOLD	COUNCIL USE	MARKET GARDENS	HOBBY FARM/ RURAL	MAINTAIN LAKE LEVELS	SUPPLY URBAN SCHEME WATER	FARM IRRIGA-TION	STOCK WATERING	TO USE AS PEOPLE PLEASE	OTHER	ROW TOTAL (%)
WANNEROO TOWNSHIP	7	7	11		6	7	1		1		40 (31.5)
WANNEROO RURAL	2		15	8	7		5	1			38 (29.9)
OTHER SUBURB	10	12	5		5	4	2		3		41 (32.3)
OTHER RURAL AREA			2		1						3 (2.4)
ELSEWHERE	1		1				1		1	1	5 (3.9)
COLUMN TOTAL (%)	20 (15.6)	19 (14.8)	34 (26.6)	8 (6.3)	19 (14.8)	11 (8.6)	9 (7.0)	1 (0.8)	5 (3.9)	1 (0.8)	127 (100.0)

TABLE 12

LOCATION OF RESIDENCE BY
MOST IMPORTANT LAND USES IN WANNEROO REGION - 1ST PREFERENCE

	MARKET GARDENS	NATURE AREAS	HOBBY FARMS	URBAN AREAS	INDUSTRIAL AREAS	ACTIVE RECREATION (OVALS)	PASSIVE RECREATION (PARKS)	QUARRYING	RURAL	TOURISM	ROW TOTAL (%)
WANNEROO TOWNSHIP	14	8	1	3	1	3	3	1	1	2	37 (30.6)
WANNEROO RURAL	25	6	5		1				1	1	39 (32.2)
OTHER SUBURB	15	8	2	2		3	3		1	4	38 (31.4)
OTHER RURAL AREA	3										3 (2.5)
ELSEWHERE	2	1		1							4 (3.3)
COLUMN TOTAL (%)	59 (48.8)	23 (19.0)	8 (6.6)	6 (5.0)	2 (1.6)	6 (5.0)	6 (5.0)	1 (0.8)	3 (2.5)	7 (5.7)	121 (100.0)

TABLE 13

LOCATION OF RESIDENCE BY
PARTICULAR GROUNDWATER CONCERNS WANNEROO - 1ST PREFERENCE

	LAKES/ SWAMPS DRYING UP	FLOODING	WATER RESTRICTIONS	HIGHER RATES & CHARGES	MANAGEMENT OF GROUND-WATER	INSECTS IN SWAMPS	PRESERVE NATURE	ROW TOTAL (%)
WANNEROO TOWNSHIP	14	1	4	9	5	1	3	37 (31.9)
WANNEROO RURAL	14		15	1	6		2	38 (32.8)
OTHER SUBURB	18		2	4	5	1	4	34 (29.3)
OTHER RURAL AREA			1	1	1			3 (2.6)
ELSEWHERE	2		1	1				4 (3.4)
COLUMN TOTAL (%)	48 (41.4)	1 (0.9)	23 (19.8)	16 (13.8)	17 (14.7)	2 (1.7)	9 (7.8)	116 (100.0)

TABLE 14

LENGTH OF RESIDENCE BY
COMMUNITY FEATURES TO BE IMPROVED - 1ST PREFERENCE

	POLLUTION	RATES & CHARGES	GENERAL SAFETY	ACCESS TO GROUND WATER	COMMUNITY SERVICES	PUBLIC TRANSPORT	SCHOOLS & COLLEGES	RECREATION FACILITIES	OTHER	DON'T KNOW	ROW TOTAL (%)
0-4 yrs	11	14	1	5	6	5	1	3	3		49 (37.7)
5-9 yrs	4	13	2	3	1		2	5	3	2	35 (26.9)
10-14 yrs	2	13	1	3		4	2	1	2		28 (21.5)
15-19 yrs	2	1		4		2			1		10 (7.7)
20+ yrs		4		2				1	1		8 (6.2)
COLUMN TOTAL (%)	19 (14.6)	45 (34.6)	4 (3.1)	17 (13.1)	7 (5.4)	11 (8.5)	5 (3.8)	10 (7.7)	10 (7.7)	2 (1.5)	130 (100.0)

TABLE 15

LENGTH OF RESIDENCE BY
BEST USES FOR GROUNDWATER - 1ST PREFERENCE

	URBAN HOUSE-HOLD	COUNCIL USE	MARKET GARDENS	HOBBY FARMS/ RURAL	MAINTAIN LAKE LEVELS	SUPPLYING URBAN SCHEME WATER	FARM IRRIGATION	STOCK WATERING	TO USE AS PEOPLE PLEASE	OTHER	ROW TOTAL (%)
0-4 yrs	11	5	7	6	7	3	4		5		48 (37.8)
5-9 yrs	3	8	10		5	4	3	1		1	35 (27.5)
10-14 yrs	4	5	8	1	4	3	1				26 (20.5)
15-19 yrs		1	4		3	1	1				10 (7.9)
20 + yrs	1		5	1			1				8 (6.3)
COLUMN TOTAL (%)	19 (15.0)	19 (15.0)	34 (26.8)	8 (6.3)	19 (15.0)	11 (8.7)	10 (7.8)	1 (0.8)	5 (3.9)	1 (0.8)	127 (100.0)

o **Differences between Socio-Economic Groups**

Socio-economic differences in attitudes to the use of groundwater is another concern for the development of a management strategy. For this survey, socio-economic group was measured by occupation (Q12). This question was cross-tabulated with Q5 (Important Aspects to have in the Area) with Q6 (Best Uses for Groundwater) with Q7 (Best Land Use in Wanneroo) and also Q8 (Particular Groundwater Concerns). For all of these cross-tabulations there was a significant relationship observed with occupation. However, due to the higher than normal proportion of certain occupations responding to the survey the results are difficult to interpret. Only one of these tables has been reported (Table 16). This table suggests that the professional and technical groups are more concerned about conservation of the natural environment than other groups. However, this suggestion is only apparent if the need for quality drinking water is taken out of the analysis. This need was again demonstrated to be the ultimate priority regardless of socio-economic group.

5.3.3 Management Implications

o **Management Priorities**

The important message that comes out of the analysis is that regardless of location, the protection of the existing natural environment is a priority issue. At the regional level natural bush was considered the most important aspect to maintain in the community, the second most important land use, and the preservation of such areas the third most important particular water concern at the local level. Similarly the importance placed on lakes was consistent both with multiple responses and open-ended questions. It was also clear that regardless of location at the local level, the importance of market gardening was recognised by the majority of people.

The need for quality drinking water was the other priority regardless of location, length of residence and socio-economic group. There is also some suggestion of differences in attitudes to the use of groundwater between socio-economic groups. Verification of this trend would require a more detailed and stratified sampling design.

TABLE 16

OCCUPATION BY IMPORTANT ASPECTS TO HAVE - 1ST PREFERENCE

	LAKES WITH OPEN BUSH	NATURAL BUSH AREAS	WELL KEPT PARKS	GREEN DOMESTIC LAWNS	LOW WATER RATES	ACCESS TO BORE WATER	QUALITY DRINKING WATER	ACCESS TO SCHEME WATER	OTHER	DON'T KNOW	ROW TOTAL (%)
PROFESSIONAL/ TECHNICAL	5	7		2		2	7	2			25 (19.7)
ADMINISTRATIVE	2	1	1				5	1			10 (7.9)
HOME DUTIES	2	1			1	5	2				11 (8.7)
CLERICAL	1	2					3				6 (4.7)
RETAIL/ WHOLESALE	1	2	1		1	1	3				9 (7.1)
PRIMARY WORKERS		4			2	4	2		1		13 (10.2)
MINERS/ QUARRYMEN							1				1 (0.8)
TRANSPORT/ COMMUNICATIONS	2					1	2				5 (3.9)
TRADES-PEOPLE		1	1	2		1	2		1		8 (6.3)
SERVICE/SPORT RECREATION	2	1			1		4				8 (6.3)
ARMED SERVICES					1						1 (0.8)
OTHER	1		1		3	3	2	1			11 (8.7)
DON'T WORK	3	1	1	2			1	2			10 (7.9)
PRIMARY SCHOOL										2	2 (1.6)
SECONDARY SCHOOL	1	1	1				1	1			5 (3.9)
TAE		1									1 (0.8)
TERTIARY (UNI/WAIT)						1					1 (0.8)
COLUMN TOTAL (%)	20 (15.7)	22 (17.3)	6 (4.7)	6 (4.7)	9 (7.1)	18 (14.2)	35 (27.6)	7 (5.5)	2 (1.6)	2 (1.6)	127 (100.0)

o **Implications for Development of Water Resources Strategy**

The results of the survey suggest a management strategy which would contain the following goals:

- o To maintain the present character of the natural environment by maintenance of lake levels and protection of natural bush areas.
- o To recognise the importance of the maintenance of adequate water to the agricultural areas which supply the local and Metropolitan food markets.
- o To ensure the highest quality drinking water.

Acceptance of these goals would lead to a set of management objectives which would be based on the maintenance of existing service levels and consequently eventual regulation of all groundwater resources in the Gnangara Mound area. As demand for water supply grows from the development of the North-West Corridor, maintenance of existing service levels will become more difficult. The need to co-ordinate future urban land use planning with a water resource strategy based on maintenance of existing service levels is an important implication of the survey results.

The priority placed on rates and charges as an issue, also suggests that the cost of water may be of some concern, especially to urban dwellers.

5.3.4 Responses To All Questions

The following section discusses and tabulates the responses to each question in the survey.

Q1 - Location of Residence

There was approximately equal survey participation by residents of 'Wanneroo Township', 'Wanneroo Rural' and 'Other Suburb' areas. Residents of 'Other Rural Areas' and 'Elsewhere' were by comparison not well represented. Definitions of the locations are presented below.

- o Wanneroo Township: The urban residential area of the actual township.
- o Wanneroo Rural: All those dwellings within the 'Rural' and 'Special Rural' zones described in the then Shire of Wanneroo's Rural Subdivision Policy (1978).

- o Other suburb: All suburbs outside the actual Wanneroo township
- o Other Rural Areas: All dwellings in rural zones outside the City of Wanneroo.
- o Elsewhere: All areas not covered by the above categories.

Q2 - Length of Residence

On the whole, respondents had lived in the area for a relatively short term with 86.2% of respondents having occupied the same locality for less than 15 years, 64.6% for less than 10 years and 37.7% for less than 5 years. This is to be expected in view of the relatively recent rapid growth rate of the area.

Q3 - Quality of Locality

The dominant feature of this question was that 94.7% of respondents liked where they lived, rating their area as 'Good', 'Very Good' or 'Excellent'. This implies that residents would like the area maintained as it is.

Q4 - Specific Community Features to be Improved

Compiling the response data for 1st, 2nd and 3rd preferences, an overall rating of 'specific features of the community to be improved' was determined as shown on Table 17.

TABLE 17

SPECIFIC COMMUNITY FEATURES TO BE IMPROVED

RANK	FEATURE TO BE IMPROVED	FREQUENCY	%	** VALID %
1	Rates and Charges	73	18.6	21.7
2	Public Transport	47	12.0	13.9
3	Pollution	40	10.2	11.9
4	Recreational Facilities	38	9.7	11.3
5	Access to Groundwater	34	8.7	10.1
6	General Safety	31	7.9	9.2
7	Community Services	27	6.9	8.0
8	Other	22	5.6	6.5
9	Schools	20	5.1	5.9
10	Don't know	5	1.3	1.4
11	Missing Values (no response)	56	14.3	Missing
		393	100.0*	100.0*

* These percentages may not aggregate to 100.0 due to rounding off.

** Percentages which exclude missing values

'Rates and charges' was not only the highest category overall with 21.7%, but also was highest in the 1st preference category with 34.4%. Note that by contrast, 'Increasing Water Charges' rated only 5th overall as a 'Particular Water Concern' (Q9).

Another important feature of this aggregation table is that 'Access to Groundwater' was, overall, only the 5th highest 'Feature to be Improved' with 10.1%. This observation was confirmed by 'Access to Bore Water' being ranked as only the 5th most 'Important Aspect to have in the Area' (Q5), and by responses to specific and overall groundwater issues (Q10, Q15 and Q16).*

'Other' (features to be improved) included such responses as child care, concrete footpaths, local swimming pools, street trees, local shops, a beach area at Whitfords, the quarry behind Edgewater Heights subdivision and the rubbish tip at Wangara.

Q5 - Important Aspects to Have in the Area

1st, 2nd and 3rd preferences for 'Important Aspects to Have in the Area' were compiled to determine the overall rank of responses as shown on Table 18.

TABLE 18

IMPORTANT ASPECTS TO HAVE IN THE AREA

RANK	IMPORTANT ASPECT TO HAVE	FREQUENCY	%	** VALID %
1	Natural Bush Areas	71	18.1	19.2
2	Lakes with Open Areas	65	16.5	17.7
3	Quality Drinking Water	65	16.5	17.7
4	Low Water Rates	43	10.9	11.7
5	Well Kept Parks	39	9.9	10.6
6	Access to Bore Water	36	9.2	9.8
7	Green Domestic Lawns	24	6.1	6.5
8	Access to Scheme Water	21	5.3	5.7
9	Other	2	0.5	0.5
10	Don't know	2	0.1	0.5
11	Missing Values	25	6.4	Missing
		393	100.0*	100.0*

*These percentages may not aggregate to 100.0 due to rounding off.

** Percentages which exclude missing values

* 'Specific Groundwater Issues' raised in question Q10 and 'Other Issues related to Groundwater and its Use' raised in Q15 and Q16 were combined into one table because of the similarity in the nature and wording of the questions and in the responses given.

As the overall table shows, 'Natural Bush' areas was considered the most important aspect to have in the community with 19.2%. This corresponds with 'Nature Conservation Areas' being the 2nd most important land use (Q7) and 'Preserving Natural Areas' being ranked as the 3rd highest 'Particular Groundwater Concern' (Q9).

The above aggregated data shows 'Lakes With Open Areas' as the 2nd most important aspect to have in the area. In other questions (Q10, Q15 and Q16), 'Lakes' was both the foremost specific issue with 25% and overall groundwater issue with 16%. Also 'Lakes/Swamps Drying Up' was the highest rating overall 'Particular Groundwater Concern' in (Q9) and 'Maintaining Water Level in Lakes' rated as the 2nd highest use of groundwater in (Q6).

'Low Water Rates' low 4th ranking in the aggregated data with 11.7% is in contrast with 'Low Rates and Charges' ranked as the number one community feature to be improved (see Q4).

Also, 'Well Kept Parks' is ranked only 5th with 10.6% and 'Green Domestic Lawns' 7th with 6.5%. Both these responses ranked equally as the 5th highest 1st preferences with 4.7%. These results support 'Public and Private Wastage' as the 2nd highest overall groundwater issue (Q10, Q15 and Q16) but are in contrast to 'Parks and Ovals' being the 3rd overall 'Best Use for Groundwater' (Q6) and also 'Passive Recreational Areas' being the 3rd 'Most Important Land Use' overall (Q7). This is discussed further in Section 5.3.2.

'Quality Drinking Water' was the number one 1st preference for the most 'Important Aspect to Have', and as the aggregated data shows, it was 3rd overall. By contrast, 'Quality Drinking Water' was only the 8th highest overall groundwater issue (Q10, Q15 and Q16) and the 6th highest specific Groundwater issue (Q10). This is discussed further in Section 5.3.3.

The low 6th rating of 'Access to Bore Water' in the above table is consistent with other responses regarding access to groundwater - see 'Specific Features to be improved' (Q4).

The two 'Other' responses related to local swimming pools.

Q6 - Best Uses for Groundwater

Combining 1st, 2nd and 3rd preference data, an overall ranking of 'Best Uses for Groundwater' was determined as shown in Table 19.

TABLE 19

BEST USES FOR GROUNDWATER

RANK	USE FOR GROUNDWATER	FREQUENCY	%	** VALID %
1	Market Gardens	71	18.1	19.3
2	Maintaining Water Level in Lakes	60	15.3	16.3
3	Council Use on Ovals and Parks	51	13.0	13.9
4	Household bores in Urban Areas	41	10.4	11.1
5	Supplying Scheme Water to Urban Areas	33	8.4	9.0
6	Farm Irrigation	30	7.6	8.2
7	Hobby Farms/Special Rural Lots	29	7.4	7.9
8	Stock Watering	23	5.9	6.3
9	To Use as People Please	17	4.3	4.6
10	Industrial Use	5	1.3	1.4
11	Other	5	1.3	1.4
12	Don't Know	3	0.8	0.8
13	Missing Values	25	6.4	Missing
		393	100.0*	100.0*

* These percentages may not aggregate to 100.0 due to rounding off.

** Percentages which exclude missing values

As the overall compiled table shows, 'Market Gardens' was ranked highest with 19.3% of respondents as the 'Best Use for Groundwater'. 'Market Gardens' was also the highest rating 1st preference among 26.0% of respondents. This is supported by 'Market Gardens' being the best 'Land Use' (Q7), and 'Livelihood Priority' the 4th overall 'Groundwater Issue' (Q10, Q15 and Q16).

'Maintaining Water Levels in Lakes' was rated as the 2nd best use for Groundwater overall with 16.3%. This was discussed earlier in Important Aspects to have in the Area (Q5).

As noted above in 'Important Aspects to have in the Community' (Q5), the relatively high 3rd position rating of 'Council Use on Ovals and Parks' both overall and as 1st preference is inconsistent with the tabulated data of Q5, Q10, Q15 and Q16 in which well kept parks and gardens are regarded as unnecessary.

Q7 - Most Important Land Uses

Data for 1st, 2nd and 3rd preferences was analysed and an overall rating for 'Most Important Land Uses in the Wanneroo Region' was determined as shown in Table 20.

The dominant feature of this compiled data table is that 'Market Gardens, etc' are regarded as the most important land use with 24.5%. 'Market Gardens, etc' was also the 1st preference of 47.2% of respondents making it the highest rating 1st preference option. As mentioned in 'Uses for Groundwater' (Q6) this is consistent with other data obtained.

Not only was 'Nature Conservation Areas' ranked the 2nd most important land use in the aggregated table with 14.3%, but 'Tourist Areas' was ranked 4th and this included national and marine parks and natural attractions. This corresponds with responses to other questions in the survey - as was noted in 'Important Aspects to Have in the Community' (Q5).

'Passive Recreational Areas' was rated 3rd with 11.0%. This was also discussed in 'Important Aspects to have in the Community' (Q5).

TABLE 20

MOST IMPORTANT LAND USES

RANK	MOST IMPORTANT LAND USE	FREQUENCY	%	** VALID %
1	Market gardens/intensive flower/ fruit growing	89	22.7	24.5
2	Nature conservation areas	52	13.2	14.3
3	Passive recreational areas, eg. parks, gardens	40	10.2	11.0
4	Tourist areas, eg. picnic areas, national and marine parks, natural and man-made attractions	39	9.9	10.7
5	Rural land for cropping or grazing	37	9.4	10.2
6	Hobby farms	33	8.4	9.1
7	Active recreational areas, eg. football ovals	32	8.1	8.8
8	Urban areas	20	5.1	5.5
9	Industrial areas	9	2.3	2.5
10	Commercial/business areas, eg. shops	6	1.5	1.6
11	Other	3	0.8	0.8
12	Quarrying	2	0.5	0.6
13	Don't Know	2	0.5	0.6
14	Missing values	29	7.4	Missing
		393	100.0*	100.0*

* These percentages may not aggregate to 100.0 due to rounding off.
** Percentages which exclude missing values

Q8 - Is Groundwater in Wanneroo a Concern?

The analysis clearly showed 89.2% of people surveyed were concerned about groundwater in Wanneroo.

Q9 - Particular Groundwater Concerns

1st, 2nd and 3rd preferences were analysed and an overall tabulation of particular water concerns was obtained as shown in Table 21.

'Lakes/swamps drying up' was not only the most common 1st preference among respondents with 41.4%, but also the highest rating concern overall, as the compilation table shows. This again shows the consistent importance respondents have placed upon lakes and their environs, as was discussed in 'Important Aspects to have in the Community' (Q5).

'Proper Management of Groundwater Use' was the 3rd highest 1st preference with 14.7% and as the compiled Table 21 shows, the 2nd most common concern overall. In relation to this, 'Efficiency of the Water Authority' and the category covering the Water Authority need for careful planning, monitoring the amount of water used, honestly giving this information to the public, etc, were both raised as groundwater issues (Q15) where they rated 4th and 3rd respectively, and then overall both rated 7th (Q10, Q15 and Q16).

The consistent concern shown for 'Preserving Natural Areas' was discussed earlier in 'Important Aspects to Have' (Q5).

TABLE 21

PARTICULAR GROUNDWATER CONCERNS

RANK	PARTICULAR WATER CONCERN	FREQUENCY	%	** VALID %
1	Lakes/swamps drying up	79	20.1	23.9
2	Proper management of Groundwater use	67	17.0	20.3
3	Preserving natural areas	57	14.5	17.3
4	Restrictions on water useage	48	12.2	14.5
5	Increasing water charges	43	10.9	13.0
6	Biting insects breeding in swamps	27	6.9	8.2
7	Other	6	1.5	1.8
8	Flooding	3	0.8	0.9
9	Missing Values	63	16.0	Missing
		393	100.0*	100.0*

* These percentages may not aggregate to 100.0 due to rounding off.

** Percentages which exclude missing values

Though it rated as the 4th most common 1st preference, 'Increasing Water Charges' was only 5th overall, with 13.0 %. Note that 'Rates and Charges' in contrast with the most important feature to be improved in the area (Q4). This implies that other charges may be of more concern than water charges.

'Other' included the need for compensation if water restrictions were imposed, that the Water Authority was pumping too much water from the Mound and that a rubbish tip was polluting the Wangara water table.

Q10, Q15 and Q16 - Groundwater Issues Raised by Respondents

'Specific Groundwater Issues' raised in Q10 and 'Other Issues Related to Groundwater and its Use' raised by Q15 and Q16 were combined into the one table (Table 22) because of similarity in the nature and wording of the questions and in the responses given.

TABLE 22

GROUNDWATER ISSUES RAISED BY RESPONDENTS

RANK	ISSUE RAISED	FREQUENCY	%	VALID %**
1	Lakes drying up (Q5)	20	16.1	16.0
2	Wastage by Council (public) and/or citizens (private) (Q6)	13	10.5	10.4
3	Compensation required	9	7.3	7.2
4	Livelihood priority	8	6.5	6.4
5	Groundwater access should be limited	7	5.7	5.8
6	Pollution	6	4.8	4.8
7	o Water Authority efficiency (Q9) o Better Metropolitan water supply management	2x5	2x4.0	2x4.0
8	o Preservation of wetlands o Water quality (Q5) o No private meters o Water table changes o Water restrictions o Build dams	6x4	6x3.2	6x3.2
9	o Pine trees effect on groundwater o Unrestricted access to groundwater	2x3	2x2.4	2x2.4
10	o Not use groundwater for home o Political influence on groundwater decisions o Staining of cars o Staining of buildings o Purify sewerage o Restrict groundwater use on market gardens o Compensation for vacant land o Limit urban expansion	8x2	8x1.6	8x1.6
11	o Public pool o Mosquito spraying o Lake Pinjar should be drained and farmed o Desalination as an alternative o Allow subdivision of rural land	5x1	5x0.8	5x0.8
		124	99.7*	99.8*

* These percentages may not aggregate to 100.0 due to rounding off.

** Percentages which exclude missing values

Some common issues raised have been discussed earlier - see question numbers referred to next to the respective issues on the above table.

'Compensation Required', the 3rd most common issue with 7.2%, means specific compensation if water restrictions limited the amount of land able to be used productively, if restrictions caused land values to fall, or if lakes on properties were affected. Otherwise, land should be resumed at a fair market price.

'Livelihood Priority' (that those who rely on water for their livelihood should receive priority in water issues) is ranked as shown in Table 22, as the 4th highest 'Overall Groundwater Issue' with 6.4% and was also the number one 'Specific Groundwater Issue' with 25% (Q10). Correspondingly, 'Restrict Groundwater Use on Market Gardens' rated an extremely low 10th in the aggregated table. These results support the high priority 'Market Gardens' have received throughout the questionnaire - being considered the Best Land Use and Best Use of Groundwater.

As was mentioned in 'Specific Community Features to be Improved' (Q4), Table 22 supports the consistently low priority given to groundwater access. As a 'Specific Groundwater Issue' (Q10), both 'Limited' and 'Unlimited Access to Groundwater' ranked only 5th. When compiled in the above table 'Limited Access' remained 5th and 'Unlimited Access' fell to an even lower 9th in importance. 'No Private Meters' interpreted as no monitoring of private use of groundwater, fell from 4th to 8th.

It should be noted, however, that due to there being 29 issues, that it is difficult to have a very high or meaningful percentage for any one of the issues.

Q11 - Place of Occupation

Data showed that most survey respondents work or go to school in 'Other Suburbs', 'Wanneroo Rural Area', 'Wanneroo Township' and Perth, whilst 12% of respondents are not employed or are retired.

Q12 - Occupation

The data clearly showed that professional and technical people are by far the dominant respondents with 20.3%, almost twice the number of respondents of the next most common occupational category, primary workers, who represent 10.2% of the survey.

It is interesting to note, however, that compared to the 1981 census data for both the North Metropolitan Statistical Subdivision and Wanneroo Shire, both these occupational categories were over represented in the survey by approximately 7.0%. All other occupational categories were slightly under represented with clerical and tradespeople under represented by approximately 15% to 18% respectively.

Q13 - Age

Data showed a good distribution of ages with 67.2% of responses from people aged 25 to 50 years. This age group is over represented in comparison with the 1981 census data. All other categories, except 65 - 74, were under represented in the survey.

Q14 - Sex

There is a disproportionately high number of males represented in this survey with a ratio of 2.6:1, compared with 1981 census data which shows, as would be expected a 1:1 ratio.

Q17 - Origin of Questionnaire

Most questionnaires were completed by the public at the Agricultural Show and Shopping Centre. A total of 73.3% of questionnaires were completed at these two locations.

6.0 REFERENCES

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ADDENDUM I

SAMPLE QUESTIONNAIRE - GROUNDWATER USE
(including corresponding analysis variables)

ADDENDUM I

SAMPLE QUESTIONNAIRE - GROUNDWATER USE

Thank you for answering the following questions. Your answers will help us to gauge public opinion on the importance and use of groundwater. The questionnaire takes approximately 5 minutes to complete.

First, we would like to ask some questions about the area in which you live.

Q1. Where do you live? (tick appropriate box)

- ☐ Wanneroo township
- ☐ Wanneroo rural area
- ☐ other suburb (where?) _____
- ☐ other rural area (where?) _____
- ☐ elsewhere (where?) _____

Q2. How long have you lived there? (tick appropriate box)

- ☐ 0 - 4 years
- ☐ 5 - 9 years
- ☐ 10 - 14 years
- ☐ 15 - 19 years
- ☐ 20 + years

Q3. How would you rate your area as a place to live? (tick appropriate box)

- ☐ excellent
- ☐ very good
- ☐ good
- ☐ fair
- ☐ bad
- ☐ don't know

Q4. From this list of specific features of your community, which 3 would you like to have improved?
(Please rank in order by putting 1, 2 or 3 in the appropriate box)

- ☐ pollution (eg. noise, air quality)
- ☐ rates and charges (eg. local authority)
- ☐ general safety (eg. police, fire brigade)
- ☐ access to groundwater
- ☐ community services (e.g. shopping centres, welfare centres)
- ☐ public transport
- ☐ schools and colleges
- ☐ recreation facilities
- ☐ other _____
- ☐ don't know

Q5. **Which 3 of the following do you consider the most important to have in your area?**
(rank in order by putting 1, 2 or 3 in the appropriate box)

- ☐ lakes with open water areas
- ☐ natural bush areas
- ☐ well kept parks
- ☐ green lawns around my house
- ☐ charges for water rates as low as possible
- ☐ unrestricted access to bore water
- ☐ quality drinking water
- ☐ access to scheme water
- ☐ other _____
- ☐ don't know

Q6. **What do you consider to be the 3 best uses for groundwater in your area?**
(rank in order by placing 1, 2 or 3 in the appropriate box)

- ☐ household bores in urban areas
- ☐ council use on ovals and parks
- ☐ market gardens
- ☐ hobby farms/special rural lots
- ☐ industrial use
- ☐ maintaining water levels in lakes
- ☐ supplying scheme water to urban areas
- ☐ farm irrigation
- ☐ stock watering
- ☐ to use as people please
- ☐ other _____
- ☐ don't know

Next, we would like to seek your opinion on the use of groundwater in the <u>Wanneroo region</u>.

Q7. **Which 3 land uses do you consider to be the most important in the Wanneroo region?**
(rank in order by placing 1, 2 or 3 in the appropriate box)

- ☐ market gardens/intensive flower, fruit growing
- ☐ nature conservation areas
- ☐ hobby farms
- ☐ urban areas
- ☐ industrial areas
- ☐ active recreational areas eg. football ovals
- ☐ passive recreational areas eg. parks, gardens
- ☐ quarrying
- ☐ rural land for grazing or cropping
- ☐ tourist areas (eg. picnic areas, national and marine parks, natural and man-made attractions)
- ☐ commercial/business areas eg. shops
- ☐ other _____
- ☐ don't know

Q8. **Are you concerned about groundwater in Wanneroo?** ☐ Yes ☐ No

Q9. **If so, which of the following are you particularly concerned about?**
(rank in order by placing 1, 2 or 3 in the appropriate box)

- ☐ lakes/swamps drying up
- ☐ flooding
- ☐ restrictions on water usage
- ☐ increasing water charges
- ☐ proper management of groundwater use
- ☐ biting insects breeding in swamps
- ☐ preserving natural areas
- ☐ other _____
- ☐ don't know

Q10. **Is there a specific groundwater issue you are particularly concerned about?**

If so, what is it? _____

_____

_____

Whereabouts, specifically? _____

_____

_____

And now, a few questions about yourself.

Q11. **I work/go to school in:-** (tick the appropriate box)

- ☐ Wanneroo town
- ☐ Wanneroo rural area
- ☐ other suburb (where?) _____
- ☐ other rural area (where?) _____
- ☐ Perth city
- ☐ elsewhere (where?) _____
- ☐ don't work

Q12. **What type of work or study do you do?** (please tick appropriate box)

- ☐ professional/technical (Doctors, dentists, teachers, engineers, vets, lawyers etc.)
- ☐ administrative
- ☐ home duties
- ☐ clerical
- ☐ retail/wholesale
- ☐ primary workers (farmers, farm labourers, timber workers, fishermen, shearers etc.)
- ☐ miners/quarrymen
- ☐ transport/communication
- ☐ tradespeople (textile workers, electricians, carpenters, builders, hairdressers, labourers etc.)
- ☐ service/sport/recreation (policemen, firemen, park rangers etc.)
- ☐ armed services
- ☐ other _____
- ☐ don't work

or

Study.

What level of study do you do?

- ☐ primary
- ☐ secondary
- ☐ TAE
- ☐ tertiary (University/WAIT)
- ☐ Technical College/College of Advanced Education
- ☐ post graduate

Q13. **My age group is:-** (tick appropriate box)

- ☐ 5 - 9 yrs
- ☐ 10 - 14
- ☐ 15 - 19
- ☐ 20 - 24
- ☐ 25 - 29
- ☐ 30 - 34
- ☐ 35 - 39
- ☐ 40 - 44
- ☐ 45 - 49 yrs
- ☐ 50 - 54
- ☐ 55 - 59
- ☐ 60 - 64
- ☐ 65 - 69
- ☐ 70 - 74
- ☐ 75 +

Q14. **My sex is:-** (tick appropriate box)

- ☐ female
- ☐ male

Q15. **Finally, are there any other issues related to groundwater and its use that you would like to comment on?**(Please use the space below to describe)

_____

_____

_____

_____

_____

_____

_____

_____

Thank you for your time and assistance.

If you prefer to mail this back to us, the address is:-

Groundwater Survey
c/o Dames & Moore
26 Lyall Street
SOUTH PERTH 6151

* * * * *

Q16. If people put 2 issues in Q15 the second was placed under another label Q16.

Q17. Origin of Questionnaire

Wanneroo Agricultural Show
Wanneroo City Council
Wanneroo Shopping Centre
Mail Back

APPENDIX H

ENVIRONMENTAL REVIEW AND MANAGEMENT PROGRAMME GUIDELINES

Prepared by

Department of Conservation and Environment

August 1985

DEVELOPMENT OF THE GROUNDWATER RESOURCES OF THE GNANGARA MOUND: ERMP

GUIDELINES

ERMP to fulfill the requirements:

1. Promote public understanding of proposal and issues.
2. Enable EPA to give advice to Government.
3. To enable the overall programme to be considered, rather than component by component.

1. SUMMARY

2. EXECUTIVE SUMMARY - must be capable of standing alone.

3. INTRODUCTION

3.1 General

a) Role of W.A. Water Authority in providing water for public supply and for managing water resources.

b) Dependence of urban development of N-W Corridor on groundwater and time frame for development. Role of the Water Authority.

c) Management philosophy.

- water needs for urban development, including WAWRC input;
- water needs for non-urban uses;
- water needs to protect the environment;
- impact of other uses.

d) Philosophy of progressive environmental review and management. Amplify need for on-going review.

3.2 Objectives

In general.

To provide an overview of demands (public, private and environmental) for groundwater resources of the Gnangara Mound superficial aquifer; environmental impacts and management. Multidisciplinary approach to management.

In specific.

To examine the impact of development of the Pinjar and/or Lexia Schemes in the context of the above.

3.3 Statutory Requirements

a) Water legislation
b) Environment legislation
c) Pollution control legislation.

4. NEED FOR THE DEVELOPMENT

4.1 Implications of deletion of project

- Needs and benefits of the N-W Corridor versus rural, recreational and forest uses.

4.2 The scheme

- Dependence on groundwater to supply the water needs of N-W Corridor. Source development plan related to developmental pressures.

4.3 Alternative strategies

- Specific needs and time frame for Pinjar and/or Lexia Schemes; relative merits of these two schemes and alternatives.

5. EVALUATION OF ALTERNATIVES

Approach at two levels:

a) Use of water from Gnangara Mound; and

b) Relative impacts of Pinjar and/or Lexia Shemes.

- Do nothing option.
- Availability of water from other resources.
- Economic costs of providing water from other resources.
- Environmental costs of reliance on other sources, eg. modification of forest catchments.

6. DESCRIPTION OF PROPOSAL

- Overall concept: staging.
- Existing schemes.
- Pinjar and/or Lexia Schemes as part of the overall scheme - location and layout.
- Construction schedule (Pinjar and/or Lexia).
- Supporting structures, eg. treatment plants, etc.
- Operation after construction, eg. sludge disposal, water yields.
- Life of projects.

7. EXISTING ENVIRONMENT (details in Appendix; key issues in report)

General description of the Gnangara Mound in the setting of the coastal plain; appraisal of key physical and ecological systems likely to be affected. Brief resume of current land allocations.

(At both general level and specifically for Lexia and/or Pinjar).

7A. PHYSICAL ENVIRONMENT

Emphasis should be relevant to an evaluation of this proposal.

1) Climate.

- Rainfall - recharge and determinant of water demand.
- Temperature - determinant of water demand.
- Evaporation - determinant of water demand
  - environmental needs.

Comment briefly on dry seasons and runs of dry years, and extreme wet years and runs of such years. Implications for natural and human environment.

2) Geology.

- Physical characteristics as they relate to groundwater behaviour.

3) Landform and Soils.

- Land capability (fertility, carrying capacity), as it relates to water use and availability.

4) Hydrology.

- Surface drainage
- Wetlands.

7B. BIOLOGICAL ENVIRONMENT

1) Overview of Gnangara Mound ecosystem.

- Native vegetation;
- wetland vegetation;
- terrestrial fauna, reliance on freewater and native vegetation;
- wetland fauna, importance of wetlands in regional context;
- cave fauna.

2) Representation in conservation reserves. Relate vegetation communities to System 6 areas.

3) Rare species.

4) Specific examination of Pinjar and/or Lexia.

- McNess-Neerabup lake axis
- Lake Pinjar

Seasonal tributaries of Ellen Brook and the Short-necked - Tortoise swamps.

7C. HUMAN ENVIRONMENT

Emphasis should be on matters relevant to an evaluation of this proposal.

1) Land Status and Use.

- Past and current land uses; land tenure and zoning, including conservation and recreational aspects. In general terms for Gnangara Mound and in specific detail for Pinjar and/or Lexia.
- State forest.

2) Community Attitudes.

- Land use and trends in Wanneroo.
- Trends in land use - market gardens, intensive culture, hobby farms.

3) Groundwater Usage.

4) Historical and Archaeological.

8. ENVIRONMENTAL IMPACTS

1) Introduction.

Implications of groundwater usage.

2) General.

For Gnangara Mound as a whole:

- effects of natural stresses apart from human induced stress.

3) Physical.

4) Biological.

- effects of drawdown on native vegetation and forest;
- effects of drawdown on wetlands and caves.

5) Social.

- effects on availability of water for other uses;
- pollution control implications, limits imposed on future land use.

Specific

Issues for Pinjar and/or Lexia:

- Loch McNess-Neerabup lake axis;
- Ellen Brook tributaries and tortoise swamps;
- native vegetation;
- limits to availability of water for other uses;
- use of public water supply imposes limits on land use.

9. ENVIRONMENTAL MANAGEMENT

Discuss W.A. Water Authority approach to management. Outline performance at Wanneroo, Jandakot, Gwelup and Mirrabooka eg. annual reports.

In accordance with the philosophy of progressive environmental review and management, the following management programmes were devised.

1) Site management)
2) Physical environment) describe programmes for
3) Biological environment) management of identified
4) Human environment) impacts.

5) Monitoring programme: WA notes items V, VI, VII.

- water level and water quality;
- establishment of reference sites for biological monitoring, eg. transects.

6) Model capacity to assist in management: (effect of various management scenarios on water levels).

- assignment of water for maintenance of environmental quality, the problem and how to address the issue;
- allocation of water for private use, proclamation, licensing, metering?
- land use planning - land uses appropriate for land capabilities and water availability;
- model to be responsive to future monitoring data.

7) Commitment to review operational and environmental monitoring.

10. OTHER AMELIORATING ACTIONS

- such as pumping groundwater for the purpose of maintaining a surface stream or pool;
- re-charge from dams;
- deepening lakes.

11. MANAGEMENT OF CORRECTIVE ACTIONS

- commitment to contingency plans to manage and ameliorate adverse effects;
- commitment by the Water Authority to fulfil its role in managing the water resource, sustain this resource, and all associated environmental aspects identified in this ERMP.

12. CONCLUSION

Monitoring to ensure that impacts are maintained within acceptable limits. Need for land use plans to ensure that the land uses are compatible with resource availability.

13. REFERENCES

14. GLOSSARY

15. APPENDICES

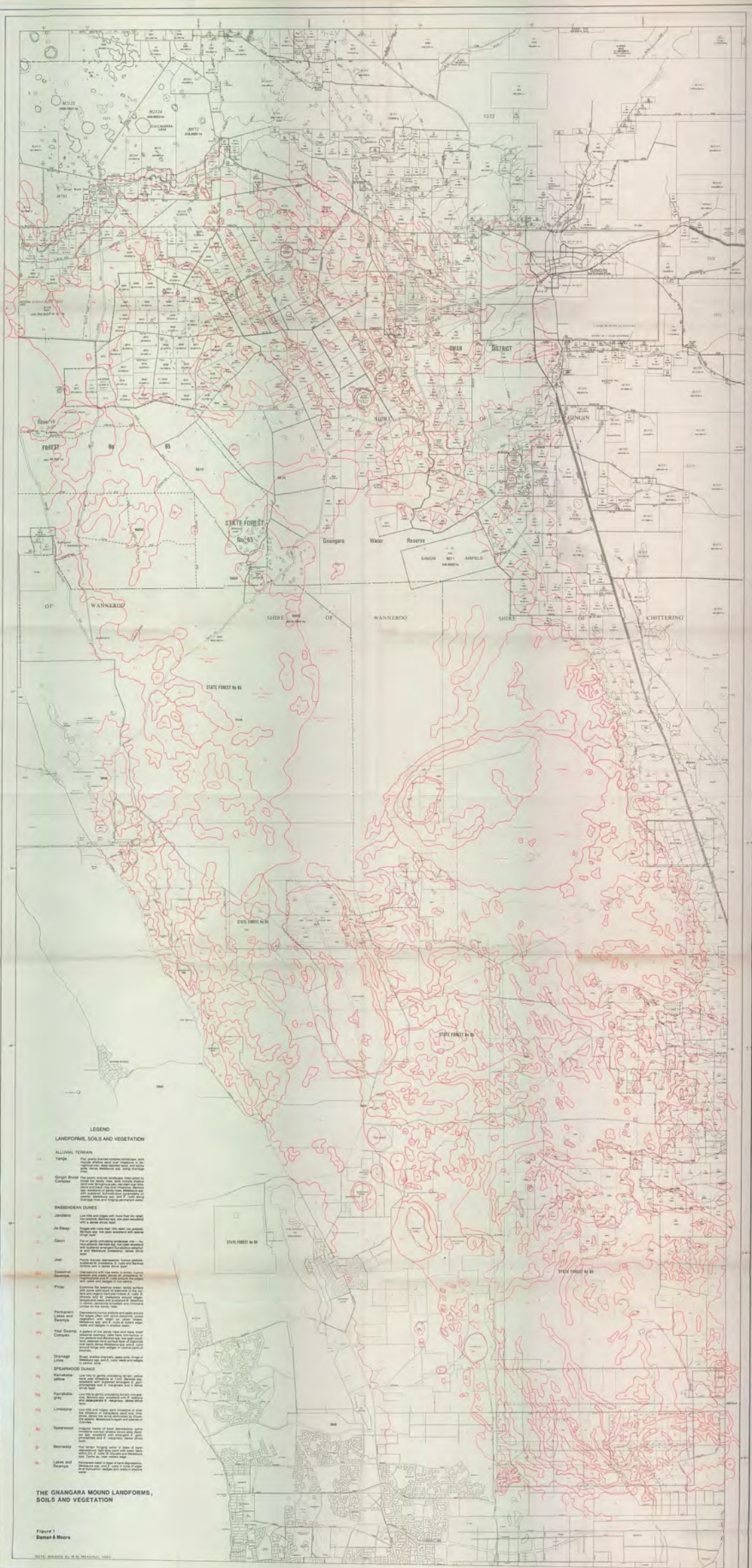
ERMP guidelines.

Relevant supporting technical information.

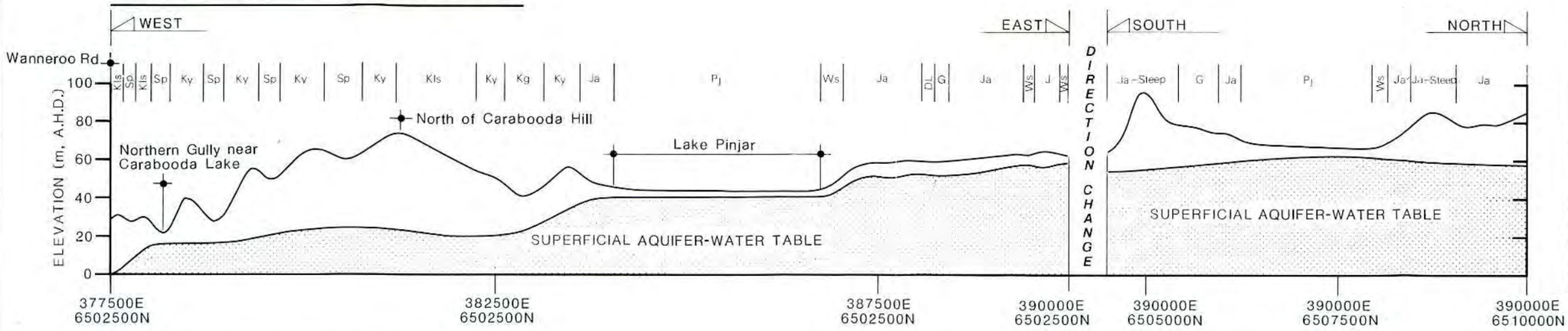
NB These Guidelines should be used in the context of the attached document 'Notes for the preparation of an ERMP'.

8 August 1985
RW/hl
RW151ZZZR1

FIGURES


SWAN DISTRICT
GINGIN SHIRE OF
WANNEROO SHIRE OF
CHITTERING SHIRE OF
STATE FOREST No 65
Gnangara Water Reserve
GINGIN MOA AIRFIELD
Reserve
FOREST No 65
STATE FOREST No 65
STATE FOREST No 65
STATE FOREST No 65
STATE FOREST No 65
LEGEND
LANDFORMS, SOILS AND VEGETATION
ALLUVIAL TERRAIN
Yanga.
Gingin Brook Complex
BASSENDEAN DUNES
Jandakot
Je-Steep
Gavin
Joel
Seasonal Swamps
Pinjar
Pemberton Lakes and Swamps
Yeal Swamp Complex
Drainage Lines
SPEARWOOD DUNES
Karrakatta-yellow
Karrakatta-grey
Limestone
Spearwood
Bexley
Lakes and Swamps
THE GNANGARA MOUND LANDFORMS, SOILS AND VEGETATION
Figure 1
Damsh & Moore

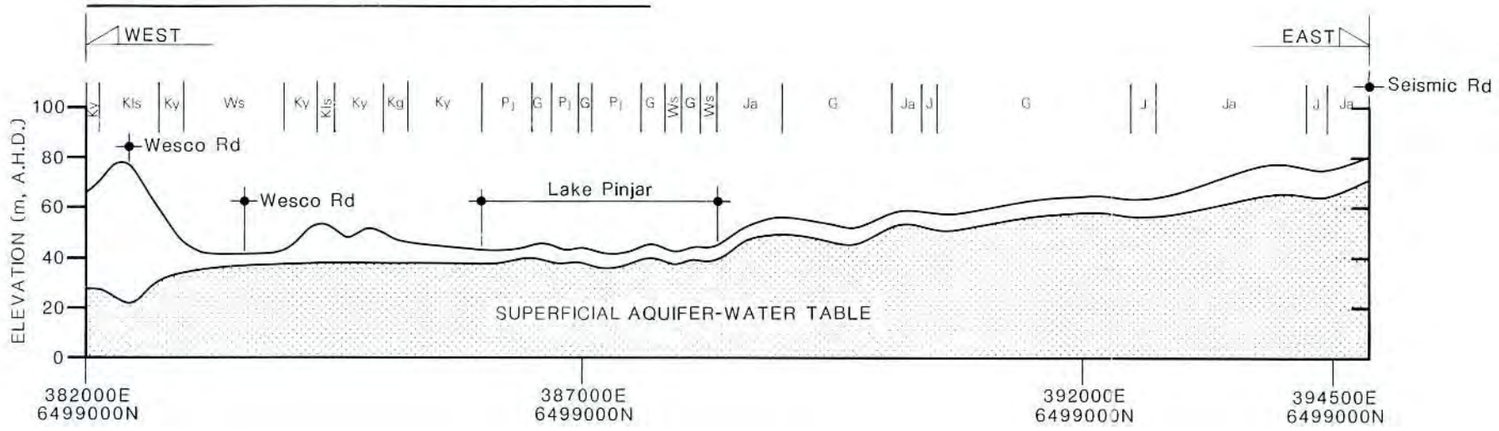
TRANSECT ONE-NORTHERN LAKE PINJAR



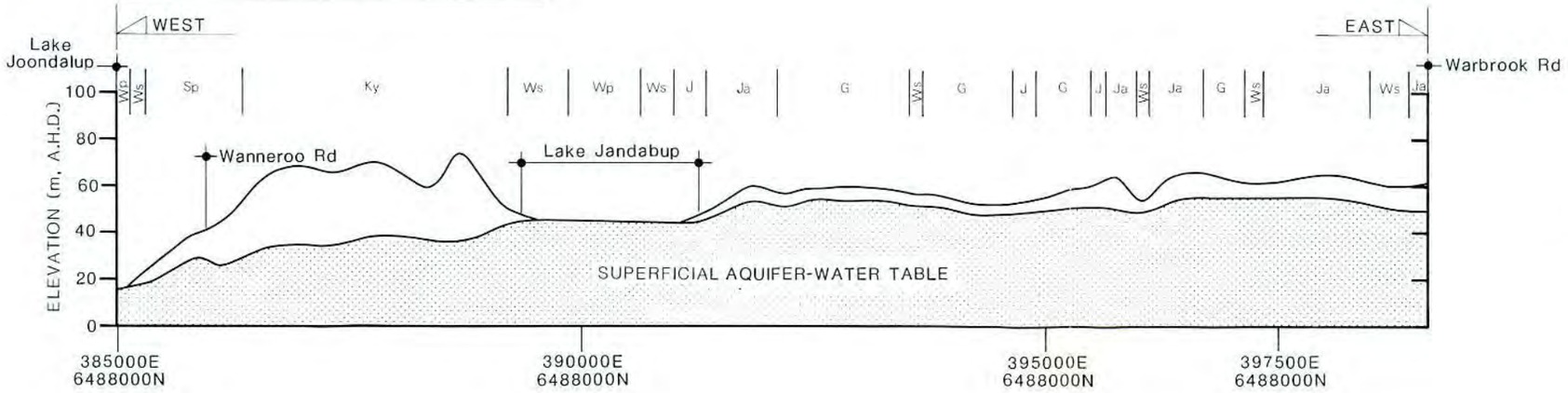
KEY TO LANDFORM & SOIL UNITS

Ky	KARRAKATTA SAND
Kg	KARRAKATTA SAND
Kls	KARRAKATTA-BARE LIMESTONE
Sp	SPEARWOOD
Ja	JANDAKOT
Ja-Steep	JANDAKOT
G	GAVIN
J	JOEL
Ws	WETLANDS SEASONAL
Wp	WETLANDS PERMANENT
Pj	PINJAR
DL	DRAINAGE LINES

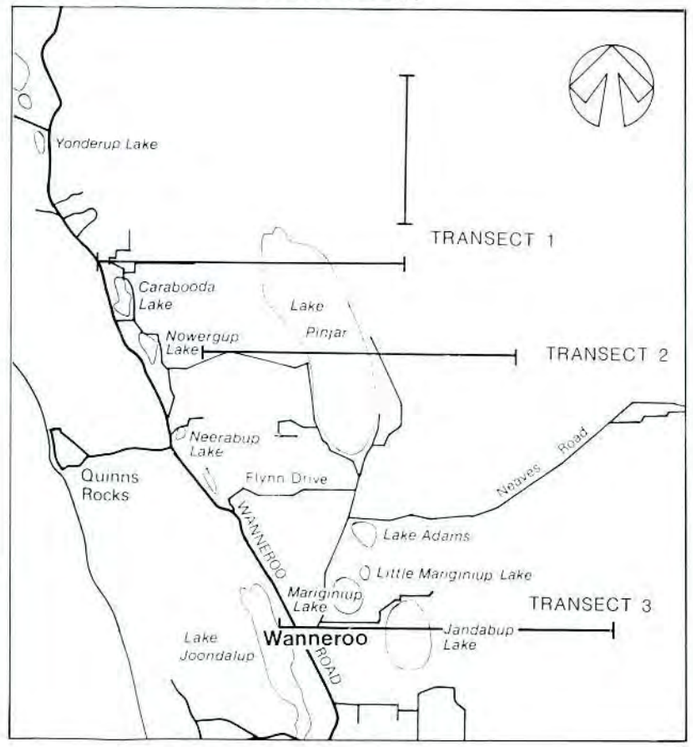
TRANSECT TWO-SOUTHERN LAKE PINJAR



TRANSECT THREE-LAKE JANDABUP



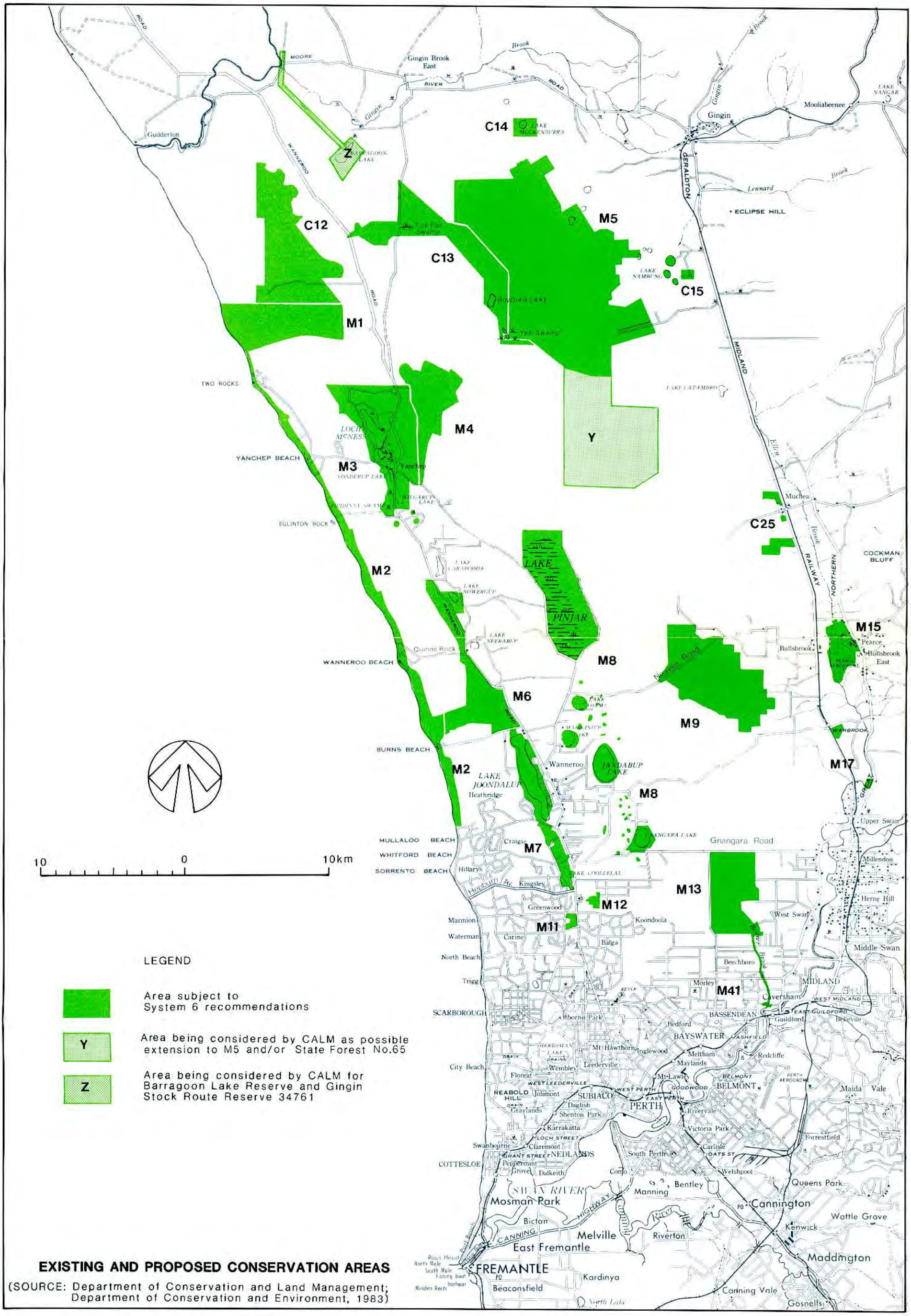
LOCATION MAP



SCHEMATIC REPRESENTATION OF RELATIONSHIPS BETWEEN ELEVATION, DEPTH TO WATER TABLE & LANDFORM-SOIL UNITS

Figure 2

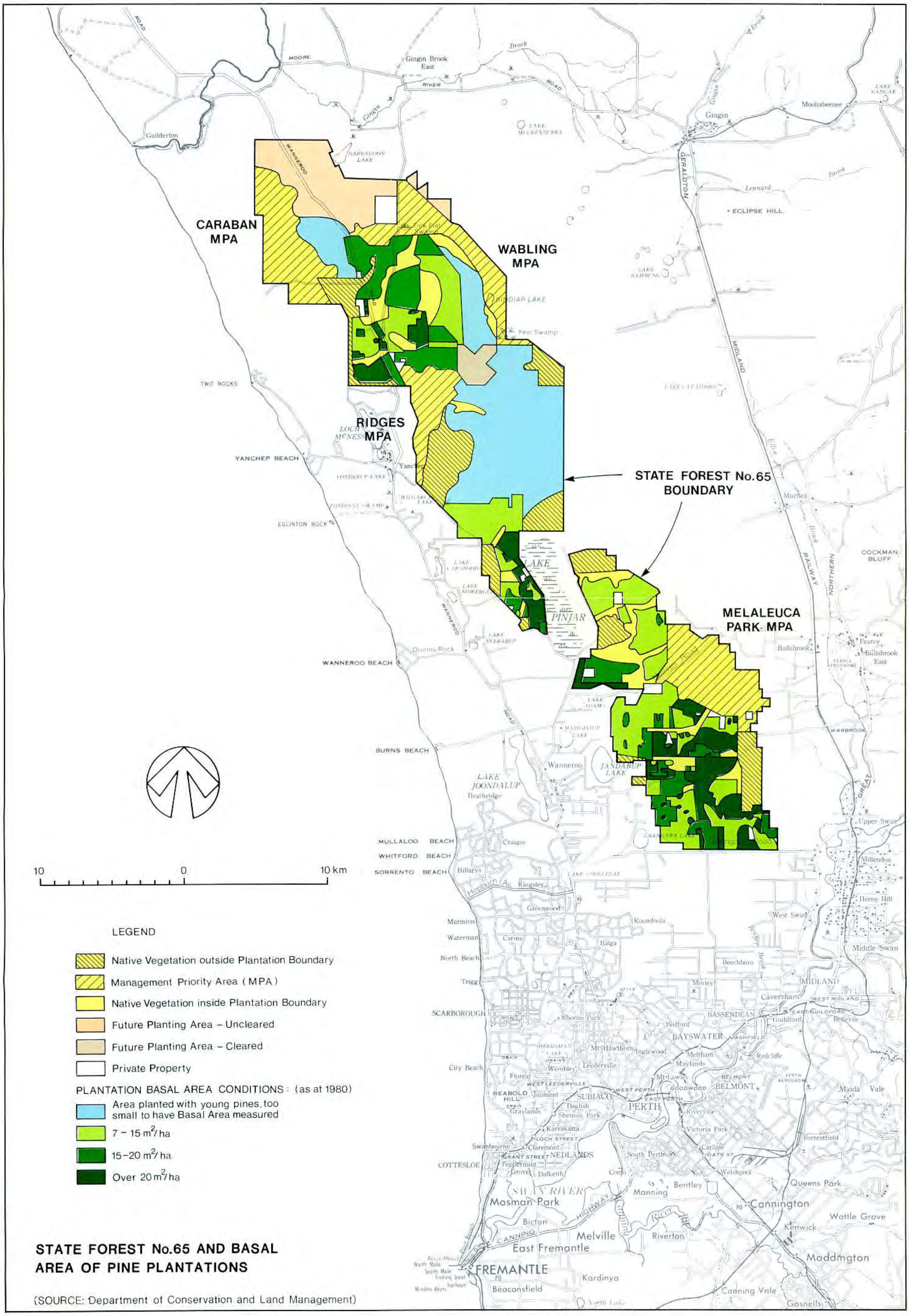
Dames & Moore



EXISTING AND PROPOSED CONSERVATION AREAS

(SOURCE: Department of Conservation and Land Management; Department of Conservation and Environment, 1983)

Figure 3
Dames & Moore



STATE FOREST No.65 AND BASAL AREA OF PINE PLANTATIONS

(SOURCE: Department of Conservation and Land Management)

Figure 4
Dames & Moore

NOTE: Reproduced with the permission of the State Planning Commission.

Wreck Point
Lake Yanchep
McNess
Eglinton Rocks
Wanneroo Beach
Burns Beach
Lake Joondalup
Wanneroo
Mariginiup Lake
Jandabup Lake
Gnangara Lake
Bullsbrook
GREAT NORTHERN HIGHWAY
BROCKMAN RIVER
AVON RIVER
Upper Swan
Whitfords Beach
Hillarys
Baiga
Morley
Scarborough
Yokine
Bassendean
Bayswater
Guildford
SWAN RIVER
Midland
Greenmount
Sawyers Valley
Mundaring
GREAT EASTERN HIGHWAY
Chidlow
Wooroloo
HELENA RIVER
INDIAN OCEAN
City Beach
Wembley
Belmont
Perth Airport
Maida Vale
Kalamunda
Helena River Reservoir
South Perth
Victoria Park
SWAN RIVER
Lesmurdie
Bickley
Cannington
Attadale
Kenwick
Pickering Brook
Melville
Maddington
Fremantle
North Lake
Bibra Lake
Jandakot Airport
Gosnells
Karragullen
Spearwood
Coogee
Jandakot
CANNING RIVER
Kelmscott
RIVER
Araluen
Lake Coogee
Woodman Point
Forrestdale
Thompson Lake
Forrestdale Lake
SOUTHERN RIVER
Canning Reservoir
COCKBURN SOUND
Armadale
Bedfordale
Wungong
Naval Base
Garden Island
Mandogalup
WUNGONG BROOK
ALBANY HIGHWAY
Kwinana
Wungong Reservoir
Byford
Medina
MANGLES BAY
Gleneagle
Rockingham
Lake Cooloongup
Mundijong
WARNBRO SOUND
SERPENTINE RIVER
WESTERN HIGHWAY
Jarrahdale
Lake Walyungup
Serpentine
Becher Point
Serpentine River Reservoir
Keysbrook
SOUTH WESTERN HIGHWAY

METROPOLITAN REGION SCHEME
PERTH, WESTERN AUSTRALIA

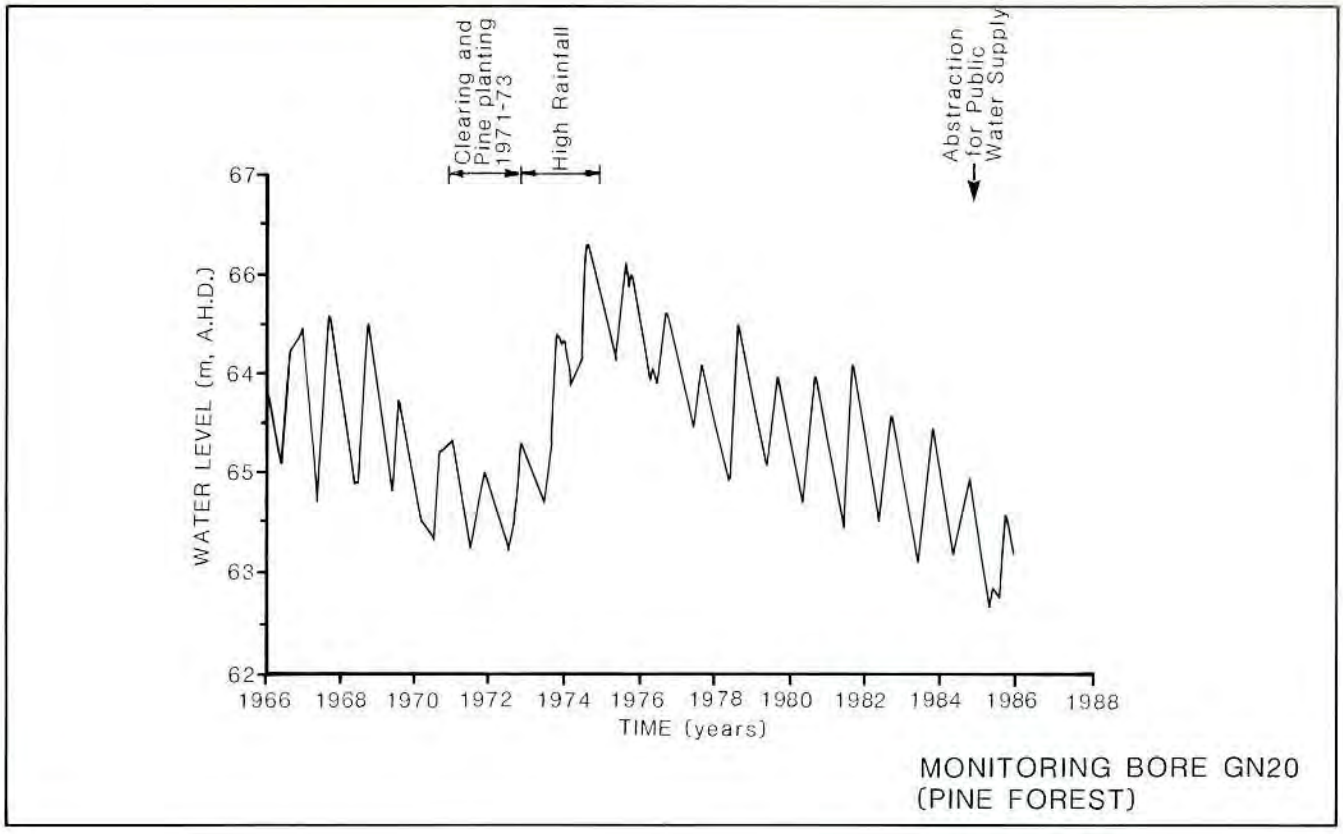
- Urban
- Urban Deferred
- Central City Area
- Industrial and Special Industrial
- Rural
- Public Purposes
- Railways and Port Installations
- Parks and Recreation
- State Forests
- Scheme Boundary
- Controlled Access and Other Major Highways

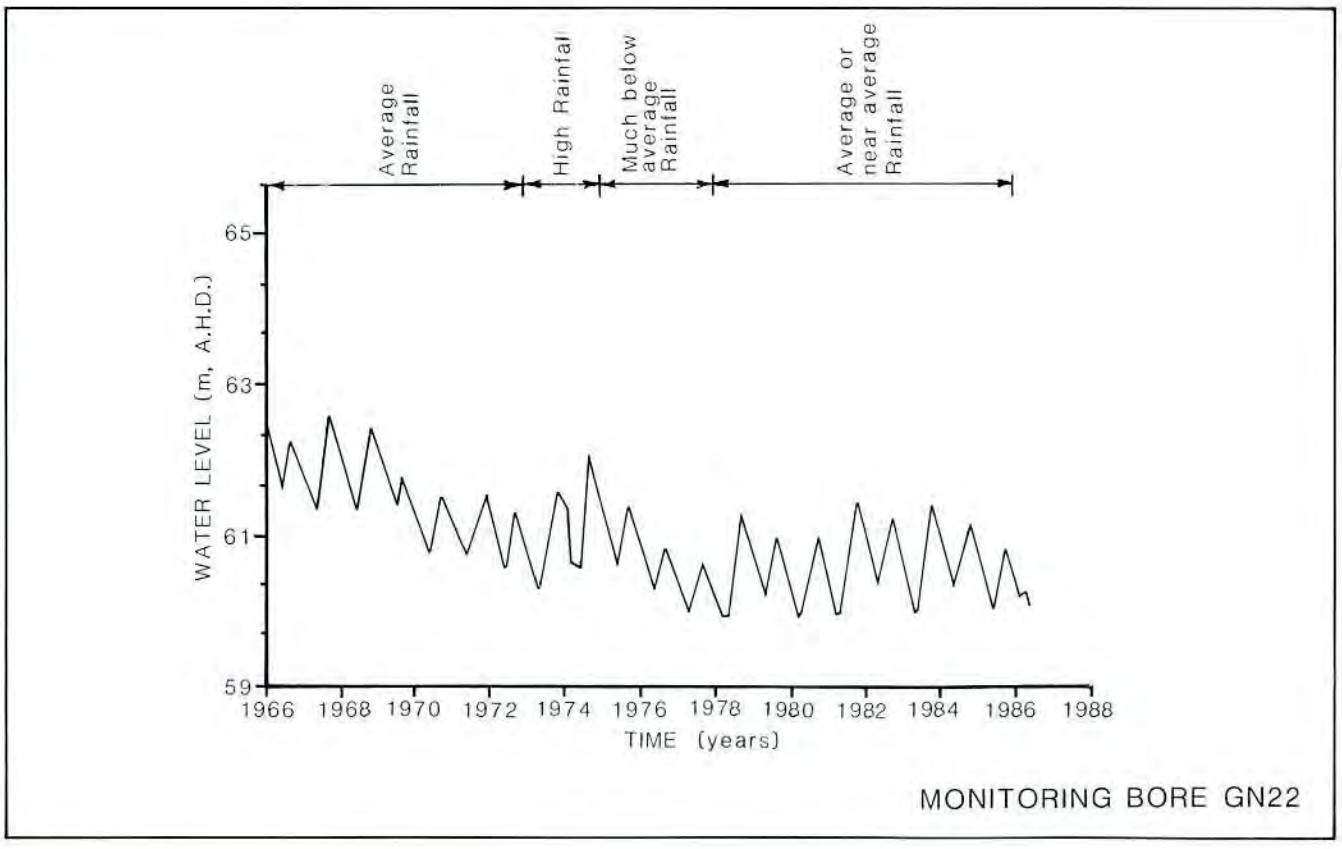
kilometres
0 5 10

Note: This map does not show all details of the Metropolitan Region Scheme. It is a simplification only.

Town Planning Department, Perth, Western Australia.
H. J. Tipping, Chief Draftsman. 1st JANUARY 1984

Figure 5
Dames & Moore

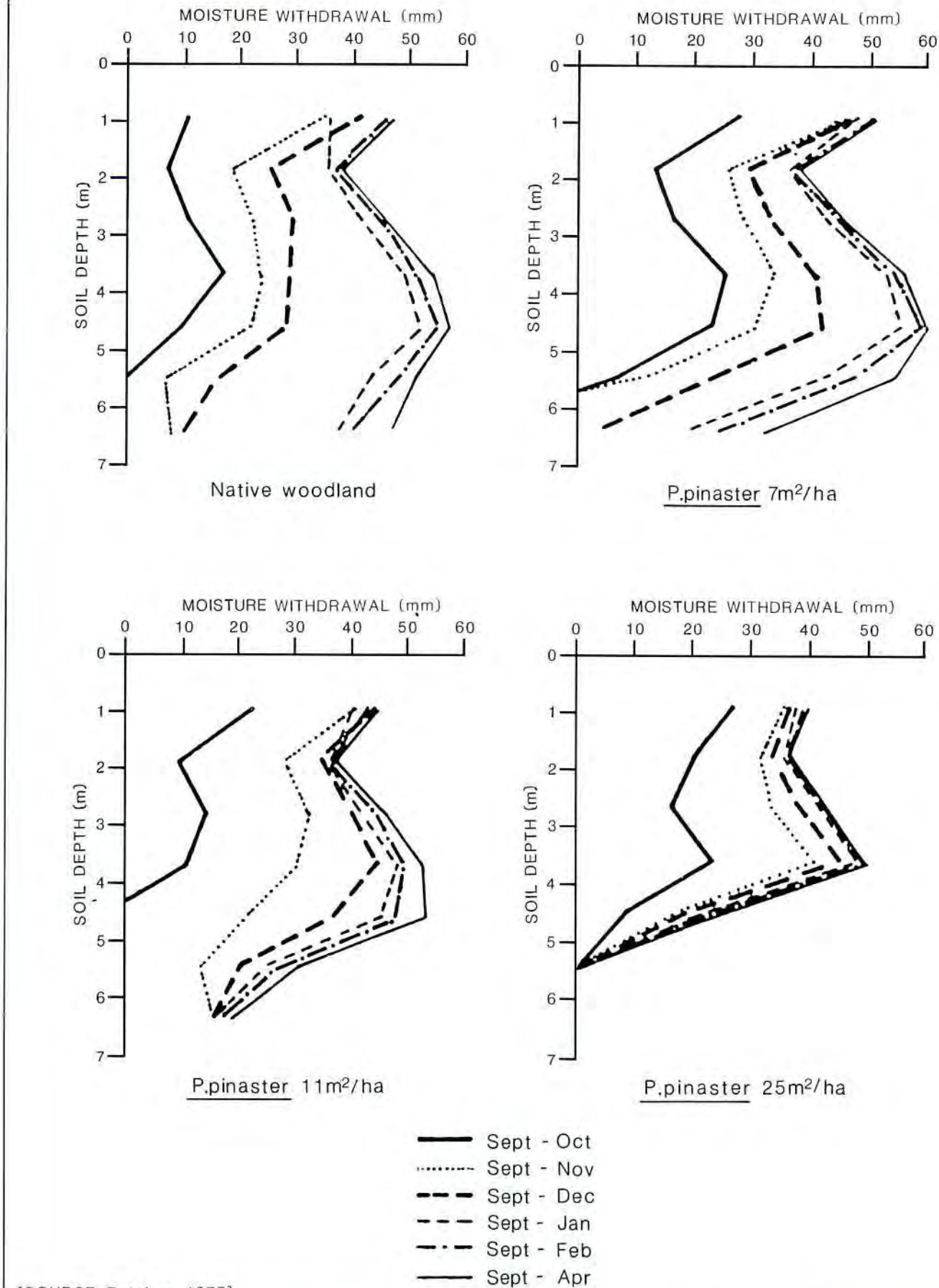




EFFECT OF CLEARING NATIVE WOODLAND & PLANTING OF PINES ON WATER TABLE

(SOURCE: Water Authority)

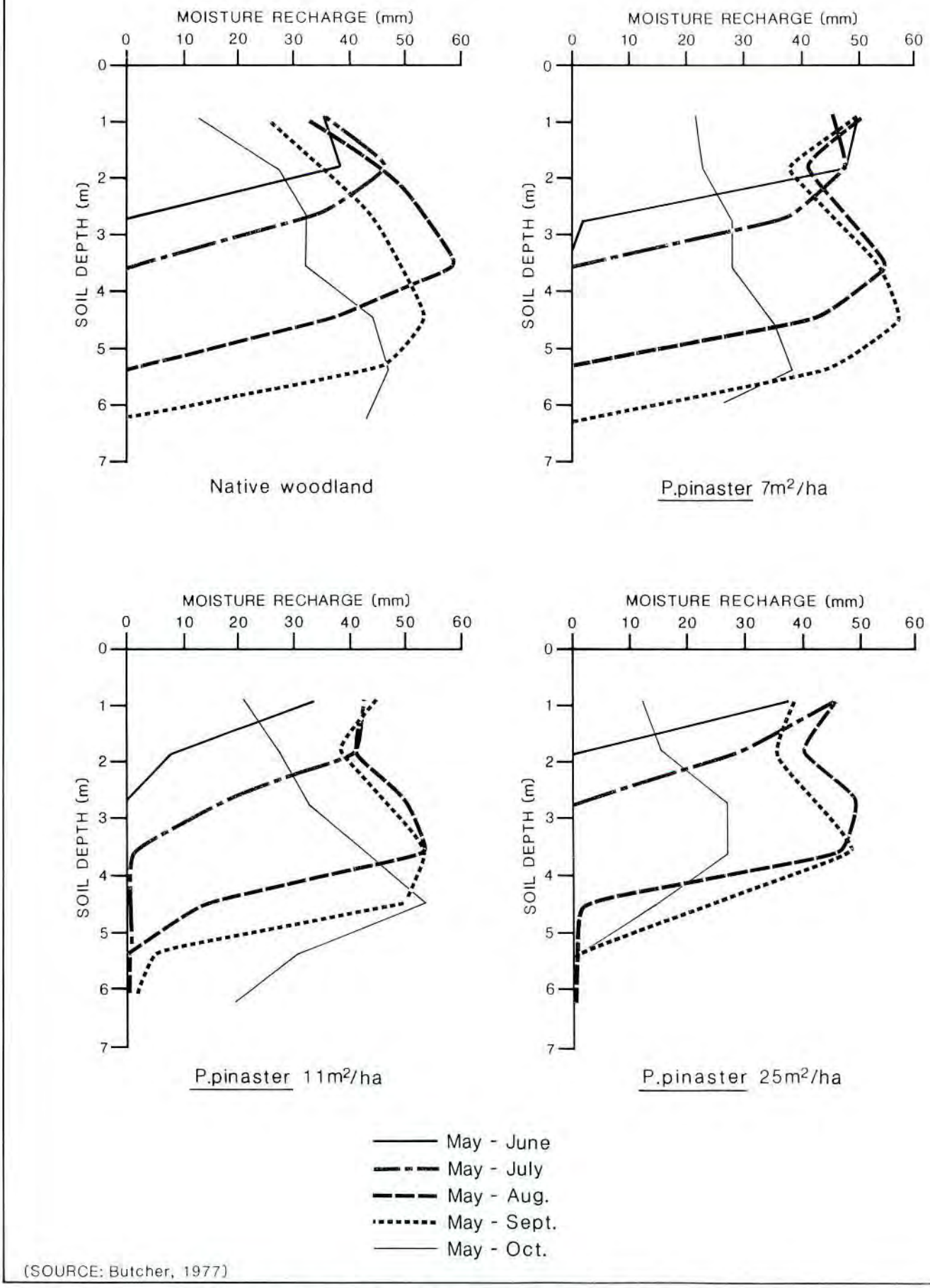
Figure 6
Dames & Moore



(SOURCE: Butcher, 1977)

SOIL MOISTURE WITHDRAWAL OF VARIOUS FOREST TYPES

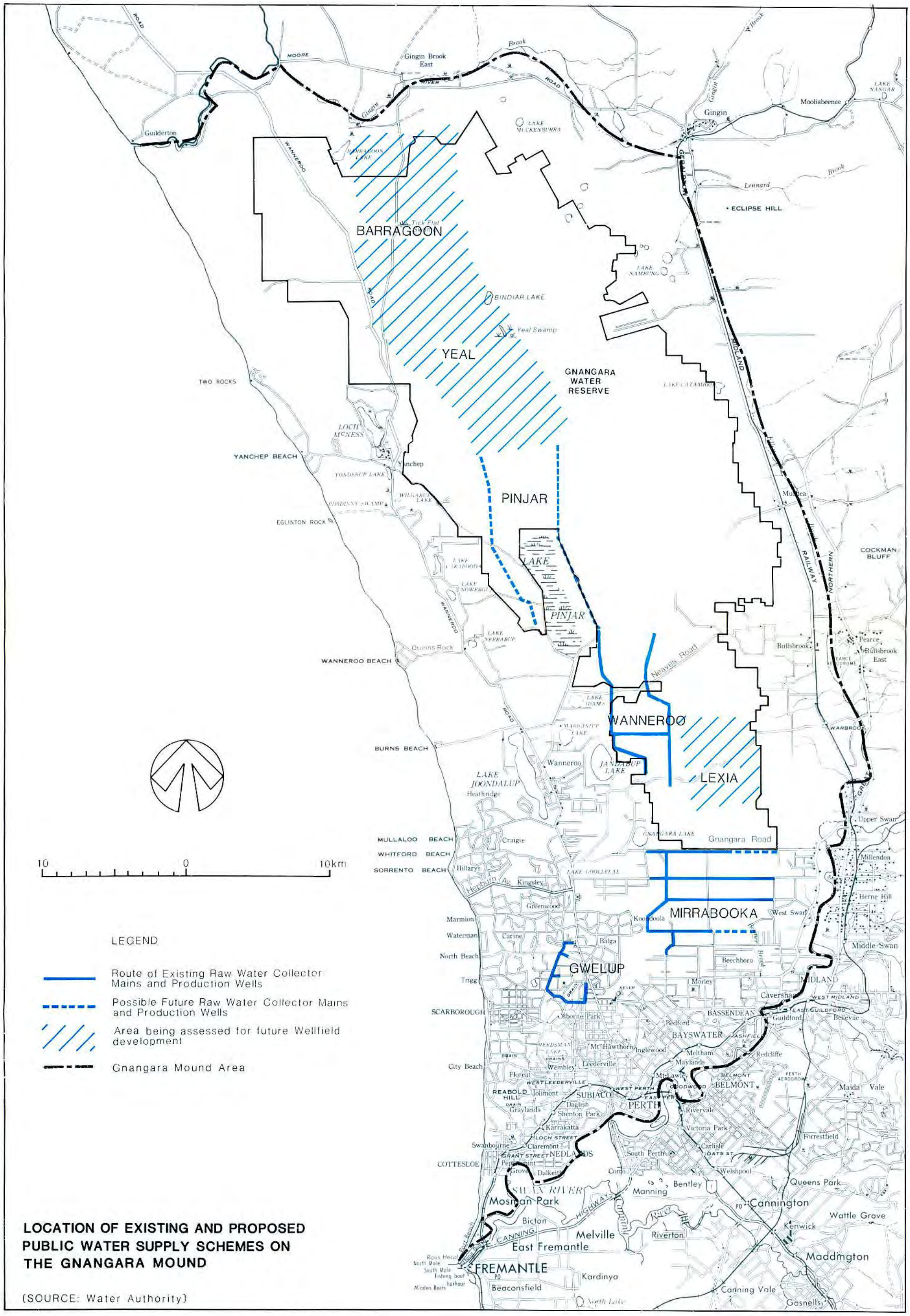
Figure 7
Dames & Moore



(SOURCE: Butcher, 1977)

GROUNDWATER RECHARGE OF VARIOUS FOREST TYPES

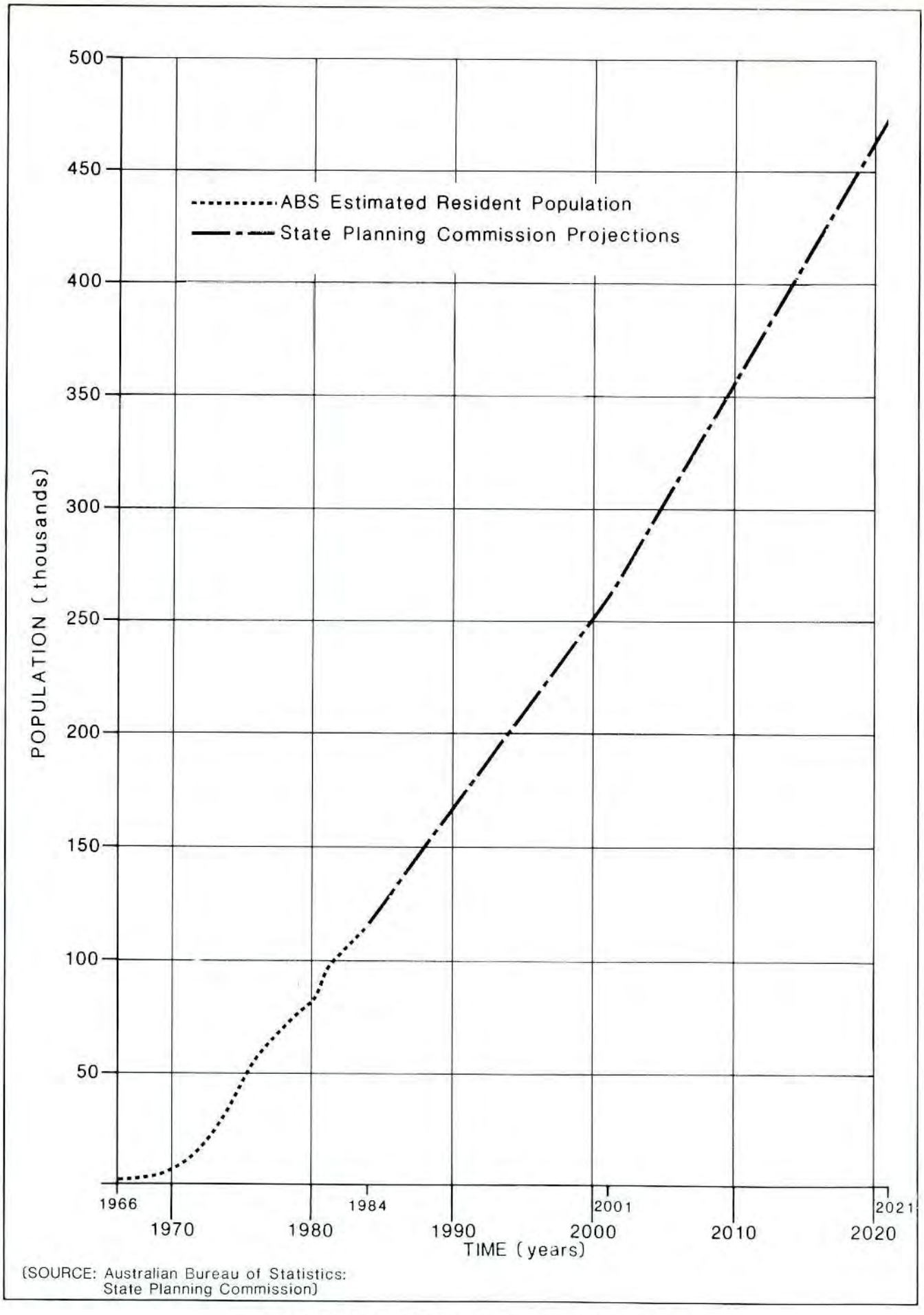
Figure 8
Dames & Moore



LOCATION OF EXISTING AND PROPOSED PUBLIC WATER SUPPLY SCHEMES ON THE GNANGARA MOUND

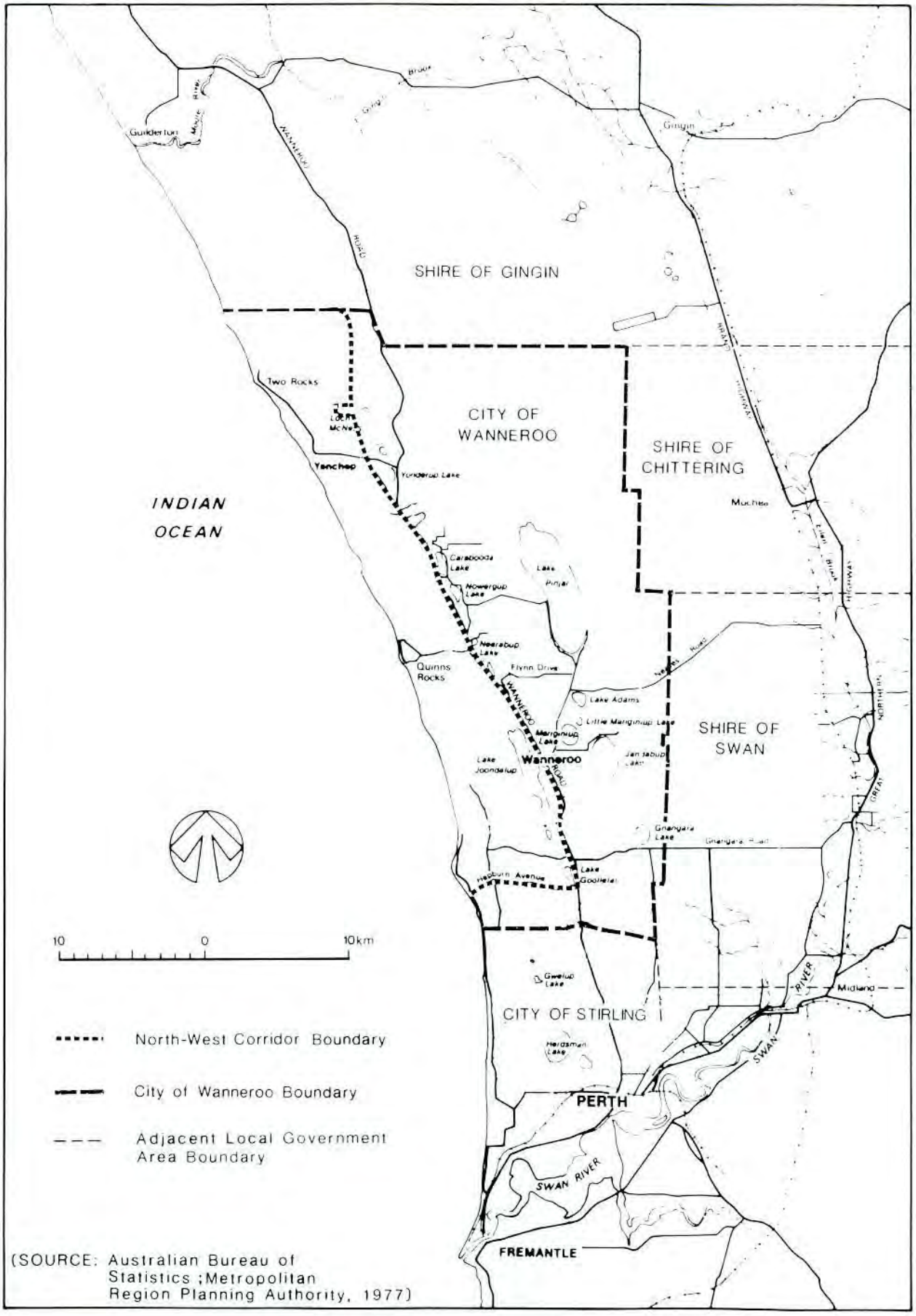
(SOURCE: Water Authority)

Figure 9
Dames & Moore



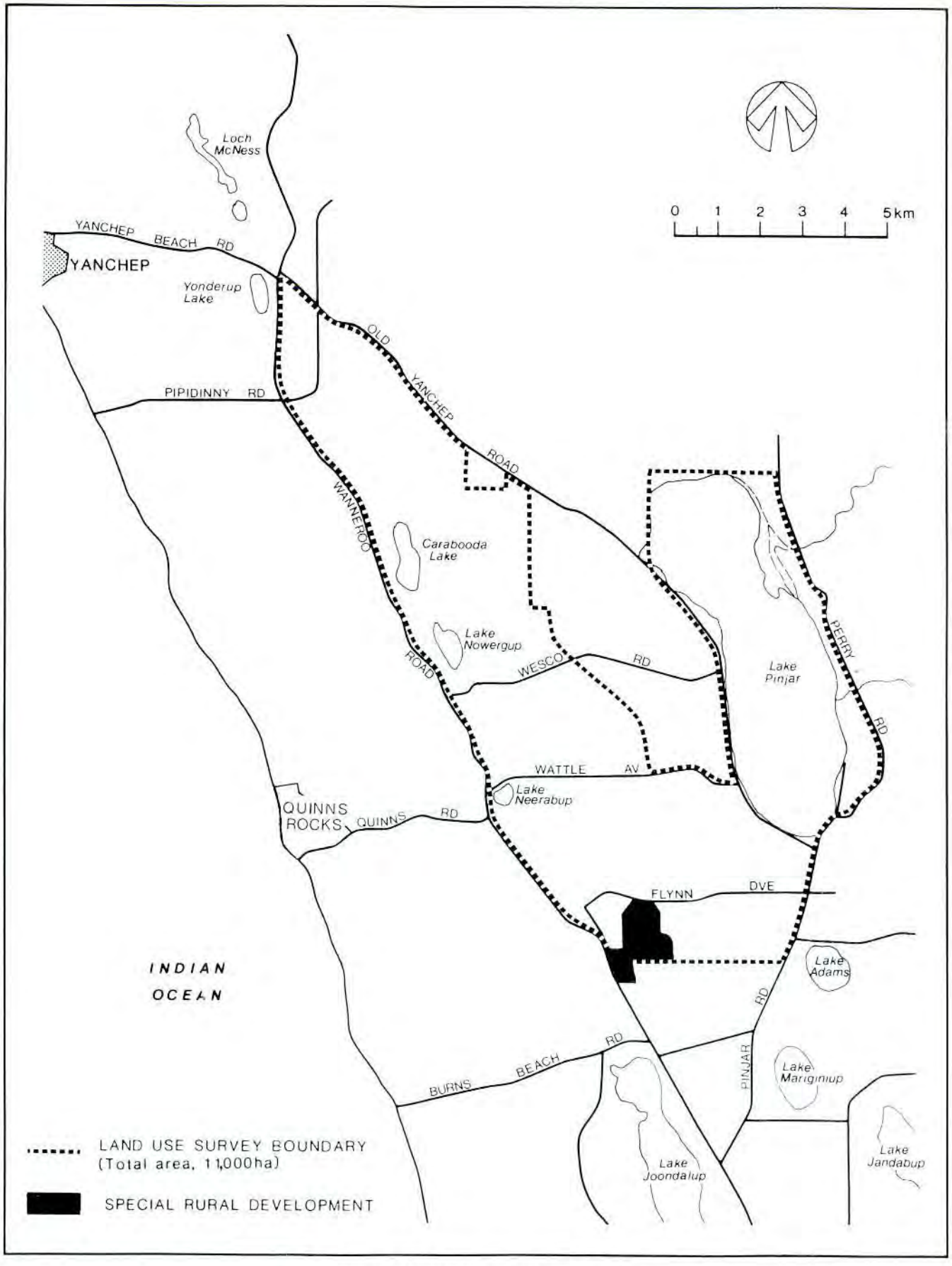
CITY OF WANNEROO POPULATION TRENDS

Figure 10
Dames & Moore



NORTH-WEST CORRIDOR AND CITY OF WANNEROO

Figure 11
Dames & Moore



1985 LAND USE SURVEY AREA

Figure 12
Dames & Moore