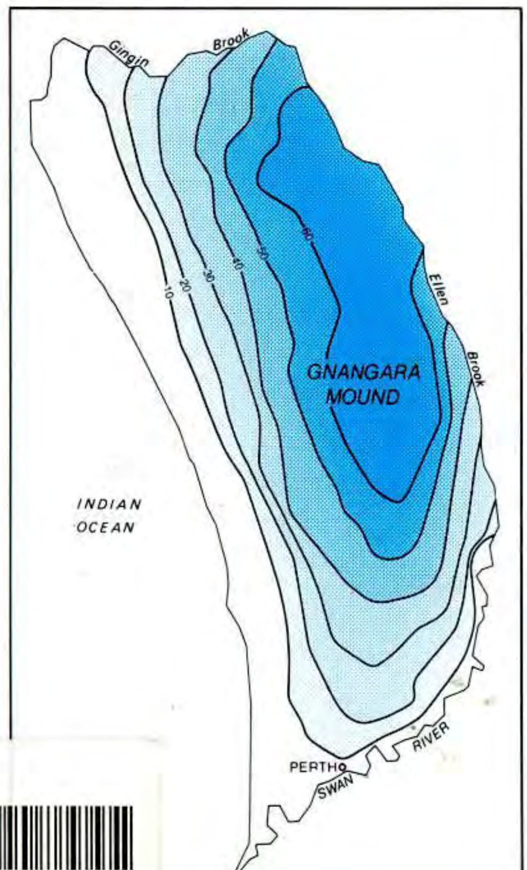
Water Authority
of Western Australia

GNANGARA MOUND GROUNDWATER RESOURCES

ENVIRONMENTAL REVIEW
AND
MANAGEMENT PROGRAMME



November 1986

Water Authority
of Western Australia

WATER RESOURCES DIRECTORATE
Water Resources Management Branch

GNANGARA MOUND GROUNDWATER RESOURCES

ENVIRONMENTAL REVIEW AND MANAGEMENT PROGRAMME

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GNANGARA MOUND GROUNDWATER RESOURCES ENVIRONMENTAL REVIEW AND MANAGEMENT PROGRAMME

The Environmental Protection Authority (EPA) invites people to make a submission on this proposal.

This Environmental Review and Management Programme (ERMP) for the proposed further development and management of the shallow groundwater resource, known as the Gnangara Mound, has been prepared by the Water Authority of Western Australia in accordance with Western Australian Government procedures. The report will be available for comment for 16 weeks, beginning on November 5, 1986 and finishing on February 25, 1987.

Comments from Government agencies and from the public will assist the EPA to prepare an Assessment Report in which it will make a recommendation to Government.

The ERMP provides a detailed analysis of issues relevant to the continued development and management of the Gnangara Mound.

WHY WRITE A SUBMISSION?

A submission is a way to provide information, express your opinion and put forward your suggested course of action including any alternative approach. It is useful if you indicate any suggestions you have to improve the proposal.

All submissions received will be acknowledged.

DEVELOPING A SUBMISSION

You may agree or disagree, or comment on, the general issues discussed in the ERMP or with specific proposals. It helps if you give reasons for your conclusions, supported by relevant data.

You may make an important contribution by suggesting ways to make the proposal environmentally more acceptable.

When making comments on specific proposals in the ERMP

- clearly state your point of view;
- indicate the source of your information or argument if this is applicable; and
- suggest recommendations, safeguards or alternatives.

POINTS TO KEEP IN MIND

By keeping the following points in mind, you will make it easier for your submission to be analysed:

Attempt to list points so that the issues raised are clear. A summary of your submission is helpful.

Refer each point to the appropriate section, chapter or recommendation in the ERMP.

If you discuss different sections of the ERMP, keep them distinct and separate, so there is no confusion as to which section you are considering.

Attach any factual information you wish to provide and give details of the source. Make sure your information is accurate.

Please indicate whether your submission can be quoted, in part or in full, by the EPA in its Assessment Report.

REMEMBER TO INCLUDE

YOUR NAME

ADDRESS

DATE

THE CLOSING DATE FOR SUBMISSION IS: February 25, 1987.

SUBMISSIONS SHOULD BE ADDRESSED TO:

The Chairman,
Environmental Protection Authority
1 Mount Street
PERTH WA 6000

Attention: Mr. C. Murray

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1.0 SUMMARY

This report presents a strategy for managing the shallow groundwater resource, known as the Gnangara Mound, located between the Swan River and Gingin Brook (Figure 1). It also examines alternatives for providing water to the rapidly expanding North-West Corridor where the demand will exceed the existing supply by 1989.

The report has been prepared to meet the requirements of the Environmental Protection Authority (EPA) for an Environmental Review and Management Programme (ERMP) of proposed developments over the Gnangara Mound. It also serves as a baseline, providing an overview of the existing and potential developments in the Gnangara Mound area and assesses strategies for the effective management of the groundwater resource.

INTRODUCTION

The Water Authority of Western Australia (Water Authority) is responsible for managing the State's water resources for the maximum benefit of the whole community. The Authority is also responsible for providing scheme water for public supplies at least cost, subject to financial, social and environmental objectives.

Groundwater makes up half of the available water resources of the Perth-Mandurah region. This significant resource already provides people in the Metropolitan area with a third of their scheme water supplies and provides all of the supply to the North-West Corridor, where the population is expected to double by the year 2001. Shallow groundwater is also used to irrigate vegetables, flowers and other products. It provides water for irrigating suburban gardens and maintains lakes, swamps and other environments.

A major consideration in the management of groundwater resources is the maintenance of wetlands. Groundwater usage must be managed to ensure that important wetlands are not significantly affected.

Groundwater from the Gnangara Mound can meet the requirement for additional public water supplies, without significantly constraining the other demands on the resource.

The strategy presented contains:

- o an overall approach to management of the Gnangara Mound groundwater resource,
- o a conceptual proposal for further public water supply developments on the Gnangara Mound as a whole, and
- o a detailed proposal for a public water supply scheme to be developed in the Pinjar area in 1989.

ALTERNATIVE SUPPLY SOURCES

All feasible sources of water for public supply are evaluated by the Water Authority. Proven sources are listed in a Sources Development Timetable. Each one is ranked according to its cost of development. Providing environmental and social objectives can be met, the most economic sources are developed first.

Alternative sources on the Sources Development Timetable for supplying the North-West Corridor include:

- o groundwater from the Gnangara Mound,
- o surface water from large new dams on the rivers in the Darling Range, and
- o surface water from small pipehead dams pumping back to existing dams.

Other alternatives, which mainly for reasons of cost, are not listed on the timetable include:

- o groundwater north of Gingin Brook,
- o surface waters outside the Perth-Mandurah region, and
- o desalination.

Environmental and social evaluations indicate that development of any alternative on the Sources Development Timetable will have some adverse effects and will require careful management.

The groundwater resources of the Gnangara Mound area are the most economic sources on the timetable and they can be developed in parallel with northward expansion of the North-West Corridor. The next proposed development is the Pinjar Scheme. This report outlines the proposed development of the Pinjar Scheme (Figure 51) with its three stages and provides conceptual wellfield layouts for other Schemes. If the first stage of the Pinjar Scheme were deleted it would cost the Perth Metropolitan community an extra \$0.9 million annually to develop alternative sources. Deletion of all of the proposed Gnangara Mound sources would cost about \$16 million per year.

ENVIRONMENTAL ISSUES AND THEIR MANAGEMENT

Natural Ecosystems

Each year rainfall contributes about 1700 million cubic metres of water on average to the Gnangara Mound area. About 1200 million cubic metres of this is evaporated or transpired from plants. The remaining 500 million cubic metres recharges the Gnangara Mound.

Prolonged periods of below average rainfall occur, with the last 10 years being the driest since records commenced in 1876. Lake and groundwater levels fluctuate both seasonally and in response to long term rainfall trends. Groundwater levels in the region are generally depressed following the recent run of dry years.

The summer period of lowest water levels and highest water demand is the time of greatest environmental stress.

The plants and animals of the Gnangara Mound area are adapted to the regime of fluctuating groundwater levels. The most sensitive ecosystems are the wetlands, which are sustained by groundwater. Ecosystems associated with the deep lakes such as Lake Joondalup are less sensitive to water level changes than those associated with shallower lakes like Lake Jandabup. Some plants and animals with restricted distributions, such as the rare orchid Thelymtra carnea and the Short-necked Tortoise rely on wetlands. None of these restricted species are known to be threatened by the proposed Pinjar groundwater development.

To effectively manage groundwater for the maintenance of wetlands, the Water Authority requires guidelines from the Department of Conservation and Environment (DCE) and the Department of Conservation and Land Management (CALM) on acceptable criteria for seasonal and longer term water level fluctuations.

The development of such criteria must take into account the sensitivity of specific areas. On-going research is currently aimed at developing these criteria. Until these criteria are developed, it has been necessary to determine an interim guideline. Following discussions with officers of DCE and CALM, a change in water level of half a metre has been adopted for the most environmentally sensitive areas, because changes less than this are within the natural seasonal fluctuation and are considered unlikely to have significant effects. This guideline will be reviewed as additional information becomes available.

Sandy upland ecosystems are generally less sensitive to water level changes and are more widespread than wetland ecosystems. On upland sites, woodland species which rely on the water table may be replaced, over small areas near wells, by other woodland species which are not water table dependent. The woodland character of these sites would be retained.

Forestry

Land within State Forest No. 65 is managed for multiple uses by CALM. The priority land use over most of this area is water production. Twenty thousand hectares overlying the Gnangara Mound area are planted with pines. Groundwater abstraction from upland sites does not affect timber production because the pines there do not depend on the deep water table. On lowland sites where the water table is closer to the surface, pine productivity may decrease if water levels decline.

Dense pine canopies intercept and evaporate much of the incoming rainfall, leading to a reduction in groundwater recharge. Recharge may be significantly increased by thinning the pines. Thinning also increases the yield of high value sawlog timber, making water and timber production very compatible.

Social Issues

Groundwater makes an important contribution to the livelihood and lifestyle of both urban and rural people in the Gnangara Mound area. A study of community attitudes to groundwater development and management has identified the following key points.

- o Wetlands are considered important by both rural and urban dwellers.
- o Market gardening is considered to be an important long term land use in the area.
- o Rates and charges for government services are of particular concern.
- o People recognise the need for equitable groundwater management.

Evaluation of historical and archaeological sites has shown that none would be affected by development of the Pinjar Scheme.

SIMULATING THE EFFECT OF GROUNDWATER USE AND MANAGEMENT

A computer model has been used to simulate the effects of over 30 groundwater use and management scenarios. This model was used to optimise the conceptual location of the proposed public water supply schemes as a whole and the abstraction pattern of the Pinjar Scheme in particular. This approach has developed a strategy to reduce effects on sensitive wetlands and limit competition with private users. The modelling has also shown the benefits of thinning pine plantations and enabled preferred private abstraction quotas to be defined.

PREFERRED DEVELOPMENT STRATEGY

The following development and management strategy is preferred for the Pinjar Scheme, private water developments and State Forest No. 65.

Pinjar Scheme

- o 28 wells in the superficial formations distributed as shown in Figure 51.
- o Abstraction to be distributed within the scheme as follows:
  - 7 wells in the southern half of the western line each producing 165,000 cubic metres per year.
  - 7 wells in the northern half of the western line each producing 500,000 cubic metres per year.
  - 14 wells on the eastern line each producing 670,000 cubic metres per year.

Private Development

- Allocation of 21 million cubic metres per year for private abstraction from the Wanneroo Groundwater Area, to the south of Flynn Drive (in accordance with the current allocation quota).
- Allocation of 15 million cubic metres per year for private abstraction from the Wanneroo Groundwater Area, to the north of Flynn Drive.

State Forest No. 65

- Maintenance of pine plantation basal areas at levels consistent with the priority land use of water production in State Forest No. 65.

MANAGEMENT AND COMMITMENTS

The preferred Pinjar Scheme layout and abstraction strategy, private allocation quotas and forest management are designed to ensure that the resultant water level declines are less than half a metre, in sensitive wetlands in conservation areas.

The Water Authority undertakes to carry out management and monitoring commitments as detailed in Section 11 and listed in Table 27. In summary these are:

- Manage public and private abstraction.
- Appropriate monitoring of groundwater levels and quality, fauna, vegetation condition and social issues, assess effects and review public and private abstraction if required.
- Work with CALM to facilitate plantation management consistent with the priority land use of water production in State Forest No. 65 and review as necessary.
- Work with Mines Department, State Planning Commission and DCE to facilitate joint land and water management consistent with planning, water supply and environmental objectives and review as necessary.
- Provide annual reports to the EPA on the management of the regional groundwater resources.
- Further assess, as required by the EPA, the proposed Lexia, Yeal and Barragoon public water supply schemes.

- o Provide assistance to DCE and CALM to develop criteria for wetland management.
- o Participate in public meetings during the ERMP review period.
- o Prepare a demand management strategy and support the Western Australian Water Resources Council groundwater management study team.
- o Maintain public representation on the Wanneroo Groundwater Advisory Committee.

The Authority will report annually to the EPA on the results of this monitoring and management.

CONCLUSIONS

The Gnangara Mound contains a significant groundwater resource capable of providing for public and private water needs as well as the environment.

Public water supply schemes have been conceptually designed and modified to provide for public, private and environmental water requirements.

Management of pine plantations is an integral part of management of the groundwater resource of the Gnangara Mound.

The Pinjar Scheme has been identified as the most cost effective means of supplying the increased need for water in the North-West Corridor. This ERMP demonstrates that implementation of effective groundwater management will enable this scheme to be commissioned in 1989, while still providing for private and environmental requirements.

2.0 INTRODUCTION

2.1 BACKGROUND

The Water Authority of Western Australia (Water Authority) is responsible for planning and managing the development of the water resources of Western Australia. The Water Authority assesses the resources available and prepares and implements strategies for development, management and conservation of the water resources.

While there are significant unutilised water resources within Western Australia, they are unevenly distributed and must be carefully managed to ensure that they provide the optimum benefit to the whole community.

In the Perth-Mandurah region groundwater makes up 51% of the available water resource (Western Australian Water Resources Council, 1984). It is important for irrigation, stock supplies, maintenance of wetlands, native vegetation and pine plantations, as well as providing about 33% of current scheme water supplies. The remainder of the public water supply comes from surface or "Hills" sources.

The Gnangara Mound is the name given to the shallow groundwater between the Swan River and Gingin Brook (Figure 1). As well as maintaining wetlands in the region, it is ideally located to serve the needs of horticulturalists close to Perth markets and the requirement for additional domestic supplies as Perth expands northwards. As a result, there are competing demands for the resource in some areas.

The North-West Corridor is the developing urban area between the coast and Wanneroo Road. Homes north of Hepburn Avenue rely on public water supplies obtained from the Gnangara Mound (Figure 2). Future public water supply requirements can be met by developing supplies from the mound in parallel with the northern extension of urban development.

This Environmental Review and Management Programme (ERMP) examines the overall management of the groundwater resources of the Gnangara Mound, taking into account the requirements for public and private water supplies and environmental considerations.

The regional effects of groundwater abstraction are considered and a strategy for development and management of the shallow groundwater resources of the Gnangara Mound is presented.

Management of the next proposed scheme, the Pinjar Groundwater Scheme, is examined in detail.

2.2 WATER RESOURCES OF WESTERN AUSTRALIA

For water resources planning purposes, Western Australia has been divided into seventeen regions (Western Australian Water Resources Council, 1984). These regions, which are based on surface water hydrological boundaries, are then grouped, based on local geographic and socio-economic factors, into four divisions (Figure 3).

The Perth-Mandurah Region of the South West Division comprises less than 1% of the total area of the State but contains about 75% of the State's population.

The divertible surface water and groundwater resources of Western Australia have been determined by investigation programmes undertaken by the Water Authority and the Geological Survey Division of the Mines Department. However, significant components of the State's water resources remain unexplored and unmeasured. Therefore, the assessments contain approximate estimates where information is limited.

Divertible water resources are assessed as the average annual quantities capable of being diverted or abstracted on a sustained basis employing current technology.

The divertible water resources are sub-divided on the basis of their Total Soluble Salts (TSS) concentrations into fresh (less than 500mg/L TSS), marginal (500-1000mg/L TSS), brackish (1000-3000mg/L TSS) and saline (greater than 3000mg/L TSS) sources.

The combined total of divertible fresh and marginal water resources for each region of the State is shown in Figure 4. About 90% of the State's divertible fresh and marginal water resources are surface water, the remainder are groundwater. The majority of the resources, about 75% of the State's total, are in the Timor Sea Division. The South West Division is the next most abundantly endowed division with about 20% of the State's divertible fresh and marginal water resources.

Within the South West Division, the Warren-Blackwood Region has the largest resource, most of which is from surface sources. The Perth-Mandurah Region is next with surface water and groundwater sources of similar magnitude. The Busselton-Harvey, and Albany Regions have the majority of their resources in surface sources while in the Moore Region groundwater sources dominate. The other regions within the South West Division contain relatively limited water resources.

2.3 WATER RESOURCE DEVELOPMENT IN WESTERN AUSTRALIA

The total annual consumption of water in Western Australia for 1981 was 836 million cubic metres ($836 \times 10^6 m^3$) (Western Australian Water Resources Council, 1984). About 40% of this was used for irrigation and about 35% for domestic purposes (Figure 5). Within the Perth-Mandurah Region of the South West Division, about 67% of the water is used for domestic purposes and about 12% for industry and a further 12% is used for irrigation.

About 60% of the total water consumed in the State is provided from public supplies, with the remainder being provided from private supplies. Within the Perth-Mandurah Region, the components of total water consumption are evenly divided between public and private supplies. Private groundwater developments provide about 30% of the State's total water supplies, while in the Perth-Mandurah Region, they provide about 45% of the total water supplies.

The utilisation of the fresh and marginal divertible water resources for each of the four divisions within the State is shown in Figure 6.

The unutilised divertible fresh and marginal water resources of the State are some 15 times greater than the current usage. However 80% of this resource is in the remote Timor Sea Division. There are limiting distances beyond which the transfer of water resources becomes uneconomic compared to desalination of seawater near to the point of demand. It is currently estimated that sources beyond 750km from Perth would be uneconomic compared to local desalination of seawater. It is therefore important to view the comparisons of water use and water resources on a regional basis (Figures 7 and 8).

The South West Division has the highest degree of utilisation with about 22% of the resources in use.

Within the South West Division, the Perth-Mandurah Region has the highest level of utilisation with about 55% of the divertible fresh and marginal groundwater resources being utilised.

The Perth Metropolitan Water Supply System is a joint development of both surface water and groundwater resources. The conjunctive use of each of these sources optimises the benefits gained from the overall system.

The surface water developments comprise storage reservoirs and pipehead schemes. In years of average rainfall it is anticipated that these sources will provide about two thirds of the public water supplies for Perth. The remainder will be supplied from groundwater sources. The extended period of below average rainfall in the 1970s resulted in low levels of storage in reservoirs in the Darling Range and water restrictions were introduced. During this period groundwater provided up to 50% of the water supplied by the Water Authority in the Perth region (Smith and Cargeeg, 1986).

There are three principal groundwater resources developed for public water supplies in the Perth area. These are:

- groundwater resource of the superficial formations,
- shallow artesian groundwater resource of the Leederville Formation, and
- deep artesian groundwater resource of the Yarragadee Formation.

Groundwater resource of the superficial formations - The superficial formations consist of a thin veneer of sediments on the coastal plain. These sediments extend to a maximum depth of about 100m and contain a significant groundwater resource. Most of the backyard wells in Perth draw water from this resource. In addition, this resource provides about 18% of the water supplied by the Water Authority. Water drawn from the superficial formations generally requires treatment for the removal of iron and colour before being used for public water supplies.

Leederville Formation groundwater - The Leederville Formation consists of interbedded sandstone, siltstone and shale. It contains an aquifer that extends beneath the coastal plain in the Perth region. In the Wanneroo area, the top of this formation is approximately at a depth of 180m. About 10% of the water supplied by the Water Authority is drawn from this resource. Water drawn from the Leederville Formation generally requires treatment for the removal of iron before being supplied to the public.

Yarragadee Formation groundwater - The Yarragadee Formation consists of interbedded sandstone, siltstone and shale. The top of the Yarragadee Formation is about 750m deep in the Wanneroo area. About 5% of the water supplied by the Water Authority is drawn from this resource. Water drawn from the Yarragadee Formation is generally suitable for public supplies without treatment.

2.4 ROLE OF THE WATER AUTHORITY

The Water Authority has the responsibility for planning and managing water resources and water services in Western Australia for the overall benefit of the State's community and the environment (Water Authority of Western Australia, 1985).

In undertaking this responsibility the Authority has three primary objectives:

> **Provision of Services:** To provide water, sewerage, irrigation and drainage services which meet quality, quantity and reliability requirements at least cost, subject to financial, social and environmental objectives and priorities.
>
> **Management of Water Resources:** To assess, plan, manage and co-ordinate the utilisation and conservation of the State's water resources for the optimum overall benefit of the community in both the short and long term.
>
> **Planning and Advice:** To work closely with other organisations in co-ordinating the provision of services; and in planning the utilisation of catchments, flood plains and other land or resources associated with water resources.

To carry out its role, the Water Authority assesses the resources available to meet the State's water requirements, and prepares and implements strategies for water resources development, management and conservation.

The Water Authority takes into account the financial, environmental and social costs of developing resources and providing services. The Authority endeavours to keep the community aware of the relationship between costs and factors such as environmental protection and standards of service.

The Water Authority's role is also to inform the community of alternative water sources and the associated consequences of developing alternative supplies.

To manage the State's water resources in accordance with its objectives, the Water Authority considers all potentially beneficial uses of the resource. The resource is then managed to provide the optimum benefit for current and future uses.

In recognition of the close link between land management and water management, the Water Authority maintains close liaison with the Department of Conservation and Land Management (CALM), the Department of Conservation and Environment (DCE), the State Planning Commission (SPC) and Local Government Authority's (LGA's).

Groundwater legislation has been introduced in Western Australia to ensure that the resource can be managed for the greatest benefit of the whole community. Administration of this legislation, contained within the Rights in Water and Irrigation Act, 1914 and the Metropolitan Water Authority Act, 1982 is the responsibility of the Water Authority. The legislation enables the proclamation of groundwater management areas where the resource requires active management (Figure 9). These areas include Water Reserves, Groundwater Areas, Public Water Supply Areas (PWSA) and Underground Water Pollution Control Areas (UWPCA). Within these areas wells may require licensing and conditions relating to well construction, permitted use and allocated volume may be applied. There are also provisions that protect the water resource from pollution.

2.5 ROLE, OBJECTIVES AND STATUTORY REQUIREMENTS OF THE ERMP

The Environmental Impact Assessment procedure is a formalised process (Department of Conservation and Environment, 1978) designed to provide information to the Environmental Protection Authority (EPA) and the public about proposed developments with the potential for significant environmental effects. The public document produced, in this case an ERMP, allows the EPA to give advice to Government, taking into account submissions received following a period of public review.

This ERMP has two major functions. Firstly, it examines groundwater use and management issues on the Gnangara Mound as a whole. Secondly, it details the Water Authority's proposed Pinjar Groundwater Scheme to provide water for the expanding North-West Corridor.

Specifically, this document aims to:

- o provide an overview of the demand and supply of water to the North-West Corridor and identify the need for new public water supply developments,
- o review alternatives for the supply of that water and select a preferred alternative,
- o provide an overview of public, private and environmental demands associated with the preferred alternative - the shallow groundwater resource of the Gnangara Mound,
- o identify the potential regional environmental and social effects as well as any conflicts associated with public and private development on the Gnangara Mound
- o outline strategic approaches to the management of the resource,
- o identify the preferred next development for the Gnangara Mound - the Pinjar Groundwater Scheme, and
- o define a management strategy for the Pinjar area with due regard for environmental and social effects.

This ERMP has been prepared in accordance with the Environmental Protection Act, 1971. Its preparation has followed submission by the Metropolitan Water Authority (MWA) in April 1985, of separate Notices of Intent for the proposed Pinjar and Lexia Groundwater Schemes. Guidelines for the ERMP, formulated by the EPA, were agreed to by the Water Authority and provide the basis for the scope of this ERMP. A copy of these guidelines forms Appendix H. Other legislation pertaining to the project and this ERMP includes:

- o Wildlife Conservation Act, 1950,
- o Aboriginal Heritage Act, 1972,
- o Conservation and Land Management Act, 1984,
- o Metropolitan Water Supply, Sewerage and Drainage Act, 1909,
- o Water Authority Act, 1984,
- o Metropolitan Water Authority Act, 1982, and the
- o Rights in Water and Irrigation Act, 1914.

3.0 NEED FOR NEW PUBLIC AND PRIVATE WATER SUPPLY DEVELOPMENTS

3.1 PUBLIC WATER SUPPLIES

3.1.1 Population Growth in the North-West Corridor

The corridor system of development for Perth was proposed in 1971 by the then Metropolitan Region Planning Authority (MRPA) - now part of the State Planning Commission (SPC) - in 'The Corridor Plan for Perth' (MRPA, 1971). Subsequent documents including the 'Planning Stucture for the North-West Corridor' (MRPA, 1977) were produced as the plan was further refined.

The North-West Corridor extends along the coast, covering an area of approximately 240km^2, bounded by the City of Wanneroo boundary in the north, Hepburn Avenue in the south and State Forest No. 65 and Yanchep National Park in the east (Figure 10). Most of the Corridor is undeveloped, although this is changing rapidly.

Population growth in the North-West Corridor has exceeded original MRPA 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 256,000 people by the year 2001 (State Planning Commission, pers. comm.). The areas of proposed urban development are shown on Figure 11.

In 1986, the SPC initiated a two year review of the existing corridor plan which could result in an amended development strategy. For the present, however, the existing plan is used to plan urban expansion, and hence to provide for services such as water, in the North-West Corridor. If the corridor plan is revised then both groundwater management and supply requirements may be affected. The SPC would need to liaise with the Water Authority prior to implementing major changes to the existing corridor plan.

3.1.2 Demand Forecasts

Two components of demand need to be considered when planning new water supplies to the North-West Corridor. Peak North-West Corridor Demand and Annual System Demand (Figure 12). Peak demand is the absolute maximum demand expected over a short hot dry spell, nominally assumed to be one week.

Annual System Demand is the total volume of water expected to be used by consumers serviced by the Metropolitan Water Supply System in a year without restrictions. New developments must be able to meet the peak local demand as well as augment the overall annual system demand.

Planning by the Water Authority for public water supply is based on the projected demand as shown in Figure 12. To assess projected water demands for the Perth Metropolitan region, estimates of likely population growth are based on figures supplied by the Western Australian Treasury (WA Treasury, 1982). Data from the Australian Bureau of Statistics (ABS) census are used as the primary source of these population statistics (Caldwell, 1981a). Demographic data on the ratio of residents per household are used to project the number of services, or equivalent households connected. Records of water usage per service are used to arrive at the most likely projected demand for water. Population projections are reviewed annually and the Authority's plans modified to accommodate anticipated changes in demand.

Demand could be limited by restricting the growth of Perth. In Western Australia, such planning issues are the responsibility of the State Planning Commission, and are outside the ambit of the Water Authority, and therefore outside the scope of this report.

The Water Authority aims to meet the most likely projected demand, without restrictions, nine years out of ten on average. This document assesses the impacts of developments consistent with this objective. The matter of <u>when</u> a source needs to be developed is controlled by the rate of increase in demand. The matter of <u>if</u> it is developed is affected by environmental, social and financial considerations.

Assessment of the likely environmental impact of the development of proposed sources well ahead of the scheduled time for development and the early preparation of management plans, facilitates a responsible and conservative approach to environmental management. If a source is deleted, the environmental impacts will not occur. However, such deletion will result in increased costs to the community. Therefore, social and environmental, as well as financial considerations need to be assessed for each project.

Based on current growth estimates, the most likely demand within the North-West Corridor will be $58 \times 10^6 m^3$/yr by 2001 and $75 \times 10^6 m^3$/yr by the year 2008.

3.1.3 Demand Management

Demand management is a technique used to manage water use by manipulating demand. Demand management is one way of reducing water consumption. This delays the need to develop new sources which results in a significant reduction in costs to consumers. The Water Authority is taking steps to promote demand management, which will play an important role in future management of all of the State's water resources.

Demand management is not a source of water and cannot replace the development of any one new source. Demand management extends the time over which developed sources on the Sources Development Timetable are able to meet demand. All currently proposed sources will remain available as feasible development options, subject to the normal environmental, social and financial evaluation process.

Demand management has been implemented in the past, primarily during droughts. The low rainfall during the winter of 1976 prompted a Water Authority campaign seeking restraint in water use. Considerably below average rainfall in 1977 and 1978 necessitated sprinkler bans from July 1977 to May 1979. A form of demand management was introduced on July 1, 1978. This took the form of a pay-for-use pricing policy.

The implementation of these policies led to a large increase in the number of private wells in Perth, resulting in a 45% reduction in the household demand for public water supplies (Figure 13).

The recent introduction of a sliding scale of charges for increasing water use has the potential to further reduce water consumption. Further pricing changes may be introduced to discourage waste and high consumption.

Introduction of these pricing measures, together with improved standards of appliance design and an education programme to encourage conservation, might reduce demand in the long term by about 25%.

A draft Demand Management Strategy incorporating all three approaches above, is being prepared by the Water Authority and is planned for finalisation in 1987.

3.1.4 Existing Supply Capability

The current demand for public water supplies in the North-West Corridor is met by groundwater, from the Mirrabooka and Wanneroo Groundwater Schemes.

The quota for each of the schemes is the maximum volume of water abstracted for public water supplies. This quota, together with the allocation for private use, is set to ensure that the safe limit of annual yield from the groundwater resource is not exceeded, taking into account the water requirements for environmental maintenance.

Details of annual abstraction of groundwater from wells in the superficial formations in the Mirrabooka and Wanneroo Groundwater Schemes is shown in Figure 14.

The total groundwater abstraction from schemes supplying the North-West Corridor for 1984/85 was 39.6 x 10^6m^3, which was 5.0 x 10^6m^3 less than the quota.

TABLE 1

GROUNDWATER QUOTAS -
EXISTING SCHEMES SUPPLYING THE NORTH-WEST CORRIDOR

SCHEME	FORMATION	QUOTA (x 10^6m^3/yr)
Wanneroo	superficial	12.2
	Leederville	9.0
Mirrabooka	superficial	12.2
	Marine Sand *	2.8
	Leederville	6.4
	Yarragadee	2.0
	TOTAL	44.6

* Local aquifer in the Osborne Formation

The current peak supply capacity to the North-West Corridor is 0.21 x 10^6m^3/day. It is anticipated that peak demand will exceed this level of supply by the end of 1989.

The existing annual system yield is 280 x 10^6m^3/yr. This volume will be exceeded by system demand towards the end of 1990.

3.1.5 Need for a New Public Water Supply Development

Local peak demand in the North-West Corridor is expected to exceed the current peak supply capability by 1989. The total system demand is expected to exceed the system supply capability by 1990 (Figure 12). A new source to meet the peak demand of the North-West Corridor is therefore required by 1989 and a source to augment the total system demand capability is required by 1990.

3.1.6 Implications of Not Developing a New Source of Water

The "No Development Alternative" implies that the next proposed source is not developed and is not replaced by any alternative. This implies a limit to the growth of Perth. In accordance with current Government policy, the Water Authority will continue to plan for the development of water resources to meet the requirements of the expanding population of Perth. Any limit to the growth of Perth is outside the control of the Water Authority and the scope of this report.

3.2 PRIVATE WATER SUPPLIES

The combined potential for irrigated horticulture on the Swan Coastal Plain may reach an upper limit of 4000 to 5000ha over 10 years (Department of Agriculture, estimate). At 15,000m^3/ha/yr this amounts to a potential demand of 60-75 x $10^6 m^3$/yr.

An estimated 200ha of extra irrigated land will be required each year to service the growth of Perth. The main areas of expansion are expected to be the Gnangara Mound, the Harvey-Busselton district and areas north of Gingin Brook.

Private wells in the Wanneroo Groundwater Area (WGA) are estimated to produce 24 x $10^6 m^3$ of water per year, principally for the irrigation of vegetables and pasture but also for gardens, playing fields, stock and domestic supplies. This quantity does not include private abstraction by backyard wells within the urbanised portion of the Gnangara Mound. Such urban wells do not interact significantly with public abstraction or environmental demands outside the urban area.

In the WGA, there have been recent initiatives by single users for large (1.5 x $10^6 m^3$/yr) allocations of water to irrigate turf and lucerne. There is therefore a potentially large legitimate demand for private abstraction of water for irrigation. Most of this demand is expected to be met by supplies from the superficial formations.

4.0 DESCRIPTION OF ALTERNATIVE SUPPLY SOURCES

4.1 PUBLIC WATER SUPPLIES

The identification and assessment of alternative water supply sources for the North-West Corridor is undertaken in accordance with the Water Authority's corporate objective to provide water services to customers at least cost, taking into account financial, social and environmental objectives and priorities.

The major demand for water in Western Australia is within the Perth-Mandurah region. Within this region available water resources are utilised to a higher degree than anywhere else in Western Australia (Western Australian Water Resources Council, 1984). Most of the State's undeveloped water resources lie outside the Perth-Mandurah region; the largest resources being located within the remote Timor Sea region. It is estimated that sources beyond 750km from Perth would be uneconomic compared to local desalination of sea water. Sources beyond this distance do not meet the financial selection criteria. The cost of desalination may vary significantly in the future with changing technology and energy costs and must therefore be regularly reviewed, so that the development programmes can be updated.

Potential sources can be classified as groundwater, surface water and other types.

Each source has an associated set of environmental issues requiring careful assessment. Any increased costs incurred due to the adoption of an alternative source must be recognised as a cost to be borne by the community for an environmental or social benefit.

4.1.1 The Sources Development Timetable

All potential sources are evaluated and ranked within a Sources Development Timetable (Table 2). The Sources Development Timetable is currently being reviewed and it will be released for public information in late 1986. The timetable schedules the time proposed for development of each source. Proposed sources are scheduled so that they fit into the pattern of projected demand (Figure 12). Unless constrained by other factors, the most economic sources are scheduled to be developed first. All sources are proposed to be developed in the order shown, subject to a detailed assessment of the environmental and social issues.

The environmental review process, of which this report is a part, is used to consider the implications of developing each source and to outline the management appropriate to ensure that social and environmental, as well as financial, objectives are met. If any source is deleted from the timetable or deferred while further studies are undertaken, then the whole timetable is reviewed. The deleted source would be replaced by an alternative source and further sources added to the end of the timetable. In this way, all suitable water resources are considered to be potential sources.

The Sources Development Timetable provides for the orderly evaluation of all potential sources. Environmental and social issues can be considered at the appropriate time during detailed planning for each development using the most up to date information available at the time, as well as recognising the issues of the day.

Should any one source be deleted, the alternatives to it, therefore, comprise a new development sequence which advances those sources remaining on the list. For example, if Pinjar Groundwater Stage 1 with a quota of $10.0 \times 10^6 m^3/yr$ were deleted, then alternative supplies from Wanneroo Deep Artesian Well ($1.5 \times 10^6 m^3$), Wungong Stage 2 Outlet Amplification (0.8), Conjurunup Pipehead Dam (5.5), East Mirrabooka Stage 3 (2.0) and North Dandalup Dam (13.4) would be considered for earlier development. This would require the rationalisation of water distribution from existing sources, as water from Hills sources such as North Dandalup Dam could not supply demand in the North-West Corridor without significant capital expenditure on extra pipelines and pumping facilities. If all the Gnangara Mound groundwater resources were deleted, then other potential sources would need to be scheduled on the Sources Development Timetable, such as:

- Jane Brook pumpback,
- Susannah Brook pumpback,
- Upper Helena River dam,
- Pumpback from Murray River tributaries, and
- Groundwater north of Gingin Brook.

TABLE 2

CURRENT MOST LIKELY SOURCES DEVELOPMENT TIMETABLE - MAY 1986

YEAR	SOURCES	GROUNDWATER QUOTA ($\times 10^6 m^3/yr$) SCHEME	TOTAL	SURFACE WATER YIELD ($\times 10^6 m^3/yr$)
1984/85	Storage Reservoirs: Canning, Serpentine, South Dandalup, Wungong (Restricted Outlet), Churchman, Victoria, Mundaring			
	Pipeheads/Pumpbacks: North Dandalup, Lower Helena			
	Groundwater Schemes:			
	Gwelup	10.5		
	Mirrabooka	16.8		
	East Mirrabooka St 1 and 2	4.6		
	Wanneroo	21.2		
	Jandakot St 1	4.0		
	Deep Artesian	12.0	69.1	
1985/86	No additional sources			
1986/87	No additional sources			
1987/88	Wungong (additional) St 1 Outlet Amplification			0.0
1988/89	No additional sources			
1989/90	Pinjar G/W St 1	10.0	79.1	
1990/91	No additional sources			
1991/92	Wanneroo DAW	1.5		
	Delete North Dandalup Pipehead		80.6	-11.2
1992/93	Mundaring Integration St 2			0.0
	Wungong St 2 Outlet Amplification			0.8
	Conjurunup Pipehead			5.5
	East Mirrabooka St 3	2.0	82.6	
1993/94	North Dandalup Dam (Part)			8.0
	North Dandalup Main Amplification			3.0
1994/95	North Dandalup Dam (Additional)	11.0		13.4
	Pinjar G/W St 2	11.0	93.6	
1995/96	No additional sources			
1996/97	Lower Serpentine St 1 (Gooralong) Pumpback			3.5
	Dirk Brook Pumpback			3.5
1997/98	Pinjar G/W St 3	11.0	104.6	
1998/99	Jandakot G/W St 2	4.0	108.6	
1999/2000	Jandakot South G/W St 1	2.6		
	Jandakot South G/W St 2	2.6	113.8	
2000/01	Lexia G/W	6.5	120.3	
2001/02	Whitfords DAW	1.5		
	Lake Thompson DAW	1.5	123.3	
	Lower Canning Pumpback (Araluen)			1.5
2002/03	Yeal G/W St 1	7.8	131.1	
2003/04	Yeal G/W St 2	7.8	138.9	
2004/05	South Canning Dam (Part)			0.5
	Hamilton Hill DAW	1.5	140.4	
2005/06	Marrinup Pumpback			6.8
	South Canning Dam (Add)			1.0
2006/07	South Canning Dam (Add)			3.0
	Lower Serpentine St 2 Pumpback			1.9
	Tamworth DAW	1.5	141.9	
2007/08	South Canning Dam (Add)			4.3
	Lower South Dandalup Pumpback			3.1
2008/09	South Canning Dam (Add)			6.0
2009/10	Barragoon G/W St 1	6.5	148.4	

G/W - Groundwater St - Stage DAW - Deep Artesian Well

4.1.2 Sources Scheduled on the Development Timetable

The current Sources Development Timetable (Table 2) can be sub-divided as follows.

- o Groundwater Sources:
  - Groundwater within the superficial formations, generally within 70m of the surface.
  - Confined groundwater beneath the superficial formations.

- o Surface Sources:
  - Large storage dams, similar to those existing at Serpentine and South Dandalup.
  - Small pipehead dams similar in size to those at Lower Helena and North Dandalup, to collect river flow in winter and pump it back to a large existing storage dam or supply it directly into the water supply network.

All of the sources on the current timetable are categorised in Table 3, with a brief description of each option.

4.1.2.1 Groundwater Resources of the Gnangara Mound Area

The superficial sand and limestone of the coastal plain near Perth contain substantial groundwater resources. North of the Swan River, extending through the Gnangara region to Gingin Brook, the sands rise to a central zone of relatively high relief. The water table beneath this area forms a mound of shallow groundwater. It slopes gradually away from the central zone to Gingin Brook to the north, Swan River to the south, Ellen Brook to the east and the Indian Ocean to the west (Figure 1).

The Gnangara Mound specifically refers to the shallow groundwater contained in the superficial formations north of Perth and south of Gingin Brook.

It is the most significant shallow groundwater resource close to the Metropolitan area, covering about 2200 square kilometres ($2200km^2$) and containing about $19,500 \times 10^6 m^3$ of groundwater in storage. Harvesting of the recharge to this resource can make a very significant contribution to the future water requirements of the area.

The groundwater system is dynamic. It is recharged by rainfall and discharges to rivers, the sea and to the atmosphere via evaporation and transpiration from plants. It is influenced by seasonally variable rainfall, evapotranspiration and abstraction.

The uppermost few metres of the groundwater flow system are of great importance environmentally, supporting native vegetation, wetlands and part of the base flow of streams such as Ellen Brook.

The Gnangara Mound is a major water resource ideally located to serve the irrigation needs of horticulturalists close to markets in Perth. It is also well located to satisfy public water supply requirements as the urban areas expand northwards. Appropriate management of existing and proposed groundwater schemes and private groundwater use is required to balance water resource utilisation with the conservation of wetlands and native flora and fauna on the mound.

The existing groundwater scheme at Wanneroo is proposed to be extended northwards into Crown land and State forest planted to pine trees. The groundwater resources are planned to be developed in stages at Pinjar, Yeal and Barragoon (Figure 2), in parallel with the northward expansion of the North-West Corridor. New wells to the east of the existing Wanneroo Scheme would constitute the Lexia Groundwater Scheme. Wells will be drilled into the superficial, Leederville and Yarragadee Formations. The water will then be treated, if necessary, and piped to service reservoirs to supply local demand in the corridor. Any excess production could be routed southward to the Mt Yokine Reservoir for distribution to other areas. Essential details of alternative sources are listed in Table 3.

4.1.2.2 Surface Water Sources

The essential features of the future alternative surface sources scheduled on the current Sources Development Timetable are listed in Table 3.

All these sources are located on streams within the Darling Range. Most of the catchments are in forested areas, however, a number such as Lower Serpentine St 1 and Susannah Brook, contain significant areas of land cleared for agriculture. Either small pipehead or larger storage dams would be constructed at suitable valley sites near the Darling Scarp.

4.1.3 Sources Not Yet Scheduled on the Development Timetable

If sources were to be deleted from the existing Sources Development Timetable, then those remaining would be rescheduled and others would be added to the bottom of the list. These are referred to as unscheduled sources in Table 3.

If all Gnangara Mound sources were deleted, then Susannah Brook pipehead, Jane Brook pipehead, Upper Helena River Dam, tributaries of the Murray River and groundwater north of Gingin Brook would be the next sources considered for scheduling on the Sources Development Timetable to make up the resulting short fall.

Water supplies from new sources to the south of Perth would be redistributed, at considerable cost for pump and pipeworks. The closer sources would be developed to meet the demand north of Perth.

Other surface waters in the South West, south coast and those in the north of the State are also potential sources. However, capital and operating costs increase with distance from the centre to be supplied. While source specific issues will occur, all sources can be regarded as subject to the same sort of general environmental constraints which will require detailed assessment closer to the time of proposed development.

Development of the groundwater from north of Gingin Brook would involve essentially the same sort of proposal as that for the Gnangara Mound. An additional 100km of pipeline would be required with consequent increases in environmental and financial impact.

The groundwater resources north of Gingin Brook are the subject of on-going investigation. About 50% of the yield available from the Leederville Formation is currently utilised for irrigation and the land in the area is substantially privately owned. Areas such as the Moore River National Park and the Karakin Lakes Nature Reserve are considered to be constraints to groundwater development. Utilisation of groundwater from the superficial formations would therefore involve similar environmental issues as those on the Gnangara Mound.

Desalination could utilise either brackish surface water or groundwater, or seawater at increased cost. Such options involve significant capital and operating costs, amounting to four to seven times the cost of water from the Gnangara Mound.

TABLE 3

DESCRIPTION OF POTENTIAL SUPPLY SOURCES FOR THE METROPOLITAN AREA

GROUP	TYPE	SOURCE	DESCRIPTION	STATUS
GROUNDWATER	Superficial	Pinjar	28 Superficial Wells	Scheduled
		Lexia	15 Superficial Wells	Scheduled
		Yeal	24 Superficial Wells	Scheduled
		Barragoon	24 Superficial Wells	Scheduled
		Jandakot St 2	15 Superficial Wells	Scheduled
		Jandakot South	15 Superficial Wells	Scheduled
		East Mirrabooka	4 Superficial Wells	Scheduled
		North of Gingin Brook	Superficial Wells	Unscheduled
	Confined	Wanneroo Deep Artesian	1 Yarragadee Formation Well	Scheduled
		Pinjar Shallow Artesian	8 Leederville Formation Wells	Scheduled
		Pinjar Deep Artesian	8 Yarragadee Formation Wells	Scheduled
		Jandakot St 2 Shallow Artesian	2 Leederville Formation Wells	Scheduled
		Jandakot South Shallow Arteisan	7 Leederville Formation Wells	Scheduled
		Whitfords Deep Artesian	1 Yarragadee Formation Well	Scheduled
		Lake Thompson Deep Artesian	1 Yarragadee Formation Well	Scheduled
		Hamilton Hill Deep Artesian	1 Yarragadee Formation Well	Scheduled
		Tamworth Deep Artesian	1 Yarragadee Formation Well	Scheduled
		North of Gingin Brook	Leederville and Yarragadee Aquifers	Unscheduled
SURFACE WATER	Storage Dams	North Dandalup Dam	54m wall, Two small saddle dams 75 x $10^6 m^3$ (storage volume)	Scheduled
		South Canning Dam	40m wall, South branch of Canning River 210 x $10^6 m^3$ (storage volume)	Scheduled
		Upper Helena	40m wall, 247 x $10^6 m^3$ (storage volume)	Unscheduled
	Pipehead Dams	Conjurunup Pipehead	5m wall, direct to supply system	Scheduled
		Lower Serpentine St 1 Pumpback	5m wall, pumpback to Serpentine Dam	Scheduled
		Lower Canning Pumpback	5m wall, Araluen pumpback to Canning Dam from site of existing gauging station	Scheduled
		Marrinup Pumpback	5m wall, pumpback to South Dandalup Dam	Scheduled
		Lower Serpentine St 2 Pumpback	Wall 1000m upstream from Serpentine Falls, pumpback to Serpentine Dam	Scheduled
		Dirk Brook Pumpback	5m wall, pumpback to Serpentine Dam	Scheduled
		Lower South Dandalup pumpback	Existing pipehead to South Dandalup Dam	Scheduled
		Jane Brook	Pumpback to Mundaring Weir	Unscheduled
		Susannah Brook	Pumpback to Mundaring Weir	Unscheduled
		Murray Tributaries	8 pipeheads pumping back to South Dandalup Dam	Unscheduled
OTHER	Any	Desalination	Specialist plant treating brackish groundwater, surface water or seawater	Unscheduled

4.1.4 Non-Viable Sources

Some options raised during the Public Awareness and Attitudes Study (Appendix G) have been examined and found to be uneconomic using current technology when compared with desalination options which theoretically have the potential to satisfy Perth's water requirements indefinitely. This category includes supplying water from the existing Ord River Dam, transferring water from undeveloped Pilbara sources and towing icebergs from Antarctica.

Sources beyond about 750km from Perth are uneconomic compared to local desalination of seawater. The Ord River is about 2200km from Perth.

4.2 PRIVATE WATER SUPPLIES

There are significant unutilised water resources in the Geraldton to Busselton region which could be developed for private use.

Of the available water resources, groundwater is favoured for private use because of its regional availability and ease of development. In the Geraldton to Perth region, surface water resources are negligible and further development of the groundwater resource will be necessary.

Based on the utilisation of the regional groundwater resources (Western Australian Water Resources Council, 1984), the proportion of groundwater utilised in the Geraldton to Mandurah region is summarised in Table 4.

TABLE 4

REGIONAL GROUNDWATER UTILISATION - GERALDTON TO MANDURAH

REGION	TOTAL GROUNDWATER RESOURCE (x $10^6 m^3$/yr)	% UTILISED
Geraldton	50	18
Moore	184	6
Perth-Mandurah	406	55

The Moore River area has a large groundwater resource which is not heavily utilised. The sandy soils in this area were historically not favoured for horticulture, however, with the introduction of sprinkler irrigation and fertilisers, horticulturalists are now developing the area successfully.

The horticultural industry has expanded rapidly in recent years and is now a significant component in the total use of available water resources. At the request of the Western Australia Water Resources Council (WAWRC), the Water Authority has initiated a study of the water resource demands of the horticultural industry. It is part of a major water planning study of the Perth to Bunbury region, and will cover the coastal strip from Geraldton to Busselton.

The terms of reference for the study include:

- Identify the factors important in determining the location of horticultural lands and use these to identify those areas most suitable.
- Prepare maps of the study area showing current and possible future areas of horticultural expansion.
- Liaise with the Department of Agriculture in order to incorporate economic considerations.
- Produce scenarios of likely water resource demands by horticulture.
- Raise issues in relation to the location of horticulture and the efficient use of water resources.

The Department of Agriculture will carry out a review of the economics of the Western Australian horticultural industry as part of the planning study.

Alternative supplies for private use do exist but are more remote from the Metropolitan area. Economic considerations associated with the establishment of horticultural industries are being addressed by the Water Authority in association with the Department of Agriculture. Evidence to date suggests that the financial returns from fruit and vegetable growers would not be great enough to compete with local domestic consumers in a free market for water (Australian Institute of Agricultural Science, 1975).

5.0 ASSESSMENT OF PUBLIC WATER SUPPLY ALTERNATIVES

All major projects to provide water services will inevitably have some social and environmental impact. The degree of these impacts will depend on the location and nature of the source, the existing and potential competition for the water resources and the costs associated with their development. It is the Water Authority's role to inform the community of the alternatives and associated consequences and to reflect community aspirations in its policies and decisions.

5.1 BENEFIT - COST ASSESSMENT

Costs have been calculated for each supply alternative. These costs have been expressed as dollars per cubic metre ($\$/m^3$) of water supplied to give a basis for comparison. The "cost per unit of water" approach has been applied to the alternative sources. For example, the cost of water from the Gnangara Mound can be compared to the cost of water produced by desalination. This approach yields a ranking of water supply costs from new sources but does not include the cost of distribution which is common to all sources.

To supply the Metropolitan area to the year 2008, the available sources have been ranked, based on their cost, in the Sources Development Timetable (Table 2) which assumes that the most economical sources are developed first. Using this table, the cost of limiting or deleting a source, for environmental or social reasons, can be calculated. This then illustrates the additional cost which the community would have to pay if a source were limited or deleted. This approach generates an "alternative cost" for items, such as environmental protection, which cannot be readily valued in monetary terms. It allows those affected to be able to ask "would we be prepared to pay this much in extra water charges to gain that environmental or social benefit?"

In assessing the alternatives to provide additional water, two decisions have to be made:

- o Can this development proceed, with appropriate management, without unacceptable impact on other users and the environment?
- o If not, is the cost of preventing this impact by deleting the source acceptable to the community?

A Capitalised Cost Investment has been calculated for the development of all sources within the Timetable. This is the amount of money that would need to be invested today, at 7% interest rate, to cover all future financial commitments for the overall Sources Development Timetable. These commitments include:

- capital investments for sources eg. dams, treatment plants,
- replacement of parts eg. pumps,
- plant extensions,
- maintenance, and
- operating costs.

The Capitalised Cost Investment is used only to compare two or more Sources Development Timetables. The minimum capitalised cost investment is the most economically desirable. Expressing the costs in December 1985 dollars assumes that this is the starting time of project investigation and design for all developments.

Deleting any source from the development timetable results in a higher present day capitalised cost for all remaining developments, due to the need to bring forward the later, more expensive, sources. These increased capital costs, expressed as the additional annual cost per service, can be obtained by dividing the capital cost by the number of services supplied at that time. This puts a cost per customer on the price of the environmental and social benefits gained by deleting the development.

Costs of water supply from alternative new sources to the North-West Corridor are continuously being reviewed. These values represent the cost to develop each source (Table 5). Distribution costs from suburban service reservoirs are not included because they are the same, regardless of the source. Currently average distribution costs amount to about 20 cents per cubic metre.

Supplies from the Gnangara Mound are the most economic way to service the North-West Corridor due to the proximity of source and demand. This is reflected by the planned inclusion of Gnangara Mound sources in the Water Authority's current Sources Development Timetable (Table 2).

TABLE 5

WATER SUPPLY COSTS FROM NEW SOURCES
($cents/m^3$)

GROUNDWATER		SURFACE WATER		OTHER	
Gnangara Mound Groundwater	Groundwater north of Gingin Brook*	Future Hills Sources	Ord River	Desalination Brackish	Desalination Seawater
22	26	33	1172	81	151

* Assumes development and treatment costs as for Gnangara Mound groundwater.

Note: Cost of supply to North-West Corridor, excluding distribution, in December 1985 prices. Distribution costs average 20 cents/cubic metre.

Costs per service and total annual costs are listed in Tables 6 and 7.

If the proposed first stage of the Pinjar development were deleted from the Sources Development Timetable, the additional total cost to supply water from more remote sources in 1989/90 would be $13.2 million in 1985 dollars. This represents an annual cost of $924,000. This additional annual cost must be spread over all Metropolitan services. If all stages of the proposed Gnangara developments were deleted, then the total additional capitalised cost would be $226 million. The additional annual cost, would be $15.8 million (in 1985 dollars) in the year 2006/07 and each year thereafter.

These figures, payable each year, can be regarded as "rates" for any environmental and social benefits gained by deleting the project. Clearly, the optimum solution would be one where the water resources could be developed while maintaining the environmental and social values. The Water Authority's objectives are to provide an appropriate balance between economy, protection of the environment and the social aspirations of the community.

TABLE 6

POPULATION, OCCUPANCY RATIO AND NUMBERS OF WATER SERVICES
PROJECTED FOR THE PERTH METROPOLITAN AREA AND THE NORTH-WEST CORRIDOR

	POPULATION [1]		OCCUPANCY RATIO (people per household)		NUMBER OF SERVICES	
	1989/90	2006/07	1989-90	2006/07	1989-90	2006/07
METROPOLITAN AREA	1,103,300	1,591,100	2.7	2.6	395,000	612,000
NORTH-WEST CORRIDOR (Water Authority Supply Area)	175,700	350,160	3.6	3.0	50,500	111,500

1. Population and occupancy ratio figure from:
- Town Planning Department, 1980a
- Water Authority of Western Australia, unpublished report
- Western Australian Treasury, 1982
- Caldwell, 1981b

TABLE 7

CAPITALISED COSTS FOR WATER SUPPLY
(WITH AND WITHOUT FUTURE GNANGARA DEVELOPMENTS)

	TOTAL CAPITALISED COST	ADDITIONAL CAPITALISED COST	ADDITIONAL [1] ANNUAL COST
ALL FUTURE WATER SOURCES	$470,000,000	-	-
DELETE PINJAR STAGE 1 (1989/90)	$483,200,000	$13,200,000	$924,000
DELETE ALL GNANGARA SOURCES (2006/07)	$696,000,000	$226,000,000	$15,820,000

1. December 1985 prices, 7% discount rate

5.2 ENVIRONMENTAL ISSUES

Environmental assessments have been undertaken using four approaches.

- o A broad scale assessment of the types of alternatives already on the Sources Development Timetable which could supply water to the North-West Corridor.
- o A broad scale assessment of other types of alternatives (eg. desalination) not yet on the timetable.
- o More detailed assessment of the environmental issues involved in development of the water resources of the Gnangara Mound in general and the Pinjar Scheme in particular.
- o Identification of potential impacts on the Gnangara Mound and an assessment of the impacts based on the effects of predicted changes in groundwater level.

Methodologies for each of these approaches are outlined below.

Broad scale assessment of alternatives was carried out by considering the likely impacts of each alternative (Tables 3, 8 and 9).

Criteria were chosen which:

- o covered the likely environmental issues generally applicable to all sources,
- o had the necessary data available, and
- o were suited to discrimination between alternatives. It is recognised that source specific issues will occur and that positive social and environmental benefits will accrue from some developments. These items and a wider range of criteria will be evaluated at the time each source is assessed in detail.

The National Health and Medical Research Council (NH&MRC) long term quality objective of less than 500mg/L Total Dissolved Solids (TDS) for domestic water supplies is assumed to be met for all sources, by treatment if necessary.

Costs are broadly classified in Table 5. This listing serves to discriminate between types of sources and their general location. These two factors have the greatest bearing on costs.

Where quantitative data exist, they have been listed. For example, the lengths of pipeline required can be quantified. Where quantitative data are not available nor applicable to all options, where they are not directly comparable or where subjective judgements are involved, the impact is noted as present or absent. An indication of the expected degree of impact is provided by categorising each impact as present, significant or major. The components considered under each category in Tables 8 and 9 are outlined below.

- Annual Yield - is listed to indicate the significance of each source.
- Construction Possible by 1989/90 - an assessment of whether there is time to assess and construct each source to provide a new supply for the North-West Corridor by 1989/90.
- Potential Competing Private Use - existing or possible future demands on the resource; from land use and zoning information.
- Reserves - presence of environmentally significant locations based on the EPA's System Six Recommendations; classified as Upland, Swamps and Lakes, or Rivers.
- Recreation - potential for recreation, based on existing usage and zoning.
- Area Disturbed - approximate area required to accommodate structures and reservoirs, does not include pipeline route which is a separate category.
- Wastes - presence of effluents generated by options where water requires treatment; based on Water Authority water quality information and experience.
- Dieback - sensitivity to introduction of dieback disease caused by *Phytophthora cinnamomi*.
- Pipelines - approximate length of new pipelines required, estimated from maps.
- Private Land - land currently in private ownership which would require resumption for structures or reservoirs. Does not cover easement for pipelines.

Assessment of environmental issues associated with the Gnangara Mound, and the Pinjar Scheme in particular, is based on the latest available information. In many cases this consists of internal or unpublished reports. The issues addressed are those identified by the ERMP guidelines issued by the EPA, augmented by other issues which have arisen in discussions with a wide range of people with an interest in the Gnangara Mound. Such issues were actively sought through the Public Awareness and Attitudes Study conducted as part of this review.

TABLE 8

GROUNDWATER : BROAD ENVIRONMENTAL ISSUES FOR FUTURE SOURCES OF SUPPLY FOR THE METROPOLITAN AREA

	ANNUAL YIELD $x10^6m^3$	CONSTRUCTION POSSIBLE BY 1989-90	POTENTIAL COMPETING PRIVATE USE	SYSTEM 6 RESERVE PROPOSALS			RECRE-ATION	AREA DIS-TURBED (ha)	WASTES	DIE-BACK	PIPE-LINE LENGTH (km)	PRIVATE LAND
				UPLAND	SWAMPS & LAKES	RIVERS						
SCHEDULED SOURCES												
superficial formations												
Pinjar	14.0	Yes	++	-	+	-	+	0 #	*	-	23	-
East Mirrabooka St 3	2.0	Yes	+	+	-	+	+	0 #	*	-	3	-
Jandakot St 2	2.75	Yes	++	+	+	-	+	0 #	*	-	5	-
Jandakot South	3.0	Yes	++	+	+	-	+	16	*	-	10	-
Lexia	6.5	Yes	+	+	-	+	+	0 #	*	-	23	-
Yeal	9.6	Yes	-	+	+	-	-	4	*	-	16	-
Barragoon	7.0	Yes	+	+	+	?	-	13	*	+	20	-
Leederville Formation												
Pinjar	8.0	Yes	-	-	-	-	-	0 #	*	-	25	-
Jandakot St 2	1.25	Yes	-	-	-	-	-	0 #	*	-	5	-
Jandakot South	2.2	Yes	-	-	-	-	-	0	*	-	10	++
Yeal	2.6	Yes	-	-	-	-	-	0	*	-	16	-
Barragoon	2.6	Yes	-	-	-	-	-	0	*	-	20	-
Yarragadee Formation												
Pinjar	10.0	Yes	-	-	-	-	-	0 #	-	-	0	-
Yeal	3.4	Yes	-	-	-	-	-	0 #	-	-	0	-
Barragoon	3.4	Yes	-	-	-	-	-	0 #	-	-	0	-
Tamworth DAW	1.5	Yes	-	-	-	-	-	0 #	-	-	0	-
Wanneroo DAW	1.5	Yes	-	-	-	-	-	0 #	-	-	0	-
Whitfords DAW	1.5	Yes	-	-	-	-	-	0 #	-	-	0	-
Lake Thompson DAW	1.5	Yes	-	-	-	-	-	0 #	-	-	0	-
Hamilton Hill DAW	1.5	Yes	-	-	-	-	-	0 #	-	-	0	-
UNSCHEDULED SOURCES												
Groundwater north of Gingin Brook	?	No	++	+	+	-	-	?	*	++	100	-

+++ Major Impact ++ Significant Impact + Impact Present - Impact Absent ? Impact Uncertain
DAW Deep Artesian Well * Small quantities of alum sludge
0 # Existing disturbed area

TABLE 9

SURFACE WATERS AND OTHER OPTIONS: BROAD ENVIRONMENTAL ISSUES FOR FUTURE SOURCES OF SUPPLY FOR THE METROPOLITAN AREA

	ANNUAL YIELD $x10^6m^3$	CONSTRUCTION POSSIBLE BY 1989-90	POTENTIAL COMPETING PRIVATE USE	SYSTEM 6 RESERVE PROPOSALS			RECRE-ATION	AREA DIS-TURBED (ha)	WASTES	DIE-BACK	PIPE-LINE LENGTH (km)	PRIVATE LAND
				UPLAND	SWAMPS & LAKES	RIVERS						
SCHEDULED SOURCES												
Conjurunup Pipehead	5.5	Yes	-	-	-	-	+	10	-	+	10	-
North Dandalup Dam*	24.6	No	-	+	-	+	+	500	-	+	existing	-
Lower Serpentine St 1 Pumpback	3.5	Yes	-	-	-	-	+	10	-	+	10	++
Dirk Brook Pumpback	3.5	Yes	-	+	-	+	+	10	-	+	8	-
Lower Canning Pumpback Araluen	1.5	Yes	-	-	-	+	++	10	-	+	1.3	-
South Canning Dam	14.8	No	-	-	-	++	+	2500	-	++	0	-
Marrinup Pumpback	6.8	Yes	-	-	-	-	++	10	-	+	8	+
Lower Serpentine St 2 Pumpback	1.9	Yes	-	-	-	+++	+++	10	-	+	10	-
Lower South Dandalup Pumpback	3.1	Yes	+	-	-	-	+	existing	-	+	10.5	-
UNSCHEDULED SOURCES												
Jane Brook	6	Yes	-	-	-	+	++	10	-	+	10	++
Susannah Brook	1.5	Yes	-	-	-	-	+	10	-	+	15	++
Murray Tributaries	21	No	+	+	+	+++	+++	1000	#	++	100	++
Upper Helena River	12	No	-	-	-	-	+	1500	-	++	-	-
Desalination	Unlimited	No	-	-	-	-	-	10	Brine	-	10	-

+++ Major Impact   ++ Significant Impact   + Impact Present   - Impact Absent   ? Impact Uncertain

\# Higher TDS to Murray River

* Development of North Dandalup Dam involves deletion of an existing pipehead ($11.2 \times 10^6m^3$), therefore incremental yield of this source is $13.4 \times 10^6m^3$

A computer model has been developed to predict the behaviour of the groundwater in superficial formations (Boughton et al., 1986). It uses a comprehensive regional data base including aquifer conditions recorded from a network of wells over an area of 30km by 100km. Factors such as rainfall, septic tank effluent, road drainage, roof drainage, garden and crop irrigation, evapotranspiration, abstraction by wells and leakage to and from the underlying aquifers are taken into account.

The model forms the basis for assessing the effect of various strategies for management of private and public water supply developments on environments which have been assessed as sensitive to water level changes. The effect of various land uses such as forestry can also be investigated. The model produces contours showing the magnitude and areal extent of changes in water levels from the existing situation.

The model has been calibrated against actual past changes in the water table and found to realistically simulate those changes.

Environmental issues are varied across the range of alternatives, which reflects the wide range of environments involved. Based on the criteria used in the environmental assessment, there appear to be no sources on the current Development Timetable which clearly have lower environmental impact than all other sources. The option which raises the least environmental issues, Desalination, is four to seven times more expensive than the alternatives, and therefore does not meet the financial selection criteria.

Development of any alternative on the current Sources Development Timetable requires planning and management to minimise and mitigate its environmental impacts.

The development of groundwater schemes for public water supply has particular features and benefits when compared to other supplies. The following features can make groundwater developments attractive in comparison to alternatives (Caldwell, 1981b).

- o Low capital costs compared to dams.
- o Close proximity to demand areas (particularly relevant in the North-West Corridor).
- o Ability to stage construction to match demand.

- o Reliability of supply during periods of drought.
- o Minimal losses from groundwater in storage.
- o Potential for conjunctive use with surface water schemes which increases overall system capability.

A major consideration of water resource development in the Perth-Mandurah Region is the higher operating costs associated with groundwater developments in comparison with surface sources. These features are considered and evaluated as part of the assessment and selection process which is undertaken before determining a preferred development option.

In planning the development of groundwater schemes, the Water Authority considers a number of factors in the assessment of alternatives, including:

- o Hydrogeology - to determine the hydraulic efficiency of proposed wells.
- o Engineering - to determine feasibility of wellfield layout, treatment plant location and other ancillary works.
- o Environmental - to assess environmental effects and consult with the EPA, which may involve public review of proposals.
- o Social - to determine local and regional influences.
- o Economic - to establish the cost of various options.

Consideration of these factors has resulted in development of conceptual plans for groundwater schemes on the Gnangara Mound.

Potential impacts of the proposed Gnangara Mound groundwater scheme developments are listed in Table 8. The issues can be largely avoided, at some additional expense, by relocation of wells and redistribution of abstraction. To reduce the potential for effects on other users, the proposed schemes are located within pine plantations and the likely impacts assessed so that the layout and distribution of abstraction can be modified if appropriate.

Careful siting, monitoring and management of the Gnangara Mound developments is designed to enable this significant and economic groundwater resource to be utilised without unacceptable environmental impact. To avoid or mitigate environmental impacts, the Water Authority will continue to:

- carefully investigate, select and design appropriate wellfield layouts,
- undertake comprehensive physical and biological monitoring, and
- maintain flexibility of operations such that production from individual wells can be varied if monitoring shows this to be necessary.

The Water Authority will ensure that the impact of the proposed developments is constrained within acceptable limits. The environmental effects of these developments will be regularly assessed and the results reported to the EPA for review.

5.3 SOCIAL EFFECTS

Assessment of the potential social effects of developing alternative water sources to supply the North-West Corridor required consideration of a range of factors with both direct and indirect social implications. The factors considered included the cost of the developments to the community, environmental impacts, aesthetic effects and restrictions on the activities of private landholders. The results of the assessment are presented below.

- Gnangara Mound Groundwater: This alternative is the most economic and consequently would have the least social impact with regard to charges for water. This alternative may, however, affect private groundwater users by potentially limiting water use in specific areas. Such limitation would be necessary to protect existing users, including the environment, irrespective of further developments on the Gnangara Mound for public water supply. If public or private development has environmental impacts, specifically the potential drawdown of water in lakes and wetlands, this has the potential to affect the perceived quality of life in the area.

- Surface Water: The development of these sources will have the social benefit of not adversely affecting the existing groundwater users on the Swan Coastal Plain. The development could however, have other environmental impacts with social implications. These include damming rivers and the loss of native bushland which are important natural features. Other potential social impacts could be resumption of private land for dam construction and reservoir areas, restrictions on activities in catchments, and increases in water rates and charges to cover the higher cost of providing water from these sources.

- Groundwater north of Gingin Brook: Development of this resource would not impact existing groundwater users in the Perth region, however, it could affect private abstraction north of Gingin Brook. There are a number of existing and potential public and private groundwater developments in that area and competition and conflict could arise from a water supply development for the North-West Corridor. There are also a number of wetlands and conservation reserves in the area which require protection. The cost of the pipeline, associated works and operating costs for the development will result in increased rates and charges.

- Desalination: Utilisation of either sea or brackish water sources would not affect private groundwater users on the Swan Coastal Plain. A large facility would affect the aesthetics of the area, and this may be unpopular if desalination of sea water requires it to be located on the coast. The desalination process would be expensive, and would affect the social environment through increased rates and charges.

No one alternative appears to have a markedly lower potential social effect than any of the others. All the alternatives will have a degree of social impact requiring careful planning and management and this has been considered in the selection of new water supply sources for the North-West Corridor.

5.4 SELECTED ALTERNATIVE

The selected conceptual alternative is progressive development of the groundwater resources of the Gnangara Mound, in parallel with urban growth in the North-West Corridor. The development of the Gnangara Mound in conjunction with existing and future surface resources, results in the most economical and flexible augmentation of Perth's water supply system.

None of the alternatives on the current Sources Development Timetable have obviously lower social and environmental impacts than the Gnangara Mound developments. With careful planning, monitoring and management, the potential impacts of the development of the Gnangara Mound can largely be contained within State forest where the primary management purpose is water production. Regardless of development of the Gnangara Mound as the source of public water supplies, there is a need for management of the groundwater resource to safeguard existing private and public developments and the environment. This selected conceptual alternative has been further refined, as discussed in the following sections, to define the preferred development strategy.

6.0 OVERVIEW OF GNANGARA MOUND

6.1 THE REGIONAL PHYSICAL ENVIRONMENT

6.1.1 Climate

The Gnangara Mound area is characterised by a temperate, mediterranean climate, experiencing warm, dry summers and mild, wet winters. The seasonal rainfall results from westerly frontal systems bringing moist air from the ocean.

Rainfall data from Perth, which has the longest available record, illustrates the occurrence of extended periods with rainfall above or below the long term average recorded over the 109 years from 1876 to 1985. Perth's annual average rainfall is 870mm, with approximately 90% of the rainfall falling between April and October. The summer season from November to March receives only 9% of the annual average rainfall. January has the least rainfall with an 9mm monthly mean and three raindays. June and July are the wettest months with 182mm and 17 raindays, and 173mm and 18 raindays, respectively. The last 11 year period is the driest on record with only one year having above average rainfall (Figure 15). Conversely, over the period 1915 to 1934, 15 of the 20 years had rainfall above the long term average.

The Bureau of Meteorology has been recording climatic data at the Upper Swan Research Station (since 1957), Pearce Station (1937), Wanneroo Station (1905) and Gnangara Station (1950), all of which are located around the Gnangara Mound area. Mean monthly and mean annual readings of climatic data referred to below have been obtained by using all available data from these meteorological stations.

The temperatures are moderate, with the highest mean monthly maximum recorded in January and February (34^{o}C) and the lowest mean monthly minimum recorded in August (7^{o}C). The mean monthly temperature varies from 12^{o}C in July to 26^{o}C in February. Table 11 shows mean monthly, mean maximum and mean minimum temperatures for the Gnangara Mound area.

Table 12 shows mean monthly relative humidity for 0900 hours and 1500 hours. The highest relative humidity is in July and the lowest in January and February.

TABLE 10

MEAN MONTHLY AND ANNUAL RAINFALL (mm)
AND RAINDAYS
(1876 to 1985)
FOR PERTH STATION

MONTH	J	F	M	A	M	J	J	A	S	O	N	D	ANNUAL AVERAGE
RAINFALL	9	12	19	45	123	182	173	137	81	54	21	14	870
RAINDAYS	3	3	4	8	14	17	18	17	14	11	6	4	

TABLE 11

MEAN MONTHLY TEMPERATURES (^{o}C)
(1940 to 1984)
FOR GNANGARA MOUND STATIONS

MONTH	J	F	M	A	M	J	J	A	S	O	N	D
MEAN TEMPERATURE	25	26	23	20	16	14	12	13	14	16	19	22
MEAN MAXIMUM	34	34	31	26	22	19	18	18	20	24	27	31
MEAN MINIMUM	16	17	15	12	10	9	8	7	8	9	11	14

TABLE 12

MEAN MONTHLY RELATIVE HUMIDITY (%) FOR 0900
AND 1500 HOURS (1937 - 1984)
SWAN AND PEARCE METEOROLOGICAL STATIONS

MONTH	J	F	M	A	M	J	J	A	S	O	N	D
0900 HOURS	46	48	54	65	70	78	79	75	71	60	53	47
1500 HOURS	31	31	35	47	51	60	61	57	47	41	33	46
MEAN % RH*	39	39	45	56	61	69	70	66	63	54	47	40

* %RH = Percent Relative Humidity

TABLE 13

MEAN DAILY PAN EVAPORATION (mm) FOR SWAN RESEARCH STATION
(1973 to 1983)

MONTH	J	F	M	A	M	J	J	A	S	O	N	D	ANNUAL AVERAGE
MEAN DAILY EVAPORATION	11	9	7	5	3	3	2	3	3	5	7	8	1750
LOWEST MEAN DAILY READING	8	7	6	4	2	2	2	2	3	4	6	7	
HIGHEST MEAN DAILY READING	19	11	9	6	4	3	3	3	4	7	8	9	

Source: Bureau of Meteorology

Table 13 shows mean daily pan evaporation levels for the Upper Swan Research Station. Mean daily evaporation is highest during the summer months, peaking in January (11mm), then decreasing until midwinter, with the lowest mean during July (2mm). Annual water demand is therefore seasonal with the greatest use occurring in the driest summer months.

Therefore, when public water supply, irrigation and environmental demand are at their peak during the summer months associated with high evaporation rates and maximum stress on plants, there is minimum rainfall and lowest groundwater levels (Figure 16). All these factors coincide with maximum groundwater demand.

6.1.2 Evapotranspiration

Evapotranspiration is a result of two processes: transpiration by plants and direct evaporation. Direct evaporation occurs from the soil, from free water surfaces and by evaporation of water intercepted by plant canopies during rainfall (Figure 17). Interception by foliage can be particularly significant in pine forests. The rate of evapotranspiration varies seasonally depending on the depth to the water table, the air temperature, the moisture content of the soil and the presence of plant roots.

Evapotranspiration uses about 70% of the average annual rainfall, amounting to $1165 \times 10^6 m^3$/yr from the Gnangara Mound. Average annual rainfall over the Gnangara Mound area amounts to about $1675 \times 10^6 m^3$. Abstraction from wells accounts for $111 \times 10^6 m^3$/yr, or 6% of the average annual rainfall. If a small percentage reduction can be achieved in evapotranspiration it will result in a relatively large percentage increase in the water available for abstraction. A 3% reduction in evapotranspiration ($36 \times 10^6 m^3$) is roughly equivalent to the planned abstraction from the public supply schemes on the Gnangara Mound.

Since evapotranspiration is high if the water table is close to the surface, it follows that lowering of the water table will reduce evapotranspiration losses, resulting in a greater fraction of rainfall being available for abstraction. Pollett et al., (1979) estimated that evaporation from a water table at 1.0m depth may be 50% of the evaporation from the surface, representing a potentially significant increase in groundwater recharge.

Plants rely on transpiration for cooling and to carry nutrients from the roots to the leaves. However, different types of plants growing on the Swan Coastal Plain show different patterns of transpiration, depending on whether they have access to groundwater all year round via deep roots or only to limited moisture stored in the upper soil profile. For example, the deep rooted Jacksonia floribunda generally transpires more water than the shallow rooted Adenanthos cygnorum (Colquhoun, 1986).

6.1.3 Geology

6.1.3.1 Geological Setting

The Northern Perth area occupies part of the southern end of the Dandaragan Trough, a structural unit within the Perth sedimentary basin. The sediments filling the basin have a thickness of about 13,000m and range from Permian to Quaternary in age. They are separated from Archaean crystalline rocks of the Yilgarn Block by the Darling Fault.

6.1.3.2 Stratigraphy and Structure

The stratigraphic units are described in detail by Playford *et al.*, (1976). The stratigraphic sequence underlying the Gnangara Mound within the upper 2000m is given in Table 14. The units are described below.

- Yarragadee Formation:

  The Yarragadee Formation consists of interbedded sandstone, siltstone and shale with the individual beds varying in thickness up to 30m. The upper surface of the Yarragadee Formation is at a depth of about 750m below the township of Wanneroo.

- South Perth Shale:

  The South Perth Shale consists of siltstone and shale with minor sand and it is about 370m thick beneath Wanneroo where its upper surface is at a depth of about 380m. The South Perth Shale rests unconformably on the Yarragadee Formation.

TABLE 14

STRATIGRAPHIC SEQUENCE OF THE GNANGARA MOUND AREA

	AGE	FORMATION	MAXIMUM THICKNESS	LITHOLOGY	GROUNDWATER POTENTIAL
CAINOZOIC	Quaternary-Late Tertiary	superficial formations	100m	Sand, limestone, clay	Major unconfined aquifer; fresh groundwater
			UNCONFORMITY		
	Early Tertiary	Kings Park Formation	240m	Shale, calcareous and glauconitic siltstone, and minor sand	Local unconfined aquifer; fresh groundwater
			UNCONFORMITY		
	Late Cretaceous	Osborne Formation	260m	Glauconitic shale, siltstone and sand	Semi-confining bed; local aquifer; fresh groundwater
MESOZOIC	Early Cretaceous	Leederville Formation	500m	Sandstone, siltstone and shale, locally calcareous and glauconitic	Major confined aquifer; fresh to brackish groundwater
		South Perth Shale (Gage Sandstone Member)	300m	Shale, siltstone, minor sand at base	Regional confining bed; minor aquifer at base; fresh to brackish groundwater
			UNCONFORMITY		
	Early Cretaceous-Middle Jurassic	Yarragadee Formation	2000m	Sandstone, siltstone and shale	Major confined aquifer; fresh to saline groundwater

Source: Allen, 1981

- Leederville Formation:

  The Leederville Formation, similar to the Yarragadee Formation, consists of interbedded sandstone (50%) and siltstone and shale (50%). Beneath Wanneroo the Leederville Formation has a thickness of 200m and rests conformably on the South Perth Shale. The upper surface of the Leederville Formation is at a depth of 180m below Wanneroo.

- Osborne Formation:

  The Osborne Formation, lying unconformably on the Leederville Formation, consists of black shale and green-black sandy shale with minor beds of clayey coarse-grained sand. The formation is characterised by the abundance of glauconite. Beneath Wanneroo, the formation is 110m thick and its upper surface is at a depth of about 70m. It is unconformably overlain by the Kings Park Formation in the southern extremity and elsewhere by the superficial formations in the Gnangara Mound area. The Marine Sand is a local aquifer within the Osborne Formation and is located in the East Mirrabooka area.

- Kings Park Formation:

  The Kings Park Formation occupies a deep erosional feature in the underlying formations near the Swan River Estuary and consists predominantly of grey, calcareous, glauconitic siltstone and shale.

- Superficial Formations:

  The complex Quaternary units, for convenience, have been called collectively the superficial formations. They range in thickness from about 10m in the eastern margin to about 100m in the centre of the mound, and unconformably overlie a gentle, seaward-sloping, erosional surface of older sediments.

  The superficial formations consist of sand, silt and clay in varying proportions. Along the eastern margin of the coastal plain, the sediments are more clayey than in the central part of the coastal plain. To the west the sandy formations pass laterally into limestone, which borders the coastal strip.

6.1.4 Regional Hydrogeology

6.1.4.1 General

The Swan Coastal Plain extends from Geraldton to Dunsborough. The plain is 6 to 35km wide and is underlain by a thin veneer of aeolian and alluvial deposits overlying older sedimentary rocks of the Perth Basin.

The major groundwater resources near Perth occur in three specific geological units, the superficial formations and the Leederville and Yarragadee Formations (Figure 17). Groundwater in the superficial formations forms a broad mound to the north of Perth referred to as the Gnangara Mound.

Regional evaluation of the groundwater resources of the Gnangara Mound commenced in 1962.

About 250 bores at 150 sites on an approximate 5km grid have been drilled. Depths of the bores range from 20 to 85m deep and included monitoring and test-production bores. In addition many observation and monitoring bores were drilled prior to the construction of the Water Authority wellfields and in areas of special interest such as around selected lakes and waste disposal sites. This work has resulted in an understanding of the hydrogeology of the region together with an appreciation of the issues involved in their effective management. The groundwater resources of the Swan Coastal Plain, near Perth have been described by Allen (1981). The information presented in this section is substantially taken from that paper with information updated as appropriate.

6.1.4.2 Occurrence of Groundwater

The groundwater of the coastal plain originates primarily from rainfall. Rain falling on the land surface infiltrates the soil. Rain which exceeds attractive forces in the soil, moves under gravity from the partially saturated zone to the saturated zone in the formation underlying the soil. The upper surface of the zone of saturation is the water table and water in this zone is referred to as unconfined groundwater.

Infiltration of rain occurs over most of the coastal plain. It is depleted by vegetation which utilises water from both the unsaturated and saturated zones. Where the water table is deep (over 6m), 30% of the rainfall may reach the water table and remain as groundwater; in areas where the water table is shallow, most of the rainfall which reaches the water table is subsequently used by the vegetation or evaporated from wetlands. In wetland areas water use through the evapotranspiration process may exceed rainfall.

The groundwater moves under gravity down gradient toward discharge areas along the coast, and in low-lying areas occupied by lakes, swamps and drainages. Groundwater may discharge from localised springs, broad areas of seepage or leak into underlying formations. In coastal areas the outflowing groundwater overlies a wedge of saltwater which tapers inland (Figure 17).

6.1.4.3 Aquifer Flow Systems

The rate of groundwater movement is controlled by the gradient of the water table, and by the size, and degree of interconnection, of void spaces in the water bearing formation. The measure of the ability of a formation to transmit water is the hydraulic conductivity. The hydraulic conductivity is low in silt or clay and high in coarse sand and cavernous limestone. Depending on the groundwater gradient and the hydraulic conductivity, the rate of groundwater flow may vary from about 0.01 to 100m/yr.

The groundwater which infiltrates the deeper sandy formation is usually confined above and below by beds of siltstone or shale except at intake and discharge areas. Consequently groundwater in these formations is under pressure and when intersected in wells may rise toward the surface (sub-artesian) or flow (artesian).

Formations which yield usable quantities of groundwater to wells are termed aquifers. On the coastal plain they consist of coarse sand, cavernous limestone, or interbedded sand and silt. They occur in well defined geological formations which may contain 10% to 35% by volume of groundwater.

The aquifers contain groundwater with salinity ranging from fresh to brackish. The salt content originates from rainfall, windborne salt, plants and animals and solution and exchange within the aquifers and confining beds. In the confined aquifers the salts may also be derived by mixing with salt water which entered the formation in the past when the coastal plain was covered by the sea. Generally the salinity is least at the intakes and greatest at the discharge areas, so that salinity varies laterally and with depth.

All the formations to a depth of about 1000m beneath the coastal plain (Table 14) contain groundwater and locally may yield supplies to wells. The most important aquifers containing the largest volumes of groundwater are the superficial formations and the Leederville and Yarragadee Formations.

The superficial formations contain an unconfined aquifer directly recharged from rainfall, whereas the Leederville Formation aquifer is confined beneath the Osborne Formation and the Yarragadee Formation aquifer is confined beneath the South Perth Shale. Groundwater enters the Leederville Formation by leakage from the superficial formations where the Osborne Formation has been eroded away or is sandy. Groundwater enters the Yarragadee Formation by leakage from the Leederville Formation where the South Perth Shale is thin or was not deposited. The groundwater in the aquifers moves in separate strata-bound flow systems except at intake and discharge areas where they are interconnected.

6.1.5 Groundwater in the Superficial Formations

6.1.5.1 Aquifer Description

The superficial formations consist of a laterally and vertically variable sequence of sand, limestone, silt and clay. They consist predominantly of limestone and calcareous sand beneath the coastal strip; sand of various grain size and sorting beneath the Bassendean Dunes; and clay, silt and gravelly sand beneath the Pinjarra Plain.

The superficial formations have a maximum thickness of 100m but average about 50m in the Northern Perth Area. The accepted hydraulic conductivity for the calcareous sediments is 100m/d and for the sands 30m/d, while the accepted specific yield is 0.3 for both. These figures have been derived from pumping tests, but results vary widely and few tests give unequivocal results.

6.1.5.2 Groundwater Systems

The superficial formations contain unconfined groundwater except locally where it is confined by beds of clay, or is under pressure at seepage zones to some lakes and swamps (Allen, 1977 and 1980). In these localities minor artesian flows may occur, which may also be the source of small mound springs in the headwaters of some of the western tributaries of Ellen Brook.

Perched water tables are not common but have been found on peat and limestone in the coastal belt, and overlying a ferruginous hardpan (coffee rock) beneath the Bassendean Dunes.

In the Gnangara Mound area, the water table reaches an elevation of about 70m above sea level beneath the Bassendean Dunes in the northern-central part of the coastal plain.

The configuration of the water table is a subdued reflection of the regional topography, with the groundwater mound occurring beneath the regionally high areas, and groundwater depressions along the major rivers. Beneath the coastal strip the water table has a low gradient for 3-4km inland and rises very steeply immediately west of the linear lakes, such as Lake Joondalup. This steep change in gradient is close to the contact between limestone and sand of different hydraulic conductivity and is believed to mark a groundwater cascade where groundwater locally moves through limestone caves. Other steep groundwater gradients are developed where sands beneath the Bassendean Dunes inter-finger with the clays underlying the Pinjarra Plain, for example in West Swan. This is in response to a change in hydraulic conductivity and aquifer thickness.

6.1.5.3 Recharge

The main recharge is during the months April to October. This is accompanied by a rise in the water table of about 0.2m in the coastal belt; 0.5 - 1.5m beneath the Bassendean Dunes; and up to 4.5m beneath the Pinjarra Plain (Moncrieff, 1974). Groundwater levels generally rise quickly after the start of the winter rains, and reach a peak in September-October. Levels decline during the summer months, reaching a low in March-April.

Recharge first occurs in lakes and swamps and later by infiltration from the land surface. The amount of recharge is dependent on the amount of rainfall, the nature of the soil, moisture content of the unsaturated zone, interception by vegetation and the depth to the water table.

Water that reaches the zone of saturation is depleted by vegetation. The water which remains is the recharge which maintains the groundwater flow system, and this varies annually depending on seasonal and climatic factors, but in general follows the trend of annual rainfall. It may also vary between localities depending on the depth to the water table.

Thus recharge is not uniform spatially or over time. The annual net recharge averaged over large areas can be estimated from the ratio of the estimated groundwater outflow from the area expressed as a percentage of the average annual rainfall. For the Gnangara Mound as a whole, it is estimated to be 22%, while for the Pinjar area of the mound it is estimated to be 14%.

Net recharge over the Gnangara Mound is higher than over the Pinjar area because of the additional contribution to recharge in the urban areas. Allen (1981) reported that recharge over the Gnangara Mound was 11.5% based on throughflow calculations and chloride balance. This estimate applies to the main body of the Gnangara Mound, which excludes the major urban areas, and compares favourably with the result from current modelling over the Pinjar area.

Some upward recharge from the Leederville Formation also occurs into the superficial formations. The potential for upward leakage into the superficial formations occurs to the west of the linear lakes on the coastal strip directly from the Leederville Formation.

6.1.5.4 Storage and Movement

The volume of groundwater in storage in the superficial formations of the Gnangara Mound is estimated to be 19,500 x $10^6 m^3$, based on a specific yield of 0.3. Groundwater moves down the hydraulic gradient perpendicular to the groundwater contours. The rate of movement is controlled by the groundwater gradient and the hydraulic conductivity of the formation and may vary from about 0.01 to 100m/yr.

6.1.5.5 Discharge

Discharge of groundwater from the superficial formations occurs by evapotranspiration; outflow to the sea; leakage into underlying aquifers and by outflow into the rivers.

The evapotranspirative discharge consists of water lost from the water table by plant transpiration, evaporation from the open water surfaces of lakes and swamps, and evaporation from the capillary fringe of the water table. It has been estimated that about 70% of all rainfall on the coastal plain is used in the evapotranspiration process.

Outflow to the sea takes place from small springs along rocky parts of the coast such as between Triggs and Sorrento, or from seepage at about low water mark along the sandy parts of the coast. The outflow has been estimated by computer simulation, for the Northern Perth Area, including outflow into the Swan Estuary, to be 372 x $10^6 m^3$/yr.

Leakage into the underlying aquifers occurs principally into the Leederville Formation and locally into all the subcropping formations. Downward leakage into the Leederville Formation and from Gnangara Mound is estimated to be 107 x $10^6 m^3$/yr of which 86 x $10^6 m^3$/yr occurs in the Pinjar area.

Discharge to river baseflow occurs in the major drainages which cross the coastal plain, as well as into some of their tributaries. The major drainages form hydraulic boundaries to the flow system in the superficial formations and are sites of permanent discharge which maintain pools or baseflow, whereas the tributaries may only contribute discharge when the water table is high. Bestow (1976) estimated that groundwater baseflow in the Northern Perth Area was 53 x $10^6 m^3$/yr.

6.1.5.6 Water Quality

Groundwater from the superficial formations varies in salinity from about 130 - 12,000mg/L TDS and has an average salinity of about 500mg/L TDS. The lowest salinity groundwater occurs near the crest of the mound and the highest salinity near discharge areas. Groundwater with greater salinities also occurs as plumes which extend down hydraulic gradient from lakes and swamps such as Lake Pinjar and Lake Jandabup.

The composition of the groundwater from the superficial formations varies depending on where the water occurs. In the calcareous sediments of the coastal strip it has a pH of 7.0 to 8.0, whereas beneath the Bassendean Dunes the presence of organic acids from the swamps causes the groundwater to be acidic, with a pH of about 5.0 to 6.5.

Similarly the hardness of groundwater ranges from hard to very hard beneath the coastal strip and moderately soft to slightly hard beneath the Bassendean Dunes. The temperature of the groundwater ranges through the area from about 18° to 24°C and may also show small seasonal variations at individual locations. It may also be coloured by organic acids and locally have a high turbidity. Dissolved carbon dioxide and hydrogen sulphide are common.

Dissolved iron, which causes the iron-staining commonly associated with groundwater use, may vary from less than 1 to 10mg/L and is generally about 2mg/L. The origin of the iron is uncertain. It may result from a bio-chemical reaction between acid groundwaters and ilmenite (Baxter, 1977) or solution of the goethitic coating of yellow sands (Glassford and Kelligrew, 1976). Several genera of iron-fixing bacteria have been identified from the groundwater (Grey, 1977).

Nitrate, fluoride, boron and heavy metals are generally at low concentrations. By contrast the concentration of phosphate, while low, is relatively high as a result of naturally occurring phosphate in the underlying Cretaceous formations, and material derived from them.

The salinity of water in the wetlands varies seasonally (Figure 16) with highest salinities during the summer months and lowest salinities in winter. Studies at Lakes Jandabup, Joondalup and Gnangara indicate a close relationship between water level and salinity. Any activity which leads to a decline in wetland summer water levels, can be expected to increase water temperature and evaporation and therefore salinity levels. As the volume of water in the wetland declines through evaporation, salt and nutrient levels become concentrated, which may enhance algal growth if nutrient levels become high enough. Such algal blooms are common in Metropolitan lakes which have high nutrient levels.

Some Metropolitan lakes, such as Perry, Monger and Thompson Lakes have also been subject to outbreaks of botulism (Grubb, 1964). Botulism is caused by a bacterium that survives under anaerobic conditions often associated with high nutrient levels and algal growth in wetlands. Outbreaks of botulism have not been recorded in lakes within the area of influence of the proposed developments, due to their lower nutrient levels (Section 6.2.3). Despite natural drying of these lakes, nutrient levels do not appear to be high enough to cause concentrations to reach critical levels.

Changes in lake water levels due to the proposed developments, are expected to remain within the range of natural fluctuations. The proposed developments are therefore not expected to cause increases in the occurrence of botulism within wetlands in the Gnangara Mound area.

6.1.6 Water Balance

A water balance is an accounting of all water entering and leaving a system over a specific period, and provides a check on the accuracy of estimated inputs and outputs.

A simplified annual water balance for the superficial formations of the Gnangara Mound region, based on modelling carried out for the ERMP, is:

(Input) $R + W_i = E_t + F_b + L_{LF} + A$ (Output)

where	R	=	rainfall
	W_i	=	imported water from reservoirs and irrigation return
	E_t	=	evapotranspiration
	F_b	=	discharge to stream baseflow and outflow to sea
	L_{LF}	=	leakage to Leederville Formation
	A	=	groundwater abstraction.

The annual water balance is shown in Figure 18 with estimates of the various components in millions of cubic metres. Taking the data from Figure 18, the annual water balance for the Gnangara Mound area (2091km^2) is:

$$\begin{aligned} 1675 + 80 &= 1165 + 372 + 107 + 111 \\ 1755 \times 10^6 m^3 &= 1755 \times 10^6 m^3 \end{aligned}$$

The annual water balance for the Pinjar area (371km^2) is:

$$\begin{aligned} 305 + 6 &= 174 + 42 + 85 + 10 \\ 311 \times 10^6 m^3 &= 311 \times 10^6 m^3 \end{aligned}$$

The inputs and outputs are based on results from a simulation of regions using the Perth Urban Water Balance Study model (Boughton, et al., 1986). The simulation was carried out using average rainfall and evaporation and included current urban development, market garden irrigation and Water Authority production from the superficial formations.

6.2 THE REGIONAL BIOLOGICAL ENVIRONMENT

6.2.1 Landform, Soils and Vegetation Associations

The Gnangara Mound area is shown in its regional setting in Figure 19. It forms the northern part of the Swan Coastal Plain which, in the surface layers, is composed of either water-borne or wind-blown materials. There are three major systems of wind-blown (dune) materials in the Gnangara Mound area.

The furthest inland and oldest is the **Bassendean Dune System** which is composed entirely of siliceous sand. The crest of the Gnangara Mound is developed beneath the Bassendean Dune System. Further west is the **Spearwood Dune System**, comprising soft sandy limestone, locally capped with secondary calcium carbonate, with a thin mantle of siliceous sand. The limestone, known as Tamala Limestone, also makes up much of the coastline and is often overlain by the unconsolidated calcareous sands of the **Quindalup Dune System.** The Quindalup Dune System is outside the area of interest and is not described here. However, it is described by McArthur and Bartle (1980).

On the eastern margin of the Plain there is a zone of **Alluvial Terrain** with deposits which originated in the Darling Plateau and were transported by streams; these deposits generally have a high clay content. The native vegetation associated with these broad scale units is described by Heddle et al., 1980.

Existing broad-scale soil mapping units of the Gnangara Mound area are shown in Figure 19. As part of the present study, these units have been further sub-divided. A full discussion of this work is contained in Appendix C. The detailed landform-soil sub-units are described below.

The relationships between the broad-scale and detailed mapping units are shown in Table 15. The units Coonambidgee, Beermullah, Guildford, Swan, Caladenia and Vasse occupy very minor areas of the Gnangara Mound area shown in Figure 19, and correlation with present mapping is not included in Table 15.

TABLE 15

RELATIONSHIPS BETWEEN BROAD-SCALE (FIGURE 19)
AND DETAILED MAPPING UNITS (APPENDIX C)

SYSTEM	BROAD-SCALE UNITS	DETAILED UNITS	
BASSENDEAN DUNES	AEOLIAN DEPOSITS		
	Bassendean (B)	Jandakot	Ja, Ja-Steep
		Gavin	G
		Joel	J
		Seasonal Swamps	Ws
		Permanent Lakes and Swamps	Wp
		Yeal Swamp Complex	Wy
		Pinjar	P
		Drainage Lines	DL
	Southern River (SR)	Jandakot	Ja
		Gavin	G
		Yanga	Ya
		Drainage Lines	DL
		Seasonal Swamps	Ws
		Joel	J
SPEARWOOD DUNES	Karrakatta (K)	Karrakatta Sands	Ky, Kg
		Spearwood	Sp
		Seasonal Swamps	Ws
		Lakes and Swamps	W
	Cottesloe (Ct)	Spearwood	Sp
		Limestone outcrop	Kls
		Karrakatta sands	Ky, Kg
	Herdsman (Ha)	Beonaddy	B
		Lakes and Swamps	W
		Seasonal Swamps	Ws
QUINDALUP DUNES	Quindalup (Q)	Not Sub-divided	
ALLUVIAL TERRAIN	FLUVIATILE DEPOSITS		
	Yanga (Ya)	Yanga	Ya
		Gingin Brook Complex	GG
	Moore (Mo)	Gingin Brook Complex	GG

6.2.1.1 Bassendean Dunes

The Bassendean Dunes have low relief and the minor variations in topography are reflected by differences in depth to water table which in turn influences the vegetation. There there are hills and ridges (Jandakot), level or gently undulating terrain (Gavin) and depressed areas which are swampy in winter (Joel). In addition permanent water and seasonal swamps are identified and, in the far north, an area of very high, steep dune ridges has been mapped separately (Jandakot-Steep).

The **Jandakot** (Ja) unit comprises a landscape of low hills and ridges with relief in excess of 5m and commonly 10-15m. The soil comprises quartz sand with a grey surface, an almost white sub-surface, and a yellow sub-soil at 1-2m.

The vegetation is low, open banksia woodland. The upper storey consists of scattered banksias (Banksia attenuata, B. menziesii, B. ilicifolia) and prickly bark (Eucalyptus todtiana). The lower storey, at about 1m, is rich in species. In the northern part is an area of steep, high, irregular dunes (**Ja-Steep**) which come within the Jandakot unit but which are separated because they may have different hydrological relationships. This area is a pattern of ridges and intervening swales and hollows and, though these are not mapped in detail, the components are quite clearly different. The vegetation on the ridges appears to be the same as on the rest of the Jandakot but, in the hollows, there may be marri (Eucalpytus calophylla) and paperbark (Melaleuca preissiana).

The **Gavin** (G) unit is a landscape of very low relief, generally less than 5m, occurring most commonly in and south of the Gnangara pine plantation. It also occurs sporadically as low sandy rises on the alluvial plain. The soil is free draining quartz sand with a dark grey surface, a grey sub-surface, and a dark brown, sometimes cemented, sub-soil; there may also be iron concretions. Gavin soils are very dry in summer.

The vegetation consists of scattered large marri trees and an open layer of small banksias (Banksia grandis, B. attenuata, B. menziesii), sheoak (Allocasuarina fraseriana), and Christmas trees (Nuytsia floribunda) with a dense shrub layer which includes blackboy (Xanthorrhoea preissii), zamia palm (Macrozamia riedlei) and Dasypogon bromeliifolius.

The **Joel** (J) unit occurs as small, separate, depressed areas which may be swampy during winter but which do not have free water on the surface for extended periods. The soil is quartz sand with a high organic content at the surface, a grey sub-surface, and a dark brown, often cemented, sub-soil at 1-2m. The water table is usually within 2m of the surface.

The vegetation is variable and may have large trees such as flooded gum (Eucalyptus rudis), jarrah (E. marginata), paperbark (Melaleuca preissiana) or swamp bankia (Banksia littoralis). The shrub layer is very dense and may consist of Hypocalymma angustifolium, blackboy, Dasypogon bromeliifolius and several sedges and rushes.

The **Seasonal Swamps** (Ws) also occur as small separate areas and are most common in the central part of the mound. In summer the water table is probably less than 1m below the surface. The soil is often peaty at the surface and may have an organic hardpan at about 1m.

Vegetation usually consists of a fringe of dense large trees - paperbark and swamp paperbark (Melaleuca rhaphiophylla), with very little development of undergrowth. There may be a zone of sedges and reeds at the upper water line. The area occupied by water in the winter is usually bare or has a cover of annual plants in summer.

Permanent Lakes and Swamps (Wp) have a fringe of peaty soils and, within the zone of water fluctuation, a zone of specialised wetland vegetation. A closed fringing community of paperbarks and swamp paperbark with a dense growth of rushes and reeds is present. This unit is also referred to as the Herdsman Unit.

There are three sub-units within the Bassendean Dune System which have importance in groundwater considerations, but which do not fit readily into the mapping units.

Lake **Pinjar** (P) is an extensive flat area which has a water table generally within 1m of the surface with small areas seasonally flooded. The soil is sandy, possibly with some diatomaceous earth in the surface, and an organic hard pan below 1m. The vegetation consists of scattered paperbark and flooded gum trees, interspersed with sedges and reeds. Shrub species include Acacia saligna, Hakea varia and H. trifurcata.

Yeal Swamp Complex (Wy) is an area of low sandy rises with many small seasonal swamps, with paperbarks, flooded gums and swamp banksias often occurring in dense thickets.

Drainage Lines (DL) have been delineated because they are significant areas of groundwater discharge from the Gnangara Mound. The vegetation is usually flooded gum and paperbarks with a dense undergrowth of reed and sedges.

6.2.1.2 Spearwood Dunes

The Spearwood Dunes consist of Karrakatta sands, a Limestone unit, Spearwood sand proper and low-lying units with lakes and swamps common.

The **Karrakatta Sands** (Ky and Kg) comprise low hilly to gently undulating terrain with well drained yellow sands over limestone. Banksia woodlands are common with scattered emergent tuarts (Eucalyptus gomphocephala) jarrah and prickly bark. A dense shrub layer is present.

The **Limestone** (Kls) unit consists of low hills and ridges with bare limestone or shallow siliceous or calcareous sand over limestone covered by dense low scrub dominated by Dryandra sessilis, Melaleuca huegelii and species of Grevillea. The limestone unit is well drained with poor soil moisture storage.

The **Spearwood** (Sp) unit comprises karst depressions with some limestone outcrop and well drained shallow brown sandy soils. Banksia spp. woodland with emergent tuarts and jarrah make up the trees with a dense shrub layer beneath.

Low lying units include the **Beonaddy** (B) and **Lakes and Swamps** (W). The flat Beonaddy terrain has light grey sand with the water table within 2m; flooded gum, swamp banksia and paperbark trees with bulrushes (Typha sp.) near the water's edge. The Lakes and Swamps have permanent water in the base of karst depressions with paperbark and flooded gums in a zone of water level fluctuation. Sedges and reeds occur in shallow water.

6.2.1.3 Alluvial Terrain

The Alluvial Terrain occurs along Ellen Brook and its tributaries. It is characterised by a flat, poorly drained complex landscape with soils ranging from shallow to deep leached sand, saline soils, red loam and black or mottled clays. The vegetation is Banksia spp. woodland on sandy rises; Melaleuca spp. with scattered Actinostrobus pyramidalis on swamp; paperbarks and flooded gums along drainage lines and fringing permanent water. A dense shrub layer dominated by blackboys is common in parts.

6.2.2 Sensitive Flora

Surveys of plant collections held in the Western Australian Herbarium from the Gnangara Mound area identified only one species, Stachystemon axillaris, gazetted as rare flora under the Wildlife Conservation Act, 1950 (Appendix D). An additional 12 species which because of their restricted distributions are considered sensitive, were identified (Table 2, Appendix D).

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 abnormal variations in water table levels than plants growing higher in the landscape.

One sensitive species, Conostephium minus, is known to occur in the Pinjar 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 in the vicinity of Gnangara and Wanneroo. The rarest vascular plant species listed in Table 2 (Appendix D) are an undescribed orchid recorded at only three sites from Wanneroo to Jandakot, 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 (C25) at Muchea (Figure 20). The lots are now cleared and being grazed, and the Darwinia now survives in only one of them (Keighery, pers. comm.).

6.2.3 Terrestrial and Aquatic Fauna

The Gnangara Mound area was extensively surveyed for mammals, herpetofauna and birds by a study team from the Western Australia Museum during 1977-78. Survey areas selected contained representative stands of the majority of vegetation associations and soil types found on the coastal plain (Western Australian Museum, 1978).

The survey confirmed the presence of 12 native mammal species, with another 3 known from earlier records from the area. 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. There were 70 species from 42 genera (distributed amongst 11 families) of reptiles and amphibians recorded during the survey, as well as a total of 223 species of birds.

Many bird species are now rarely seen in the area as a result of human activities. The clearing of native woodlands and modification of wetland ecosystems has reduced the availability of food sources and nesting sites for certain species. On the other hand some terrestrial species have benefitted from clearing and have become common in the area.

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., Johnston, pers. comm. and Lane, 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 shallow lakes of the eastern chain do dry out but still do not support large wader populations, possibly because lower nutrient levels do not support the same biomass of organisms on which the waders feed.

Seventeen species (approximately 25%) of the reptiles or amphibians are scarce or rare in the area, primarily due to a lack of suitable habitats on the coastal plain. The Short-necked Tortoise is restricted to a few swamps in the Ellen Brook area. No other species are restricted to the Gnangara Mound area and they are common elsewhere. Four, however, are at their respective limits of distribution.

Representative water courses and lakes were sampled during the 1977-78 survey for freshwater fishes. The fish fauna of the area is represented by 13 species belonging to 10 families. Of this total, 2 are introduced and 7 are endemic to the South-west of Western Australia. Ellen Brook is regarded as a particularly important aquatic habitat because it supports relict populations of native fish species which no longer occur in other water bodies in the area, due to the introduction of exotic competitors such as the Mosquito Fish (Gambusia affinis).

Appendix E contains a detailed description of the fauna of the Gnangara Mound area.

6.2.4 Cave Fauna

Within Yanchep National Park there are more than 100 limestone caves (DCE, 1983). Of the Yanchep Caves, Crystal Cave is the only cave open to the public.

The blind, cave dwelling, gilgie (Cherax quinquecarinatus) is known to inhabit the caves of Yanchep National Park (Muir, pers. comm.). The caves are also inhabited by a number of amphipods and isopods with restricted distributions (Austin, pers. comm.). Concern has been expressed by CALM about the potential impact of a decrease in the regional groundwater table on these habitats.

6.2.5 Wetland Ecosystems

6.2.5.1 Types of Wetlands

There is increasing recognition of the importance of a network of wetlands, with varying morphology and resources, to serve the needs of the fauna throughout the year. Birds, in particular, move from one wetland to the other as each wetland shrinks and dries up seasonally. The fringing vegetation is important as well as the free water surface. Three distinct morphological types of wetland occur within the Gnangara Mound area (Singleton, 1979). These are the circular lakes, linear lakes and the swamps.

The typically **circular** lakes which include Lakes Jandabup, Mariginiup, Adams and Gnangara, occupy depressions within the Bassendean Sand. These shallower lakes are less than 2m deep and contain relatively impermeable organic deposits of diatomite.

The water table slopes gently to the lakes from the east and lake levels fluctuate in sympathy with the water table. These circular lakes are more susceptible to water table changes than the linear lakes, because of their shallowness and gently sloping floors. A fall in water level therefore exposes a wider fringe than the same fall in a linear lake.

The **linear** or Joondalup type lakes include Lakes Goollelal, Neerabup, Joondalup and Loch McNess (Figure 1). They are collectively referred to as the western chain. These linear lakes are relatively steep sided and deep with up to 3.5m of water.

Maximum water levels are controlled by caves in the coastal limestone acting as spillways (Allen, 1981), with some interlake flow (Bridge, 1968; Congdon, 1985). The water table contours rise steeply to the east of these lakes (Bekle, 1980) such that lake levels are less susceptible to reductions in groundwater levels to the east. In addition, their steep sides and depth mean that falls in level affect a narrower fringe than would be the case with a shallower lake (Figure 21).

Swamps are mainly situated on the eastern and central coastal plain. Examples include Yeal Swamp and Tick Flat. They are less common in the west due to the depth to water in the coastal dune system. They occupy interdunal depressions thought to be the sites of former infilled lakes (DCE, 1981). The swamps are surface expressions of sites where the water table lies close to the ground surface, rather than above the surface as occurs in the shallow lakes. In winter they are occasionally flooded. Their location and morphology means that they react similarly to the shallow lakes.

Declining water tables may be due to low rainfall, high evapotranspiration or high groundwater abstraction. Water level declines have been noticeable at the shallow Lakes Gnangara and Jandabup over the last 10 years of low rainfall and increasing groundwater abstraction for both private and scheme supplies. Swamps remote from groundwater abstraction, such as Tick Flat, have also recorded declining groundwater levels and loss of wetland tree species, due to low rainfall over the last 10 years. The deep Lake Joondalup however has been less affected by the run of dry years and the increase in abstraction to the east.

6.2.5.2 Wetland Water Balances

The wetlands of the Gnangara Mound are 'windows' in the water table in hydraulic connection with the shallow groundwater flow system. The relationships between the groundwater and the various types of wetland have been investigated and water balance studies carried out.

Typical Circular Lake

Lake Jandabup is a typical circular lake. It occupies an area of approximately $4km^2$ and is partly covered by swamp vegetation with an area of $1.2km^2$ of open water in its centre.

The lake level and surrounding water table fluctuate seasonally, being generally highest in October and lowest in March. The magnitude of the fluctuation is greater in the lake due to direct recharge from rainfall and direct discharge by evaporation and transpiration.

Water balance calculations for the period April 1977 to March 1978, were reported by Allen (1980) as shown in Table 16 below.

TABLE 16

WATER BALANCE FOR A TYPICAL CIRCULAR LAKE
LAKE JANDABUP

PARAMETER	AVERAGE ANNUAL VOLUME (x 10^6m^3) 1977-1978 INPUT	OUTPUT
Groundwater	4.49	1.10
Rainfall	2.04	-
Evaporation/Evapotranspiration	-	5.87
TOTAL	6.53	6.97

Lake storage fell from $0.31 \times 10^6m^3$ in 1977 to $0.19 \times 10^6m^3$ in 1978.

These figures show that the lake is maintained primarily by groundwater inflow and to a lesser extent by direct rainfall. Using salinity and water table contours, Allen (1980) concluded that groundwater inflow to the lake was primarily from the upper half of the superficial formations. However, thick organic lake deposits on the downstream side of the lake impede groundwater throughflow, creating an evaporation cell where in excess of 90% of the groundwater and rainfall input is lost to evaporation and transpiration.

Similar conclusions were drawn from later studies on the whole of the East Wanneroo wetland chain by Allen (1981) and on Lake Mariginiup by Hall (1983).

Typical Linear Lake

Lake Joondalup is a typical linear lake which occupies an interdunal depression approximately 8km long and 1.2km wide at its broadest point, with an open water surface of $6.1km^2$. There are only small zones of low lying fringing swamp at the northern and southern extremities (Bekle, 1980) which occupy 16% of the total area (Congdon, 1985). Recharge to the lake is by rainfall and groundwater inflow.

The annual water balance averaged for 1969-1980 as shown in Table 17 has been studied by Congdon (1985).

TABLE 17

WATER BALANCE FOR A TYPICAL LINEAR LAKE
LAKE JOONDALUP

PARAMETER	AVERAGE ANNUAL VOLUME (x 10^6m^3) 1969 - 1980 INPUT	OUTPUT
Groundwater Flux*	2.54	-
Rainfall	3.22	-
Evaporation/Evapotranspiration	-	5.94
TOTAL	5.76	5.94

* Including surface water inflow.

The change in lake storage was not estimated.

The actual inflow and outflow of groundwater from the lake system could not be quantified, but Congdon computed a net annual inflow of groundwater to Lake Joondalup of 2.54 x $10^6 m^3$. Based on these calculations and observed water level fluctuations in the lake and in three adjacent wells for the period September 1978 - May 1981 he concluded that 95% of losses were due to evapotranspiration.

Over the last 30 years, the clearing of natural vegetation and urbanisation around the lake has increased surface runoff and reduced groundwater losses by evapotranspiration. This has resulted in an overall rise in lake water levels as illustrated by submerged fence lines and dead, flooded paperbark trees.

Because of their depth, the linear lakes are less prone to drying than are the circular lakes. In general the linear lakes are also further from the groundwater abstraction zones and therefore less affected by pumping.

Swamps and Springs

Topographic depressions on the eastern and central parts of the Gnangara Mound area contain extensive swamps and springs. They occur where the water table is close to the surface and occasionally may be flooded in winter.

The total loss by evapotranspiration from lakes and swamps was computed by Singleton (1979) as follows:

TABLE 18

EVAPOTRANSPIRATION FROM LAKES AND SWAMPS OF THE GNANGARA MOUND AREA

	AREA (km^2)	WATER LOSS (x $10^6 m^3/yr$)
Lakes	15	27
Swamps	148	200

Swamps occupy about 10 times the area occupied by lakes in the Gnangara Mound area. Water losses from swamps as a result are an order of magnitude greater than the losses from lakes.

The wetland water balances given above illustrate that evapotranspiration is the major output from the groundwater system, while rainfall and groundwater flow are the major inputs. Reduced rainfall and groundwater inflow can thus have significant effects on wetlands, especially those of the shallow circular type. Conversely, management of evapotranspiration such as is possible with the Gnangara pine forest, can lead to increased water levels in lakes.

6.2.5.3 Wetland Synthesis

Wetlands and the plants and animals they support are most vulnerable to lowering of the water table for two reasons. Firstly, the biota are adapted to and rely on water above or near the surface. Species will tend to be lost rather than decrease in abundance or stature. Secondly, wetlands are limited in extent and are discontinuous. Their discontinuity means that if species are lost from an area due to a temporary water table decline, it is more difficult for them to re-establish from the next, remote, population. For these reasons the loss of part of the limited area of wetlands assumes greater importance than loss of part of the more extensive upland ecosystems.

Wetlands support the vegetation types least tolerant of a permanent decline in the water table (Appendix A). Species such as Swamp Banksia, Swamp Paperbark and the Flooded Gum as well as understorey species important as habitat or food resources are adapted to seasonally fluctuating water tables but vulnerable to permanent changes.

The littoral zone and associated habitats are important to invertebrates which form the base of the flood chain for birds and animals. Species diversity and abundance increase following winter rains, and decline when lake levels drop during summer.

Amphibians typically require clear water in lakes, swamps or streams and would be affected by reduced availability of these habitats. The Short-necked Tortoise is restricted to a few swamps in the Ellen Brook area, the maintenance of which is vital to the survival of this rare species. Fish are clearly dependent on the maintenance of lake, swamp and stream habitats.

The waterfowl most at risk if the water table declines are the inhabitants of the deeper water such as the diving ducks (eg. Musk Duck). Three mammalian species, namely the Southern Brown Bandicoot, Water Rat and Bush Rat also prefer swamp and lake habitats.

The waterbirds, tortoise and mammals depend on the vegetation supported by wetlands as well as the presence of the water itself. There has already been considerable deterioration of the wetlands through drainage, landfilling, fire and clearing activities. The bird species composition has been influenced by this deterioration of the dense fringing swamp vegetation.

Wetland flora and fauna are naturally adapted to quite dramatic seasonal fluctuations in water levels and are sufficiently resilient to recover from seasonal variations and prolonged droughts. Permanent changes in water levels are likely to cause permanent changes to the wetlands and their biota, however it is significant that the only wetland dependent species known to be restricted to the Gnangara Mound area is the Short-necked Tortoise.

Conservation of representative examples of the biota requires maintenance of habitats. A network of sites of different types (eg. swamps, shallow lakes and deep lakes) contributes to the resilience of the ecosystem as a whole.

As well as providing habitats for wetland dependent species of plants and animals, wetlands provide centres of interest in the landscape. Wetlands thus have 'social' as well as 'natural' values (Arnold and Wallis, 1986). Wetlands can also be considered to have economic values as they tend to increase the Real Estate values of adjacent land and form an important recreation resource. The maintenance of these wetlands is therefore a major consideration in groundwater management within the area.

The dependence of wetlands on groundwater levels has been recognised by the Water Authority. Groundwater management strategies have been developed which mitigate impacts on sensitive wetlands. The level of mitigation has been determined on a case by case basis dependent on perceived quality and sensitivity of each site. For example, the wetlands of the Wanneroo Eastern Chain have been ranked in the EPA's recommendations for conservation reserves in System 6 (DCE, 1983) and the operation of the existing Wanneroo wellfield modified in recognition of the importance of Lake Jandabup.

6.2.6 Upland Ecosystems

Upland ecosystems are represented by the Jandakot and Gavin sand ridges of the Bassendean Dune System and the Karrakatta, Limestone and Spearwood units of the Spearwood Dune Systems. The vegetation is dominated by open banksia woodland or low proteaceous and myrtaceous scrub on the limestone. The fauna contains many species of birds and mammals which depend on the banksias and scrub species for nectar and cover. Reptiles are also most common here. In general the fauna of the uplands do not rely on ready access to water or are wide ranging enough to obtain water from the wetlands. Examples of such species are the larger arboreal birds, raptors and macropods such as the kangaroos.

On the upland sand ridges much of the vegetation can be sub-divided into species with deep roots and species with shallower roots. Deep rooted species rely on the water table whereas shallow rooted species do not. Therefore, deep rooted species are more likely to be affected by water table declines and may be replaced by shallower rooted species if significant declines occur. The change from deep rooted Banksia ilicifolia to the shallower rooted B. attenuata is such an example (Appendix A). Most species growing on the limestone do not rely on the water table and therefore, these associations are not expected to be affected by water table declines.

Such changes in species composition would be likely within the zone of greatest water table drawdown. If the drawdown is gradual the deep rooted species may adapt to the change. The upland ecosystems are generally less susceptible to changes in water table than wetland ecosystems. If deep rooted species like B. ilicifolia are gradually replaced by shallower rooted ones like B. menziesii, the overall woodland character of the site will re-establish. Mature trees may also be replaced by seedlings of the same species which establish and adapt to the altered groundwater regime. Species change may reduce the diversity and food resources of the site as the species may have different flowering times which is of importance to Honeyeaters for example.

Localised, sudden tree deaths may occur within a few tens of metres of production wells. Some tree deaths have been recorded over a limited area in the vicinity of two existing production wells. Recent observations have indicated that Banksia attenuata is now regenerating in the area. Epicormic shooting on mature trees and stem elongation and leaf production on juvenile trees has been observed. This area will be closely monitored to assess the success of this regeneration.

6.2.7 Ecosystem Representation in Conservation Reserves

Conservation Reserves are selected to adequately represent the ecosystems of the area and should therefore be protected.

The Water Authority has within its objectives, the provision of services subject to environmental objectives and priorities and to seek an appropriate balance between economy, environmental protection and the social aspirations of the community. The Authority therefore aims to ensure that conservation reserves are protected by careful management of all forms of groundwater use including extraction for scheme supplies.

National Parks, nature reserves and System 6 conservation areas recommended by the EPA, occur within the Gnangara Mound area (Figure 20). These are listed and described in Table 4 of Appendix D.

Yeal Nature Reserve (M5) contains representative areas of the Bassendean Dune sand ridge ecosystems, while the Spearwood System is well represented in Yanchep National Park (M3) and Ridges Management Priority Area - MPA (M4). The limestone ecosystem is represented within the Ridges MPA.

As well as being quite well represented in proposed reserves, the upland ecosystems are more extensive and continuous than the wetlands.

Shallow lake habitats are represented in the Wanneroo Wetlands - Eastern Chain (M8). Deep lake habitats occur in Yanchep (M3) and Neerabup (M6) National Parks and Lakes Joondalup and Goollelal (M7). Swampy habitats are located in many reserves; most notably Yeal Nature Reseve (M5) and its proposed extension, Wabling MPA (C13), Whiteman Park (M13) and the Ellen Brook and Twin Swamps reserves (M17).

The reserves known to contain restricted biota and in need of special protection are Mound Springs (C25) for Darwinia sp., and the Ellen Brook and Twin Swamps reserves (M17) for the Short-necked Tortoise.

6.2.8 Forestry

State Forest No. 65 covers approximately 50,000ha, 23% of the Gnangara Mound area, with about 20,000ha planted with pine; mainly Pinus pinaster. These pine plantations are presently being expanded at the rate of 500ha/yr and are located on the Bassendean and Spearwood Dunes, stretching from Gnangara Road towards Gingin Brook (Figure 22). The State forest is managed by the Department of Conservation and Land Management (CALM) for multiple uses; including water, timber production and conservation. The priority land use is water production over much of State Forest No. 65 south of the Gingin Brook (Figure 23). Under the multiple land use concept some areas are designated for conservation or scientific study.

CALM have applied for an extension to State Forest No. 65 to include a further 6000ha for pine plantation. The proposed area is located in vacant Crown Land and overlaps with the proposed extension of the Yeal Nature Reserve to the boundary of the airforce bombing range (Figure 20). The current Land Use Management Plan for the Swan Coastal Plain (North), (Forests Department, 1981) states that:

> "... State Forest No. 65 ... overlaps the large body of high quality water close to the surface known as the Gnangara Mound. It is especially important in years of below average rainfall ... The bulk of the area has been converted to Pinus pinaster plantations ... Increased timber and water yields can be quite compatible in this zone since the silvicultural treatments which increase timber value (heavy thinnings) favour infiltration into the unconfined surface aquifers."

The stated management strategy for State Forest No. 65 south of Gingin Brook is:

> "The area will be managed primarily for the production of potable water. Activities associated with other secondary or tertiary land uses will be such that this objective is not significantly affected ... Pine plantations will be intensively managed to optimise sawlog and water production."

The tree density within pine plantations is expressed as the basal area in square metres of tree stems per hectare. Large numbers of trees are planted as seedlings so that early canopy closure will control branch size until the best trees can be high pruned. This results in straight trunks with a maximum of clear, knot-free wood. Optimum growth rate is achieved by thinning inferior trees. The optimum tree density is related to the water and nutrient resource supply of the site.

Generally, the limiting factor for plant growth is water supply and a tree density which uses a similar amount of water to the native woodland formerly on the site is believed to optimise growth. A growing stand density range of between 7 and $17m^2$/ha, with an average of 11 m^2/ha has been proposed by CALM to provide the optimum benefit for wood and water production. This average approximates the basal area of native banksia woodland. However, the water use by pines of this density is greater than that of native banksia woodland (Butcher, 1979).

Sharma and Pionke (1983) estimated that recharge under native vegetation was about 12% of annual precipitation while recharge beneath an unthinned mature pine plantation was negligible. Therefore increased recharge can be achieved if thinning is undertaken.

There is presently no market for thinned trees and as a consequence there are old plantations with basal areas considerably larger than $11m^2$/ha (Figure 22). It is believed that a market for thinnings is imminent, in which case commercial thinning is expected to commence. Without suitable markets, non-commercial thinning of these stands would have to be accounted for by the gains in groundwater recharge. Resolution of these issues is being addressed jointly by the Water Authority and CALM. It is evident that effective groundwater management involves appropriate land management.

A more detailed account of forestry issues on the Gnangara Mound is contained in Appendix B.

6.2.9 Synthesis of Water Use

If the water table is close to the surface then any lowering of the water table will reduce evapotranspiration losses, resulting in a greater fraction of rainfall being available for abstraction. Vegetation types which depend on the water table must either extend their root systems to greater depths or be replaced by vegetation types which utilise moisture stored in the soil above the water table. If the water table is reduced adjacent to lakes, the lake levels will fall.

To increase the amount of rainfall recharge, and make additional water available for abstraction, it is desirable to lower the water table. This results in an annual increase in available yield due to reduced evapotranspiration.

It is also desirable, however, to maintain lakes and the sensitive vegetation which depends on the water table. Therefore, the best location for groundwater abstraction is within an area which is not environmentally sensitive to reductions in water levels. Pine forests provide an ideal location.

Additional recharge can also be gained under pine forests by thinning. This decreases interception and direct transpiration of stored soil moisture (Butcher, 1977).

Thus, all elements of the water cycle which can practically be manipulated, need to be managed. In this way manipulation of recharge, as well as abstraction, facilitates better overall management of the water resource. The resource can be manipulated by managing:

- public abstraction,
- private abstraction, and
- forest density.

Effective water management relies on integration with land management.

6.3 THE REGIONAL SOCIAL ENVIRONMENT

The social effects assessment (Appendix G) has been limited to those areas of the social environment potentially affected by the proposed Gnangara Mound groundwater developments, principally the Pinjar Scheme. The study of the social environment was broken into three main sections.

- The existing social environment.
- Impacts of the development on the social environment.
- Community attitudes study.

The existing social environment was examined at two levels. The regional study area corresponds to the City of Wanneroo Local Government Area. The area in which direct social effects may occur as a result of the Pinjar Scheme was defined as that shown in Figure 24. This is referred to as the Pinjar/Carabooda area and closely approximates the land use survey area discussed in Appendix G.

The study assessed population trends, urban development, land use, zoning and groundwater users. Where applicable, the study considered future trends in an endeavour to ascertain the potential impacts of the proposal. The social implications of impacts on the biological and physical environment which have indirect effects on the soical environment, were also investigated.

6.3.1 Population

Most people who will be supplied by the proposed developments or influenced by groundwater management of the Gnangara Mound, will live in the Wanneroo region. For the purposes of the sociological study, the Local Government Area of the City of Wanneroo has been regarded as the regional study area (Figure 10).

The estimated resident populations for the City of Wanneroo from 1966 to 1984 are presented in Figure 25. This figure shows the population to have increased from 2440 in 1966 to 114,300 in 1984 which is a mean average annual growth rate (AAGR) of 26.1%. The majority of this increase is attributed to rapid urban development of the North-West Corridor. Since 1976, the growth rate has fallen to a mean AAGR of 10.8%. This is still greater than the AAGR for the State over the same time period of 2.1%. It is estimated that the population of the City of Wanneroo will reach 260,000 by 2001, and 470,000 by 2021 (State Planning Commission estimate). These estimates are based on the planned development of the North-West Corridor.

The State Planning Commission (SPC) has initiated a two year review of the existing corridor plan which could result in an amended development strategy. Any such change would be taken into account in the course of the Water Authority's on-going planning.

6.3.2 Land Use, Tenure and Zoning

The Gnangara Mound covers an area of approximately 2200km^2. The Local Government Authorities administering the area include the Shires of Chittering, Gingin, Swan and Peppermint Grove, Cities of Bayswater, Belmont, Nedlands, Perth, Stirling, Subiaco and Wanneroo and the Towns of Bassendean, Claremont, Cottesloe and Mosman Park.

A detailed analysis of the regional land use, tenure and zoning is given in Appendix G.

The majority of the Gnangara Mound is contained within the boundary of the Metropolitan Region Scheme, a statutory plan outlining the broad scale land zoning of the Metropolitan area (Figure 11). The 15 Local Government Authorities each have Town Planning Schemes containing additional, specific information.

In 1977 the MRPA published the report "Planning Structure for the North-West Corridor". This plan showed that the Gnangara Mound was the likely source of water for future urban development and also delineated the proposed Public Water Supply Area boundary. The plan aimed to create employment for a high proportion of the resident workforce, by the establishment of industrial and commercial centres, as well as residential areas within the North-West Corridor. The corridor plan of development is presently under review. Any major changes to the plan would require SPC to liaise with the Water Authority, to assess the implication for water supply and groundwater management.

The broad zoning categories now applying within the Gnangara Mound area are: urban, urban deferred, industrial, rural, special rural, parks and recreation, State forest and vacant Crown Land (Figure 11).

The urban areas occupy the south-west portion of the Gnangara Mound area together with the coastal developments of Quinns Rock, Yanchep and Two Rocks. The growth of the North-West Corridor on the coastal strip will progressively open up areas that are presently zoned urban deferred. Joondalup is the only sub-regional centre designated on the North-West Corridor Plan. It is located on undeveloped bushland to the west of Lake Joondalup away from existing residential areas.

Industrial areas within the Gnangara Mound area are located in designated zones and are often located close to either basic raw materials or major transportation routes. Accessible basic raw material deposits within the Metropolitan region were the subject of an MRPA study (MRPA, 1984). The basic raw materials include sand, limestone and clay, and the main areas of extraction within the Gnangara Mound area are Wanneroo, Gnangara, Beechboro and Henley Brook.

Significant deposits of diatomite occur in many of the lakes and swamps within the region, particularly the circular lakes. Mining leases occur over most lakes. Mining on these leases would have significant implications for groundwater management.

If an area were mined for example, then management of water levels to protect wetland vegetation may no longer be relevant. Alternatively the guidelines for management may change. It is important that the Water Authority be consulted before permission to proceed with mining is granted. Commerical extraction of diatomite could provide an economically feasible means of deepening some lakes so that they dry out less frequently. The Western Australian Wildlife Authority has approved mining for diatomite in Yeal Swamp under strict conditions (DCE, 1983).

Planning for the North-West Corridor recognised that the deposits of limestone and sand should not be rendered inaccessible by other land uses. Excavation should ideally occur before urban or other development. Groundwater abstraction is not expected to adversely affect any of these resources; conversely sand and limestone extraction will affect surface topography and could have some slight impact on recharge and on the configuration of the water table contours. Some control of mining operations may be required to prevent groundwater contamination by oil or fuel spills.

The orientation of the North-West Corridor channels urban development away from valuable land resources including agricultural land for market gardening, viticulture and orchards as well as sources of basic raw materials. A study was undertaken statewide under the title "A Rural Small-Holdings Policy Study" (Town Planning Department, 1980b). The report recommended two main areas within the Gnangara Mound area that should be preserved for intensive agriculture.

- The Swan Valley (particularly the area suitable for viticulture).
- The market garden areas of Wanneroo.

It was also recognised in the study that a demand existed for small rural allotments. To accommodate this, the Town Planning Department (now joined with MRPA to form the SPC) adopted the Special Rural Zone planning concept. The purpose and intent of a Special Rural Zone is to select areas within the rural area to permit hobby farms, horse breeding and training and rural residential retreats by making provision for the retention of the rural landscape and amenity in a manner consistent with the orderly and proper planning of the area.

Parks and recreation areas have been established within the Gnangara Mound area. These areas include National Parks, reserves vested in Shires or other Government Departments and State forest. Appendix D contains a description of the existing conservation reserves in the Gnangara Mound area.

Conservation reserves have variable status. Some are already gazetted while others are the subject of EPA System 6 recommendations. Most of these recommendations have not yet been implemented. As well, there are two additional areas which have been proposed as further conservation reserves. These areas are the proposed Gingin Stock Route Reserve and the proposed Yeal Nature Reserve extension (Figure 20).

These proposals were made by the Department of Fisheries and Wildlife before it amalgamated with the Forests Department to form CALM. The area proposed as the Yeal Nature Reserve extension has also been subject to a recommendation by the former Forests Department for addition to State Forest No. 65.

6.3.3 Historic and Archaeological Aspects

There are 121 historic sites identified by the Historic Sites Advisory Committee of the City of Wanneroo. The majority of these are European houses.

A survey was undertaken for Aboriginal archaeological sites in the Pinjar area and forms Appendix F. As this area is now within pine forest, it has already been disturbed and this has affected any archaeological site integrity. No cultural material was located during the survey. Additional surveys will be conducted for each of the other proposed schemes as part of the detailed environmental studies for these developments.

6.3.4 Community Attitudes Study

6.3.4.1 Introduction

The assessment of community attitudes towards proposed groundwater development and management was primarily aimed at documenting perceived issues and public aspirations. It was undertaken in two parts. The first part was a series of personal interviews with representatives of concerned community groups. The second was a public questionnaire, known as the Public Awareness and Attitudes Survey (PAAS), circulated in conjunction with a public display of the proposed groundwater developments.

This was conducted in an endeavour to identify water management issues of concern to the public, both inside and outside the Pinjar/Carabooda area. The survey was primarily aimed at documenting the perceived issues and public aspirations so that the Government would be aware of them, could keep them under review and make decisions with them in mind. It is recognised that the assessment is not representative of all community groups. For example, those people who will derive most benefit from new public water supplies, that is the future urban dwellers in the North-West Corridor, do not live there yet. Consequently, a non-statistical basis was adopted for the attitudes survey. The results are considered to give a reasonable impression of the attitudes of the population of Wanneroo and its environs, toward issues associated with groundwater development and management. A more detailed description of the community attitudes assessment procedure is presented in Appendix G which provides details of the relevant community issues, analyses and assessment.

Both parts of the study provided wide ranging and varied responses, reflecting the variety of community groups within the area.

6.3.4.2 Community Perceptions of Groundwater

Perceptions were regarded as those points raised that related directly to the way people view existing groundwater use. A summary of the main perceptions raised is presented below. As the factors are points of view, it was not appropriate to rate them, so they are listed alphabetically. To convey an appreciation of peoples' views, often repeated comments are also quoted.

- "Groundwater is being wasted by overwatering and watering during the day." Rural groups and urban groups perceive each other as being the main offenders.

- Groundwater is seen as a community resource to be shared equitably between private and public users but a number of people, particularly from the rural community, felt that "groundwater management controls were not being fairly applied."

- "Hobby farms and other Special Rural pursuits require lawns and gardens and too much water." This view was expressed primarily by rural people. Alternatively, it was suggested that, due to current groundwater controls on Special Rural lots, there is a net groundwater recharge on these areas.

- Natural features - bush, lakes, National Parks, etc, played an important part in respondents lifestyles. Conservation areas were regarded as highly important by rural and urban people alike. People have perceived heavy degradation of System 6 areas due to a variety of suggested causes including lowering of the water table and clearing activities. Tree deaths have been perceived to be due to public supply pumping from production wells.

- People are claiming reduced utility, due to water restrictions, as an argument for lower rates.

- The importance placed on market gardens and other rural pursuits was consistently apparent in responses throughout both parts of the study. Groups from all locations considered market gardens to be important, however, as would be expected, rural dwellers gave these land uses highest priority. Respondents also considered it important that those who rely on water for their livelihood, such as primary producers, should receive priority in groundwater management considerations.

- The majority of residents of Wanneroo saw degradation of all natural things, especially lakes, as a major concern. There was general concern about declining lake levels, particularly Lakes Gnangara, Jandabup and Neerabup. Wetlands are seen by all parties to be important natural features of ecological, scenic and passive recreational value, to be conserved wherever possible.

- "Values of land have dropped where restrictions have limited the amount of groundwater available for irrigation." "Land is not worth much without water." Some people "weren't informed of groundwater restrictions" when they bought their properties and now "can't develop them due to a lack of water."

- Wanneroo is desirable for market gardening, other rural activities and Special Rural areas, due to its proximity to the Metropolitan markets and Perth. Production at Wanneroo is also important seasonally, to meet the demand for specific vegetables when they are not available from other districts.

6.3.4.3 Community Aspirations at Wanneroo

Aspirations were considered to be the future expectations and wishes of the people regarding groundwater in Wanneroo. Once again results were not rated and are in alphabetical order.

- Because of its proximity to Perth and Metropolitan markets, Wanneroo is considered a desirable location for all rural activities and there is a concern as to their future. Market gardening and other rural pursuits were considered the best land use by most groups.

- Management strategies suggested to reduce impact on wetlands included locating wells as far from wetlands as possible, artificially maintaining lake levels by pumping groundwater into them, or a winter pumping strategy where groundwater could be pumped into storage reservoirs.

- Rates and charges were considered an important community issue.

- Rural Wanneroo people are most concerned about water restrictions and future water availability, as it affects their livelihood. This group also preferred an unlimited groundwater supply.

- Some landowners felt their livelihood was being adversely affected by groundwater controls. They suggested that "if the overall community benefitted from public water supplies, then the community should compensate disadvantaged water users."

- The future of the wetlands was a particularly prominent issue. These are considered by all groups interviewed, as important areas worth preserving, though rural people were more inclined to place them as equal in importance to rural activities.

- The majority of groups interviewed emphasised a need for public education and access to information. "There is a need for greater public input into water resource management decisions." People need to be educated and informed of the status of the resource, the reasons for its management and be taught how to conserve it. "The public should also be informed of any limitations prior to purchasing land in managed areas."

- The predominant aspiration was that groundwater should be shared and any restrictions should apply to all users. It was felt that all should have access to groundwater on an equal footing with the Water Authority. There were views, expressed mainly by rural people, that groundwater should be reserved for private use only. Conversely, representatives of the urban community stated that urban development requires water and is a legitimate groundwater user. This latter group also commented on the importance of good water quality. There was much debate on 'ownership' of the groundwater with rural people being inclined to state their priority to it. Rural respondents consistently placed greater importance on access to groundwater whereas urban dwellers were more concerned about water quality, which probably relates to its use for irrigation and drinking respectively.

- The Water Authority was seen as responsible for management of the entire resource, not just for public water supply. Groundwater management was seen as necessary, should apply to all users and should be fair and equitable. The use of meters on wells to monitor groundwater met with a mixed reaction. Demand management, that is, lowering water demand by educating public water supply users to conserve water, was also suggested.

- "There are choices to be made." It was suggested that there needs to be a balance between wetlands, market gardens, population, wild rivers and green lawns. Limitation of urban growth was seen as an alternative by some.

- There was a strong suggestion from many community groups that the Water Authority should look for alternatives to utilisation of the Gnangara Mound. Suggestions included the Ord River, desalination, and utilising groundwater resources north of the Gingin Brook. Reasons for this were primarily to avoid any further impact on the environment of the Gnangara Mound area due to water table drawdown and to allow more water for private groundwater users. It was pointed out that conservation of the environment will cost money either by well restrictions, conversion to native gardens or as higher water rates and that the community should be prepared to pay more for water to afford conservation.

- There was much debate about the presence of future Special Rural areas in rural Wanneroo. People appeared equally divided on their appropriateness, both as a land use and as groundwater users.

- o There were opposing views expressed on public parks and private gardens in the community and consequently, the amount of water that should be allocated to these uses. The rural respondents did not consider these features important, whereas urban dwellers placed more emphasis on them.

6.3.4.4 Synthesis of Community Attitudes Study

It is significant that personal interviews indicated that preservation of the environment was considered to be a priority in the development of a management strategy by many people from both rural and urban backgrounds. Embodied in this finding was the need for more efficient land use and consequent use of water resources. For example, conservation groups viewed the use of groundwater resources for the development of pine plantations to be inefficient. In contrast, the use of groundwater for irrigation purposes to grow vegetables and the supply of water to urban development were viewed as legitimate users by broad sectors of the community. The emphasis that urban people in particular place on rates and charges is also noteworthy.

Other results of the personal interviews indicate the type of issues that should be addressed in an education programme concerning the conservation of groundwater resources. The important components are listed below.

- o To improve access to information about water conservation and the water cycle.
- o The need to develop paths of communication between public authorities, especially closer liaison between bodies responsible for land use planning and the Water Authority.
- o 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.
- o The need for a regional office of the Water Authority which is seen to be involved with issues concerning local people.

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

Analysis of the public questionnaire confirmed that the protection of the existing natural environment is a priority issue. Natural bush was also considered an important feature to maintain in the community. Similarly, consistent importance was placed on lakes. It was also clear that the importance of market gardening was recognised by the majority of people.

The need for quality drinking water was also regarded as a priority. There was also some suggestion of differences in attitudes to the use of groundwater between socio-economic groups. Verification of this trend would require more detailed sampling.

The results of the survey suggest a management strategy containing 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 access to adequate water in 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 based on the maintenance of existing service levels and consequently eventual management of all groundwater resources in the Gnangara Mound area. As demand for water supply from the North-West Corridor grows, there is likely to be an expectation of maintenance of existing service levels. 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.

7.0 GROUNDWATER DEVELOPMENTS ON THE GNANGARA MOUND

7.1 PRESENT DEVELOPMENT

7.1.1 Public Water Supply Schemes from the Superficial Formations

A component of public water supplies for the Perth Metropolitan area, is drawn from the shallow groundwater resources at Gwelup, Mirrabooka and Wanneroo (Figure 2). Within each of these regions groundwater management areas have been proclaimed to enable these resources to be managed. The Jandakot Groundwater Scheme is located to the south of the Swan River and outside the scope of this ERMP.

Gwelup is the only scheme located entirely in an urbanised area. The Mirrabooka Scheme is largely within a rural area, partly used for agriculture and recreational open space. The Wanneroo Scheme is located within State Forest No. 65.

The Mirrabooka Groundwater Scheme was the first of the Water Authority groundwater schemes to be developed. Investigation of the potential of the Mirrabooka area for groundwater extraction commenced in 1960. The first stage of the Mirrabooka Groundwater Scheme began production in 1971. Since then, the scheme has been expanded to include a total of 28 wells in the superficial formations (Figure 2). Total production from the superficial formations and the Marine Sand aquifer in 1984/85 was $13.3 \times 10^6 m^3$ or 89% of the public water supply quota of $15.0 \times 10^6 m^3/yr$ (MWA, 1985a). The quota is the volume of water allocated for public supply which can safely be withdrawn without depleting the resource in the long term, taking into account other uses, including maintenance of the environment.

The Gwelup Groundwater Scheme commenced production in 1974. The scheme consists of 12 shallow wells drawing water from the superficial formations (Figure 2). The quota for the scheme is $5.5 \times 10^6 m^3/yr$. As the Gwelup Groundwater Scheme is on the southwestern flank of the Gnangara Mound, new developments in the North-West Corridor will not be serviced from this scheme. The Gwelup Scheme will not influence the effects of any new schemes, and therefore will not be considered further.

With increasing development in the Wanneroo area in the 1960s, there was a need to identify a future water supply for the area.

The Metropolitan Water Board (MWB) initiated investigations into the possible establishment of a groundwater scheme east of the Wanneroo townsite. The Wanneroo Groundwater Scheme was subsequently commissioned in 1973, abstracting water from the Leederville Formation. The superficial formations component of the scheme was commissioned in 1976.

The scheme consists of 24 shallow wells, which are located at 1km intervals along two sub-parallel lines, 5-8km apart. The 24 wells have a quota of $12.2 \times 10^6 m^3/yr$.

7.1.2 Private Groundwater Developments

The major component of agriculture in the City of Wanneroo is intensive horticulture, predominantly for vegetable production. Presently there are some 718ha of market gardens in the City of Wanneroo. It is a particularly suitable growing area for broadleaf vegetables and currently produces 58% of the total lettuce crop in Western Australia (Shire of Wanneroo, Unpubl. Rept). Each hectare used for horticulture requires $15{,}000 m^3/yr$ of irrigation water on average.

The current quota for private abstraction of groundwater from the Wanneroo Groundwater Area (WGA) is $36 \times 10^6 m^3/yr$. This has been distributed with $21 \times 10^6 m^3/yr$ in the area south of Flynn Drive and $15 \times 10^6 m^3/yr$ in the area north of Flynn Drive. Within these areas groundwater has been allocated to take into account the needs of the environment. Unconfined groundwater provides the only source of easily accessible irrigation water for the majority of private landholders within the Wanneroo region.

Private wells in the WGA are used for household, garden, stock and commercial irrigation. Within the section of the Wanneroo Groundwater Area south of Flynn Drive, there are over 780 licensed wells with a groundwater allocation of about $15 \times 10^6 m^3/yr$, of which approximately $12 \times 10^6 m^3/yr$ is currently used. This can be compared with $12 \times 10^6 m^3/yr$ drawn for public water supply from the Wanneroo Groundwater Scheme, located in the nearby pine plantation. In the area north of Flynn Drive, the estimated usage in 1985 was $9 \times 10^6 m^3/yr$. Growth in the use of private groundwater in the WGA, south of Flynn Drive primarily for irrigation since 1982 is illustrated in Figure 26.

Within the WGA, south of Flynn Drive, the irrigated lot sizes are usually between 1 and 5ha, with the market gardens producing a diverse range of crops to supply the Metropolitan area. Market gardens to the north of Flynn Drive near Lake Carabooda are larger (average of 20ha) producing specialist crops, usually on a seasonal rotation basis, for the export market. Approximately half of the privately owned lots (about 600ha) are being used for agriculture. The remaining private lots are not being irrigated. It has been estimated that 96% of the private groundwater abstraction is used for horticulture (vegetables, lucerne, avocados, citrus fruit, wildflowers and turf grass) and poultry on only 2% of the area. Agricultural users also often rely on groundwater for domestic purposes.

7.2 POTENTIAL DEVELOPMENTS

7.2.1 Proposed Public Water Supply Schemes

Four additonal schemes have been proposed for public water supply, Pinjar, Yeal and Barragoon to the north and Lexia to the east of the Wanneroo Scheme. As the North-West Corridor expands, Pinjar is the first scheme proposed, followed by Lexia, then Yeal and Barragoon - the development of each scheme being dependent on population increase and public water requirements. These proposed schemes are located within the Gnangara Water Reserve, with the exception of the northern part of the Barragoon Scheme. The distribution of the proposed public water supply schemes is shown in Figure 2 and the proposed timing and quotas from the superficial formations for each scheme is given in Table 19.

TABLE 19

PROPOSED PUBLIC WATER
SUPPLY SCHEMES - SUPERFICIAL FORMATIONS

PROPOSED SCHEME	PROPOSED COMMISSIONING DATE	NUMBER OF WELLS	PLANNED QUOTA ($\times 10^6 m^3/yr$)
Pinjar	St 1 - 1989/90 St 2 - 1994/95 St 3 - 1997/98	28	14.0
Lexia	2000/2001	15	6.5
Yeal	St 1 - 2002/03 St 2 - 2003/04	24	9.6
Barragoon	St 1 - 2009/10	12	3.5

* Based on Most Likely Sources Development Timetable

The Pinjar Scheme is planned to extend north from the existing Wanneroo Groundwater Scheme, through vacant Crown Land and State Forest No. 65 (Figure 2).

Groundwater abstraction from three formations is proposed.

- o The lower third of the superficial formations aquifer.
- o The Leederville Formation aquifer.
- o The Yarragadee Formation aquifer.

The proposed scheme comprises two lines of wells located 4km apart, running north-south and straddling Lake Pinjar. Each well will be connected to a collection main and where necessary, the water delivered to a treatment plant. The distribution of the wells is shown in Figure 2 and the proposed abstraction details for each of the three aquifers are given in Table 20.

TABLE 20

PINJAR GROUNDWATER SCHEME
PROPOSED ABSTRACTION DETAILS

FORMATION	NUMBER OF WELLS	AVERAGE DEPTH (m)	PLANNED QUOTA ($\times 10^6 m^3/yr$)
Superficial	28	70	14.0
Leederville	8	150	8.0
Yarragadee	8	400	10.0
Total Scheme Abstraction			32.0

Groundwater from the superficial formations and the Leederville Formation normally requires treatment to make it suitable for public water supply. Groundwater from the Yarragadee Formation does not normally require treatment. An exploratory well will be drilled into the Yarragadee Formation in 1986/87 and if the quality of the water drawn from this well remains satisfactory during testing, the staging of the Pinjar Groundwater Scheme may be as follows:

TABLE 21

PINJAR GROUNDWATER SCHEME DEVELOPMENT SCHEDULE

STAGE	COMMISSIONING DATE	NUMBER OF WELLS SUPERFICIAL	LEEDERVILLE	YARRAGADEE	ANNUAL QUOTA ($\times 10^6 m^3/yr$)
1st	1989/90	-	-	8	10.0
2nd	1994/95	14	4	-	11.0
3rd	1997/98	14	4	-	11.0
TOTAL		28	8	8	32.0

Alternatively, if the groundwater from the Yarragadee Formation requires treatment, the first stage may involve development of all three formations to produce an annual quota of about $10 \times 10^6 m^3$.

7.2.2 Potential Development of Private Groundwater Supplies

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 reach an upper limit of 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 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 $1.5 \times 10^6 m^3/yr$ 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 Unpub. Rpt.). At an irrigation rate of $15{,}000m^3$/ha/yr this would require an additional allocation of $3 \times 10^6 m^3$/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 1100ha 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 1100ha 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 1100ha were developed in the WGA, for local and export markets, then an additional $16.5 \times 10^6 m^3$/yr would be required. This is a 65% increase over the present estimated usage in the WGA. If 2000ha were developed on the Gnangara Mound the total demand for groundwater would be some $30 \times 10^6 m^3$/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 $12 \times 10^6 m^3$/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.

8.0 EFFECT OF GROUNDWATER DEVELOPMENT AND ASSOCIATED LAND MANAGEMENT

An assessment of the effects of groundwater development on the groundwater resource is required in order to manage the resource. The effect of any associated land management may also be important and combinations of groundwater developments and land use changes require careful analysis to determine the optimum development scenarios.

The Water Authority has foreseen this requirement for detailed analysis and has accumulated the relevant information on groundwater aquifers and water levels. The Authority has also developed the analytical expertise to assess various management options.

Historical water level monitoring can be used to assess the impacts of current groundwater schemes. When combined with computer modelling techniques, the impacts of future water resource developments, management and other land use changes can be assessed.

8.1 HISTORICAL WATER LEVEL CHANGES

8.1.1 Factors Affecting Water Levels

In order to explain the past and present water levels and to be able to predict water levels in the future, the factors which affect water level changes need to be understood. These factors are both natural and man-made and the most significant are listed below.

- Climate and recharge.
- Groundwater abstraction for public use.
- Groundwater abstraction for private use.
- Vegetation cover and land use changes.

In order to illustrate the effect of each of these factors reference will be made to hydrographs for different areas on the Gnangara Mound. The locations of the monitoring points used to obtain the hydrographs are shown on Figure 27.

8.1.1.1 Climate and Recharge

The most important climatic factor which affects groundwater levels is rainfall, as it is the only source of recharge to the Gnangara Mound. Recharge to the Gnangara Mound is dependent on a number of factors such as vegetation canopy cover, transpiration, soil types and the depth to the water table. Areas of high depth to water (more than 6.0m) generally have high recharge, while areas of low depth to water, such as swamps, have low or negative recharge.

The hydrographs of monitoring bores GN24 (Figure 28) located on the eastern margin of the area and GN22 (Figure 29) located near the edge of the pine plantation, on the crest of the mound, illustrate the effects of variations in rainfall on water level. These hydrographs show the cyclical nature of water level fluctuations, both seasonally and in the longer term. While the seasonal fluctuations remain relatively constant (0.5 to 1.0m), the long term trends change significantly. From 1966 to 1973 a gradual decline in water levels occurred as a result of low rainfall. High rainfall in 1973 and 1974 caused a 0.5m rise in water levels. In the period 1975 to 1980 lower than average rainfall has contributed to a gradual decline in water levels of about 0.5m. This decline occurred in the driest five year period on record (Figure 15). Since 1980 there has been a small and gradual rise in water levels in response to near average rainfall.

While long term records of water levels are not available, local knowledge of historical events and analyses of known water level records indicate that cyclic changes of up to 3.0m in water level have occurred in the past due to climatic variation.

8.1.1.2 Groundwater Abstraction for Public Water Supply

The effect of pumping from public water supply schemes can be illustrated by reference to hydrographs from monitoring bores located within and adjacent to wellfields. Monitoring bores JB10A and JB10C are located at the same site approximately 600m north of a Water Authority production well. Bore JB10A is screened in the lower part of the aquifer while JB10C is screened in the upper part. The hydrograph from JB10A (Figure 30) shows a rapid response associated with intermittent pumping from the production well, while the hydrograph from JB10C (Figure 30) shows only the normal seasonal rise and fall in water level.

When pumping from the production well ceased in 1985, water levels stabilised. These hydrographs illustrate that the stratified characteristics of the aquifer in the area reduces the effect of pumping from wells drawing from the lower part of the aquifer.

8.1.1.3 Groundwater Abstraction for Private Water Supply

Private abstraction of groundwater, mainly for market gardening, occurs in the Wanneroo Groundwater Area.

Figure 31 indicates that while water levels within the area have fallen generally in the period 1976 to 1985, falls in the Pinjar/Carabooda area have been greater than normal.

The hydrographs for three observation bores, PM33, JP17 and JP19 (Figures 32, 33 and 34) in the area between Lake Neerabup and Lake Carabooda show consistent declines from 1976 to 1985. While a portion of this decline can be attributed to climatic conditions, the lack of water level recovery in these bores (JP17, PM33) when compared with other monitoring bores (eg. GN24 and GN22) indicates that private pumping may have contributed to a decline in water levels, in the order of 0.2 to 0.3m.

It has been calculated that private groundwater abstraction in the vicinity of Lakes Mariginiup and Jandabup has caused water level declines of 0.5m and 0.15m respectively in the period 1976 to 1985.

8.1.1.4 Vegetation Cover and Land Use

Because of rainfall interception and transpiration losses, trees and other plants have a large effect on seasonal aquifer recharge. Trees, because of their size, are the largest users and interceptors of rainfall. Within the area of the Gnangara Mound, tree cover is predominantly either native banksia woodland or pine trees planted for softwood production.

Controlled and natural burning of the native Banksia woodland areas affects recharge by reducing interception and transpiration following burning. As the woodland regenerates, interception and transpiration gradually increase again.

In order to establish pine plantations, native forests are cleared and young pine seedlings are planted.

The clearing of trees in this manner causes a temporary but significant increase in recharge to the aquifer by eliminating interception and transpiration for a number of years in the cleared area. In addition, the water use characteristics of pine forests can be markedly different from native forests. Pines growing on upland sites do not depend on the water table but survive on moisture stored at shallow depths in the soil pores. Many native trees draw moisture directly from the water table. These are known as phreatophytes. In addition, pines intercept a much larger proportion of rainfall than do native trees, due to the nature and distribution of their canopy cover.

The hydrograph of Bore GN20 (Figure 35) shows the typical influence that the establishment of a pine plantation can have on water levels. The bore is near the Gnangara Pine Plantation cleared about 1971 and planted in 1973. The increased recharge period, associated with clearing and planting, occurs from 1971 to 1975. As the pines mature, they begin to intercept more of the rainfall, recharge is reduced and water levels decline from 1975 onwards. This decline has been compounded by the below average rainfall which occurred over roughly the same period. Many other monitoring bores in the pine forest exhibit similar trends in water levels as a result of clearing of native vegetation and planting of pines. Recharge can also be affected by burning practices. Removal of leaf litter in pine plantations can improve recharge (Butcher, pers. comm.) as can burning of native vegetation.

8.1.2 Historical Water Level Changes in Lakes and Wetlands

As wetlands are surface expressions of the water table, their levels respond to changes in groundwater level.

Three lake hydrographs (Jandabup, Gnangara and Joondalup) are presented in Figures 36, 37 and 38 and hydrographs for bores near Tick Flat Swamp and Yeal Swamp are shown in Figures 39 and 40.

Lakes Jandabup and Gnangara are shallow circular lakes that occur within the Wanneroo Groundwater Area. Historical water level records for both lakes extend from the early 1960s.

During the early 1960s, Lake Jandabup had minimum water levels about 0.7m lower than at present. An area close to the lake was cleared in 1963 and pine seedlings were planted from 1963 to 1968. Combined with higher than average rainfall, this resulted in an unusual rise of 3.0m in water levels.

Since 1968, as these pines have matured, and in response to generally below average rainfall lake levels have continued to drop. Pumping from the superficial formations for public and private supplies, has affected the lake water level equally, by about 0.15m each in the period 1976 to 1985 (Metropolitan Water Authority, 1985b).

Lake Gnangara has a similar water level trend to Lake Jandabup. It is also situated near a pine plantation which was planted in the early 1960s. A rise of 2.0m in water level resulted from clearing and above average rainfall at that time. Since 1966 water levels have declined in response to both increasing interception of rainfall by the maturing pine trees and the run of dry seasons. Pumping from public and private supplies has affected the lake water levels by about 0.15m and 0.1m respectively (Metropolitan Water Authority, 1985a).

Lake Joondalup, a deep linear lake to the west of Lake Jandabup, has a similar water level trend to those described above. Long term residents of the Wanneroo area can recall occasions early this century, prior to significant groundwater abstraction or land use changes, when Lake Joondalup dried up during drought periods. It was during this time that the fences still visible in the centre of the lake, were established (Crisafulli pers. comm.). Water levels were about 1.0m higher in the early 1960s than they are at present. The rise in water levels in the late 1960s is primarily due to climatic factors and clearing of native woodlands for agriculture and urbanisation around the lake. From 1969 a gradual decline in water levels occurred. Since 1978 minimum water levels have shown a gradual recovery. Lake Joondalup water levels have declined less than the other lakes.

Other wetlands are generally responsive to climatic changes. Tick Flat Swamp (Figure 39) in the north has shown a continuous decline in water level since recording started. The decline in water level is most likely a combination of climatic factors and of forestation activities. The adjacent area to the south was planted with pines in 1970, and local water levels may have declined in response to a reduction in recharge due to the maturing pines.

The hydrograph of monitoring bore GA10 (Figure 40) near Yeal Swamp shows a slight recovery in groundwater levels in the period 1981 to 1985 in response to the period of nearer to average rainfall. This rise may have been accentuated by clearing for pines in the adjacent State forest and may be reversed as the pine forest matures.

No significant changes in water levels have been observed in the wetland area around Mussel Pool since the East Mirrabooka Scheme was commissioned (Water Authority, 1986). It appears that the water table in this area is regulated by drainage into Bennett Brook and has not been significantly influenced by the period of low rainfall or by scheme pumping.

8.1.3 Contours of Historical Groundwater Level Changes

Groundwater level changes have been determined using a network of bores which are monitored on a regular basis. Contours of minimum water levels since 1976 are illustrated in Figure 31. The minimum water levels in 1985 were generally lower than those recorded in 1976, as a result of lower than average rainfall. Most of the decline in water level has occurred between 1976 and 1980. The declining water level trend has generally either ceased or reversed since 1980 because of nearer to average rainfall.

Both the Mirrabooka and Wanneroo Schemes are associated with depressions in the water table of 1.0m and 2.0m respectively which have developed over the last ten years. If the effects of climate and the pine forest are taken into account, it is considered that the maximum drawdowns attributable to these schemes is in the order of 0.5 to 1.0m near the centre of the wellfields. The effect of the pine forest is difficult to assess but modelling has shown that significant increases in rainfall interception occurs in the forest around the Wanneroo Scheme due to high forest canopy cover.

A significant rise in water levels has occurred in the State forest north of Lake Pinjar due to the clearing of native vegetation for pine plantation during the late 1970s and early 1980s.

The decline in water levels of up to 2.0m in the State forest southeast of Barragoon Lake is probably associated with the aging pine plantations in the area.

8.2 SIMULATIONS OF FUTURE WATER LEVEL CHANGES

8.2.1 Methodology

To aid management of the groundwater resource, a sophisticated computer model has been developed to predict future water levels. Various combinations of the factors which can affect water levels have been examined.

The model incorporates both recharge and hydraulic algorithms, which allows water movement in both the unsaturated and saturated zones to be simulated. Factors such as the abstraction of groundwater, interception by vegetation, evaporation, transpiration and the effects of urbanisation are considered in the model.

For the Gnangara Mound, the model grid covers a total area of $2092km^2$ and extends from the Swan River to the Gingin Brook and from Ellen Brook to the coast (Figure 1). This area is divided into a grid with physical parameters assigned to each cell. For the unsaturated zone the grid is finer in order to model the large number of factors which contribute to determination of recharge. In the saturated zone the mesh is coarser as the same degree of resolution is not required.

The model allows all the physical parameters associated with the surface water and groundwater environments to be varied. Because the aquifer parameters of the superficial formations are relatively well known, these were held constant for all simulations. In order to evaluate management options parameters relating to the following factors were varied:

- o Urbanisation.
- o Public wellfield layouts and pumping configurations.
- o Volumes and locations for private pumping for market gardens.
- o Forest/vegetation cover.
- o Climatic Factors.

These factors were chosen because they can be manipulated to assess the effect of various management strategies.

Altogether 30 model simulations were completed (a short description of each of these is given in Table 22) and results for a selected number are presented as plots of water level change to demonstrate the effect of each option.

The model has been calibrated or matched to observed groundwater behaviour by estimating parameters from recorded data and varying these slightly until a simulation was reached which matched the historical groundwater levels in the period 1979 to 1985. May 1985 was selected as the starting point for all subsequent modelling simulations and these base conditions are shown in Figure 41.

TABLE 22

SUMMARY OF MODELLING SIMULATIONS AND RESULTS

SIMULATION NO.	SIMULATION CODE	FIG. NO.	SCENARIO	OBJECTIVES	WELLFIELD LAYOUT	ABSTRACTION $\times 10^6 m^3/yr$ PUBLIC	ABSTRACTION $\times 10^6 m^3/yr$ PRIVATE	PLANTATION BASAL AREA m^2/ha	RESULTS	CONCLUSIONS
1	-	41	Existing situation*	Define Base case	Existing	Existing + Total 27	Existing + Pinjar/Carabooda 9 Wanneroo 15	Existing	Results from this simulation used to assess effects of other simulations	
2	XX	-	Delete existing public water supply schemes	Assess groundwater level recovery if existing schemes deleted	Deleted	Deleted	Existing continues	Existing	0.5-2m rise at Wanneroo wellfield 0-0.5m rise at Mirrabooka wellfield 0-1.5m rise at Gwelup wellfield	Simulated rises greater than presently observed falls, modelling therefore conservative
3	ZZ	-	Delete existing private abstraction	Assess groundwater level recovery if existing private use deleted	Existing	Existing continues	Deleted	Existing	<0.5m rise in Pinjar/Carabooda area 0.5-1.5m rise in Wanneroo area	Simulated rises greater than presently observed falls modelling therefore conservative
4	A	43	Original conceptual Pinjar Scheme alone	Assess scheme effect alone	Original layout	Pinjar 28 wells @ 0.5 Total 14	Existing	Existing	0.5m decline in Western Lakes	Affects Western Lakes
5	B	44	Modified Pinjar Scheme alone reduced abstraction in S-W wells	Reduce effect on Western Lake Chain	Original layout	Pinjar 14 east wells @ 0.5 7 S-W wells @ 0.165 7 N-W wells @ 0.5 Total 11.6	Existing	Existing	<0.5m decline in Western Lakes	Benefit from reduced abstraction S-W wells
6	Y	42	All schemes original layout existing private use	Assess effect of all schemes alone	Original layout	Original abstraction Pinjar 28 wells @ 0.5 Total 14.0 Lexia 15 wells - 6.5 Yeal 24 wells - 9.6 Barragoon 24 wells - 7.0	Existing	Existing	0.5m decline in Western Lakes, no effect on Eastern Lakes 1m decline in Yeal Swamp	Unfavourable effects on wetlands
7	Y1	-	All schemes changed layout	Relocate wells away from Western Lakes	All wellfields moved 3km east except Lexia	Original abstraction as Simulation 6	Existing	Existing	No effect on Western or Eastern Lakes 1-1.5m decline in Yeal Nature Reserve extension 1m decline in Yeal Swamp	Unfavourable effect on Yeal wetlands

Table 22 Continued

SIMULATION NO.	CODE	FIG. NO.	SCENARIO	OBJECTIVES	WELLFIELD LAYOUT	ABSTRACTION $\times 10^6 m^3/yr$ PUBLIC	PRIVATE	PLANTATION BASAL AREA m^2/ha	RESULTS	CONCLUSIONS
8	Y2	42	All schemes changed layout	Relocate wells away from Western Lakes some wells away from Yeal wetlands	Rearranged into groups of 3 lines	Original abstraction as Simulation 6	Existing	Existing	<0.5m decline in Western Lakes no effect on Eastern Lakes 0.5 -2.0m decline in Yeal extension 0.5m decline in Yeal Swamp	No benefit from rearranged wellfield
9	Y3	42	All schemes preferred abstraction preferred layout	Reduce effects on Western & Eastern Lakes and Yeal Swamp	Preferred layout Pinjar as original Lexia as original Yeal moved 2km west Barragoon moved 2km west	Preferred abstraction Pinjar 14 east wells @ 0.67 7 S-W wells @ 0.165 7 N-W wells @ 0.5 Total 14 Lexia 15 wells - 6.5 Yeal 24 wells - 9.6 Barragoon 24 wells - 7.0	Existing	Existing	<0.5m decline in Western Lakes no effect on Eastern Lakes <0.5m decline in Yeal Swamp 0-1m decline on western edge of Yeal extension	Redistribution lowers effects on wetlands
10	Y4	-	All schemes changed layout	Concentrate drawdown in State Forest (S.F.)	Move S-W Pinjar wells, Pinjar 3 lines. Others as Simulation 9	Original abstraction as Simulation 6	Existing	Existing	<0.5m decline in Western Lakes no effect on Eastern Lakes 0.5m decline in Yeal Swamp	No benefit from rearranged wellfield
11	Y5	-	All schemes preferred layout reduced abstraction in Pinjar	Reduce effect on Western Lakes	Preferred layout as Simulation 9	Reduced abstraction Pinjar 21 wells @ 0.5 7 S-W wells @ 0.165 Total 11.6 Others as Simulation 9	Existing	Existing	<0.5m decline in Yeal Swamp no effect on Eastern Lakes <0.5m decline in Yeal Swamp 0-1m decline on western edge of Yeal Swamp	No benefit from reduced Pinjar abstraction
12	K	45	Existing schemes medium private use	Assess effect of medium private use alone	Existing	Existing	Medium - Pinjar/Carabooda 15 Wanneroo 21	Existing	<0.5m decline in Western Lakes 0.5m decline in Eastern Lakes	Managing private use lowers effects on lakes
13	H	45	Existing schemes high private use	Assess effect of high private use alone	Existing	Existing	High - Pinjar/Carabooda 21 Wanneroo 21	Existing	0.5-1m effect on Western Lakes 0.5-1m decline on Eastern Lakes	Unfavourable effect on lakes

Table 22 Continued

SIMULATION NO.	CODE	FIG. NO.	SCENARIO	OBJECTIVES	WELLFIELD LAYOUT	ABSTRACTION x $10^6 m^3/yr$ PUBLIC	PRIVATE	PLANTATION BASAL AREA m^2/ha	RESULTS	CONCLUSIONS
14	D	45	Existing schemes very high private use	Assess effect of very high private use alone	Existing	Existing	Very High - Pinjar/Carabooda 29 Wanneroo 21	Existing	1-1.5m decline on Western Lakes 1-1.5m decline on Eastern Lakes	Unfavourable effect on lakes
15	I	49	All schemes original layout medium private use	Assess effect of all original schemes plus medium private use	Original layout	Original abstraction as Simulation 6	Medium as Simulation 12	Existing	0.5-1m decline on Western Lakes 0.5-1m decline on Eastern Lakes 1m decline in Yeal Swamp	Unfavourable affect on Lakes and Yeal Swamp
16	U	-	All schemes original layout existing private use plus urbanisation	Assess effect of urbanisation with no increase in private use	Original layout	Original abstraction as Simulation 6	Existing	Existing		Urbanisation has little effect on water levels
17	J	-	All schemes original layout medium private use plus urbanisation	Assess effect of urbanisation of N-W Corridor	Original layout	Original abstraction as Simulation 6	Medium as Simulation 12	Existing		Urbanisation has little effect on groundwater levels
18	C	-	All schemes modified layout medium private use	Reduce effect on Western Chain and Yeal Nature Reserve	Pinjar becomes 3 lines Lexia as original Yeal moved 2km west Barragoon moved 2km west	Original abstraction as Simulation 6	Medium - Pinjar/Carabooda 15 Wanneroo 21	Existing	<0.5m decline on Western Lakes <0.5m decline on Yeal Swamp	No benefit from moving S-W wells
19	M	-	All schemes preferred layout reduced abstraction medium private use	Assess effect of reduced abstraction from Pinjar Scheme	Preferred layout as Simulation 9	Reduced Abstraction Pinjar Total 11.6	Medium as Simulation 12	Existing	0.5m decline in Western Lakes <0.5m decline at Yeal Swamp 0.5m decline in Eastern Lakes	No significant benefit from reduced total abstraction
20	N	48	All schemes preferred layout preferred abstraction medium private use	Assess effect of redistributing Pinjar abstraction	Preferred layout	Preferred abstraction Pinjar 14 east wells @ 0.67 7 S-W wells @ 0.165 7 N-W wells @ 0.5 Total 14 Lexia 15 wells - 6.5 Barragoon 24 wells - 7.0	Medium as Simulation 12	Existing	0.5m decline in Western Lakes 0.5m decline in Eastern Lakes <0.5m decline in Yeal Swamp	Redistribution lowers affect on Western Lakes and allows additional private use

Table 22 Continued

SIMULATION NO.	CODE	FIG. NO.	SCENARIO	OBJECTIVES	WELLFIELD LAYOUT	ABSTRACTION $\times 10^6 m^3/yr$ PUBLIC	PRIVATE	PLANTATION BASAL AREA m^2/ha	RESULTS	CONCLUSIONS
21	F1	-	Existing schemes only plantation managed	Assess effect of plantation management component alone	Existing	Existing	Existing	7-15	0.5-1.5m rise in southern S.F. 65 0.5-1m decline in northern S.F. 65	Plantation basal area affects water levels
22	F2	-	Existing schemes only plantation managed	Assess effect of plantation management component alone	Existing	Existing	Existing	Equivalent to native woodland	1-3m rise in southern S.F. 65 0.5-1m rise in northern S.F. 65	Major increase in water levels with reduction in plantation basal area
23	F3	46	All schemes, preferred layout plantation managed	Assess effect of plantation management component alone	Preferred layout Pinjar as original Lexia as original Yeal moved 2km west Barragoon moved 2km west	Preferred abstraction Pinjar 14 east wells @ 0.67 7 S-W wells @ 0.165 7 N-W wells @ 0.5 Lexia 15 wells - 6.5 Yeal 24 wells - 9.6 Barragoon 24 wells - 7.0	Medium - Pinjar/Carabooda 15 Wanneroo 21	7-15	0.5-2m rise in southern S.F. 65 1m decline at Yeal Swamp 0-0.5m rise on Western Lakes 0-0.5m rise on Eastern Lakes	Plantation thinning can favourably affect wetlands
24	F4	46	All schemes, preferred layout assume plantation equivalent to woodland	As above with lower plantation basal area	Preferred layout as Simulation 23	Preferred abstraction as Simulation 23	Medium as Simulation 12	Equivalent to native woodland	1-3m rise in southern S.F. 65 no effect on Yeal Swamp 0.5-1m rise in northern S.F. 65 0.5m rise on Western and Eastern Lakes	Thinning beneficial in southern plantation retain low basal area in northern plantations
25	F5	46	All schemes, preferred layout plantation managed at high basal area	As above with high plantation basal area	Preferred layout as Simulation 23	Preferred abstraction as Simulation 23	Medium as Simulation 12	15-20	0.5-1m rise in southern S.F. 65 1.5m decline in Yeal Swamp 0.5-1.5m decline in northern S.F. 65	Some benefit in south - very unfavourable in north
26	Y6	-	Pinjar Scheme deleted All others retained medium private abstraction	Assess effects of schemes and private abstraction without Pinjar Scheme	No Pinjar Lexia as original Preferred layouts for Yeal and Barragoon	No Pinjar Preferred abstraction for others as Simulation 23	Medium as Simulation 12	Existing	0-0.5m decline in Western Lakes 0.5m decline in Eastern Lakes <0.5m decline in Yeal Swamp <0.5m decline in Yeal extension	Benefit to Yeal extension

Table 22 Continued

SIMULATION NO.	CODE	FIG. NO.	SCENARIO	OBJECTIVES	WELLFIELD LAYOUT	ABSTRACTION x $10^6 m^3/yr$ PUBLIC	PRIVATE	PLANTATION BASAL AREA m^2/ha	RESULTS	CONCLUSIONS
27	L	-	All schemes, lowered heads in Leederville Formation	Assess effect on groundwater in superficial formations of abstraction from Leederville Formation	Original layout	Original abstraction as Simulation 6	Existing	Existing	<0.5m decline at Lake Pinjar, no effect on Western or Eastern Lakes	Abstraction from Leederville Formation does not significantly affect levels in superficial formations
28	NWET	-	All schemes as Simulation 20	Assess effect of wet climatic sequence	Preferred layout	Preferred abstraction as Simulation 23	Medium as Simulation 12	Existing	<0.5m rise in Western and Eastern Lakes and Yeal Swamp	10 year wet sequence increases groundwater levels regionally, partially offset by increased evapotranspiration
29	NDRY	-	All schemes as Simulation 20	Assess effect of dry climatic sequence	Preferred layout	Preferred abstraction as Simulation 23	Medium as Simulation 12	Existing	1m decline in Western and Eastern Lakes and Yeal Swamp	10 year dry sequence reduces groundwater levels regionally
30	O	50	Preferred Management Strategy - All schemes - Medium private use - Forest management	Optimise groundwater development and environmental management	Preferred layout	Preferred abstraction as Simulation 23	Medium as Simulation 12	7-15 in southern S.F. 65 Existing or 7-15 whichever is less in northern S.F. 65	0.5m decline in Western Lakes <0.5m decline in Eastern Lakes <0.5m decline at Yeal Swamp 0-1m decline on western edge of Yeal extension	Optimal groundwater development with suitable environmental management

* All other Simulations except 2 and 3 assume existing land use

\+ Existing - means zero additional abstraction from new schemes or private use

S.F. State Forest

Note: All Simulations for 10 year period.

All modelling runs have been simulated for a ten year period. The starting conditions (Figure 41, Simulation 1) include all present day pumping, both public and private, existing forest and vegetation cover and aquifer parameters. Water balances have been calculated for both the entire Gnangara Mound and the area of the proposed Pinjar Scheme and a representative range is presented in Table 23.

Because of the assumptions made in the recharge processes and because of the relatively coarse grid used to simulate hydraulic conditions, water levels are simulated on a regional basis only. The simulation of processes at specific points such as lakes and wetlands is approximated. The simulations enable a relative comparison of water level changes on a regional basis so that the best option can be selected. The model is regarded as conservative because simulations of drawdown at existing groundwater abstraction schemes indicate slightly greater drawdowns than have actually been measured.

8.2.2 Public Water Supplies

In order to evaluate the effects of the proposed public supply schemes, a series of model simulations were completed using different wellfield configurations. These are shown on Figure 42.

Simulation 6 shows the effect of the originally proposed wellfields (Pinjar, Yeal, Lexia and Barragoon) on water levels. The simulation shows that conservation and market garden areas are adversly affected. Of most importance are the 1.0-1.5m drawdowns which occur in the Wabling MPA and the 0.5m drawdown in the Neerabup and Lake Carabooda areas.

In an attempt to reduce drawdowns in these areas a wellfield configuration comprising three lines of wells was simulated by moving portions of wellfield lines away from conservation, wetlands and market garden areas. The results are shown in Simulation 8 (Figure 42). While the drawdowns at Wabling MPA are reduced to about 0.5m, additional drawdown occurs in the Lake Carabooda area and the drawdown trough associated with this configuration has deepened to greater than 3.5m. In addition, the discontinuous layout of wellfields would cause engineering problems.

TABLE 23

WATER BALANCE SUMMARY FOR
SELECTED MODELLING SIMULATIONS

DESCRIPTION	SIMULATION NUMBER	WATER BALANCE PARAMETERS (x $10^6 m^3/yr$) GNANGARA								PINJAR							
		R +	OF -	PG -	IR +	ET -	IE -	LK -	NR +	R +	OF -	PG -	IR +	ET -	IE -	LK -	NR +
Existing Conditions	1	1675	372	111	80	905	260	107	22.2%	305	42	10	6	127	47	86	13.7%
Zero Public Supply Pumping	2	1675	383	84	80	920	260	108	22.9%	305	42	9	6	127	47	86	13.7%
Zero Market Garden Pumping	3	1675	382	84	61	904	258	109	22.8%	305	46	1	0	125	47	87	15.0%
Original Conceptual Supply Pumping	6	1675	357	150	80	894	260	95	21.3%	305	35	26	6	125	47	78	11.5%
Proposed Pinjar Scheme Pumping Alone	5	1675	370	122	80	901	260	103	22.1%	305	38	20	6	126	47	81	12.5%
<u>Wellfield Configurations</u>																	
Two Lines 2-3km apart	6	1675	357	147	80	895	260	95	21.3%	305	35	26	6	125	47	78	11.5%
Three Lines 1km apart	8	1675	356	147	80	897	260	95	21.3%	305	35	27	6	126	47	77	11.3%
Two Lines Shifted	9	1675	353	147	80	898	260	97	21.1%	305	35	26	6	125	47	87	11.4%
<u>Urbanisation: N-W Corridor</u>																	
No Urbanisation	6	1675	357	150	80	895	260	95	21.3%	305	35	26	6	125	47	78	11.5%
Full Urbanisation	16	1675	344	165	101	904	268	94	20.6%	305	36	26	6	125	47	78	11.7%
<u>Private Abstraction</u>																	
Medium Pumping Rate	12	1675	370	125	90	904	260	106	22.1%	305	39	16	10	129	47	84	12.9%
High Pumping Rate	13	1675	369	131	96	906	260	105	22.0%	305	38	21	14	130	47	83	12.4%
Very High Pumping Rate	14	1675	366	139	100	907	260	103	21.9%	305	36	29	20	131	47	82	11.7%
<u>Forest Management</u>																	
Existing to 15-20 m^2/ha	25	1675	344	161	90	909	262	89	20.5%	305	29	32	10	130	50	74	9.6%
Existing 7 to 15 m^2/ha	23	1675	356	161	90	903	251	95	21.2%	305	32	32	10	128	46	77	10.7%
Existing to Native Forest	24	1675	370	161	90	894	239	101	22.0%	305	36	32	10	124	42	80	11.8%
<u>Forest Management and Wellfield Layout</u>																	
Proposed Wellfields - Current Cover	15	1675	353	161	90	895	260	94	21.1%	305	33	32	10	127	47	77	10.7%
Modified Wellfields - Current Cover	20	1675	350	161	90	900	260	95	20.9%	305	32	32	10	127	47	77	10.6%
Modified Wellfields - Desirable Cover	23	1675	356	161	90	903	251	95	21.2%	305	32	32	10	128	46	77	10.7%
Preferred Conceptual Wellfield Layout and Pumping Distribution with Desirable Canopy Cover	30	1675	356	161	90	901	251	96	21.3%	305	33	32	10	127	45	77	10.8%
<u>Climatic Factors</u>																	
High Rainfall	28	1971	464	161	88	983	342	110	23.6%	360	47	32	10	144	61	85	13.2%
Low Rainfall	29	1411	284	161	90	771	219	67	20.1%	257	23	32	10	110	39	64	9.0%

\- = Loss from superficial formations
\+ = Gain to superficial formations

OF = Lateral Flow out
PG = Pumping
IR = Irrigation return and Imported

ET = Evapotranspiration
IE = Interception/Export
LK = Leakage downward

NR = Net Recharge (% of rainfall)
R = Rainfall

Amounts may not balance because of rounding errors
A water balance example is given below for Simulation 1

$$R + IR = ET + IE + PG + LK + OF$$
$$1675 + 80 = 905 + 260 + 111 + 107 + 372$$
$$1755 = 1755$$

Simulation 9 (Figure 42), shows a favourable compromise. In this run, the lines of wells for the Yeal and Barragoon Schemes have been relocated to the west and positioned much closer together. In addition the pumping rates from the wells in the southwestern line of the Pinjar Scheme have been reduced. The result of these changes produces a drawdown configuration which is much more acceptable to both conservation and wetland areas. In the Wabling MPA, drawdowns are less than 0.5m and in the linear lake system south of and including Lake Carabooda, drawdowns have been reduced to less than 0.5m.

Simulation 4 (Figure 43) shows the potential drawdown effects caused by the Pinjar Scheme alone. The major effect is within the pine forest where the maximum drawdown is 2.5m. At Lakes Carabooda and Neerabup drawdowns are less than 0.5m. The simulations in Figure 42 show there is little to be gained by moving this proposed scheme but that drawdown effects can be reduced in the adjacent wetland and lake areas by reducing the yields for the southwestern wells of the scheme.

This latter effect is shown in Simulation 5 (Figure 44) where yields from the seven southwestern wells have been reduced to $0.165 \times 10^6 m^3/yr$ each. This results in a reduced drawdown especially to the west and south of the scheme where the effects at the shallow lakes south of Lake Pinjar and at the linear lakes to the west is reduced to less than 0.5m.

The water balances for the various simulations described in this section do not differ because only the locations of the wells and pumping distribution have been changed, not the total withdrawal rate.

8.2.3 Private Water Supplies

Simulations 12, 13 and 14 (Figure 45) have been completed to determine the effects of varying market garden pumping in the future. In these simulations private pumping from the area of the WGA south of Flynn Drive has been increased from a current estimated usage of 12 to 21 $\times 10^6 m^3/yr$ while the private pumping from Pinjar/Carabooda area has been increased from 9 to 15 $\times 10^6 m^3/yr$, 9 to 21 $\times 10^6 m^3/yr$ and 9 to 29 $\times 10^6 m^3/yr$. The pumping variations have been used to simulate the various densities of market gardens which could occur in each area in the future.

Simulation 12 shows the effects of increasing pumping to 21 x 10^6m^3/yr at Wanneroo and to 15 x 10^6m^3/yr at Pinjar/Carabooda. Water levels decline by 0.5m over the northern two thirds of the region (Figure 45) where the increased pumping occurs.

Simulation 13 models the effects of the same increased pumping at Wanneroo and a total pumping of 21 x 10^6m^3/yr at Pinjar/Carabooda. This results in a deepening of the drawdown cone to 1.5m and an extension of the 0.5m contour.

If the pumping in the Pinjar/Carabooda area is increased from 9 to 29 x 10^6m^3/yr, the drawdown deepens and extends to the north and west. This is shown in Simulation 14 (Figure 45). The greatest drawdowns of 2.5m are concentrated in the southern portion of Lake Pinjar. Drawdowns of 1.0-1.5m of also occur in the northern portion of Lake Pinjar and at Lakes Joondalup, Jandabup and Mariginiup.

Increased private abstraction in the Wanneroo and Pinjar/Carabooda areas lowers water levels in Lake Pinjar. This may be advantageous to landowners as the land is subject to winter flooding. A drawdown of the water table below the lake may make the land more suitable for horticulture and other uses. On the other hand it may result in a shift in distribution of summer pastures.

The simulations incorporating the higher rates of private abstraction (Simulations 13 and 14) show an adverse effect on water levels at Lakes Mariginiup and Jandabup. These lakes have already been subjected to some lowering of water tables from abstraction in the area.

Changes in the water balances for the private abstraction simulations (12, 13, and 14) are shown in Table 23. The most significant changes in the water balance occur in the pumping, irrigation and evapotranspiration figures. Net recharge to the aquifer remains relatively constant at 22% over the Gnangara Mound and 12 to 13% over the Pinjar area. Outflow and leakage from the aquifer is reduced marginally as pumping increases.

8.2.4 Urbanisation

Urbanisation of the North-West Corridor will occur gradually over the next 30 to 40 years in the coastal strip north of Wanneroo. Urbanisation changes the water balance of local areas by affecting recharge and runoff characteristics and introducing the use of private wells for garden watering. The major effect of urbanisation is to increase the net rainfall recharge by directing runoff into drainage sumps and other holding structures. The increased recharge from rainfall is counteracted by the increased groundwater abstraction associated with urbanisation.

In order to estimate the maximum impact of urbanisation, suburban development of the North-West Corridor was modelled (Simulation 16) in combination with the originally proposed wellfield layout and abstraction configurations.

The results of Simulation 16 were then compared to an identical abstraction configuration, Simulation 6, with only present day levels of urbanisation. The two simulations are similar both in drawdown magnitude and distribution. It is concluded that full urbanisation of the North-West Corridor will have little effect on water levels.

8.2.5 Pine Plantation Management

Tree cover in the area consists of native woodland or pine plantation in various stages of maturity. The recharge which occurs beneath pine forest and native woodland is different due to changes in canopy cover, leaf area, depth of canopy and leaf litter layer and therefore rainfall interception. Pine plantations produce softwoods and as the trees mature, thinning is carried out to maintain timber quality. This thinning increases recharge to the aquifer by reducing rainfall interception. Recharge can also be further improved by removal of dead thinned material, known as slash, from the ground surface. Current fire management in the plantations can be used to safely eliminate the slash.

Pine plantations in various stages of maturity occupy a large portion of the State Forest No. 65 (Figure 22). Only small pockets of native woodland remain within State Forest No. 65. Mature pines with basal areas greater than $15m^2$/ha occur south of Melaleuca MPA, west and south of Lake Pinjar and north of Loch McNess. Large areas of young pines occur in the area between Lakes Pinjar and Carabooda.

Canopy cover within the pine plantations was estimated from planting histories, and outside pine plantations by analysis of Landsat imagery. Canopy cover was then correlated to basal area for the pine plantations.

Simulations have used a range of basal areas, based on available information (Figure 22). Broad categories have been defined as:

- young pines (too small to have basal area measured),
- basal area 7-15m^2/ha, excluding young pines,
- basal area 15-20m^2/ha, and
- basal area >20m^2/ha.

The Department of Conservation and Land Management's target stand density, to optimise water and timber production, is between 7 and 17m^2/ha with an average of 11m^2/ha. However, as current basal areas were not mapped on this basis, simulations of forest density have been based on the available broad categories. Given the approximations involved in estimating basal areas and the relationships with canopy cover, it is considered that the adoption of a basal area of between 7-15m^2/ha is the best available approximation of CALM's target stand density.

Five simulations have been used to display the effects of varying vegetation cover over the State forest area (Figures 46 and 47). Simulations 23, 24 and 25 (Figure 46) show how changing the existing forest cover to that equivalent to basal areas of 15-20m^2/ha, 7-15m^2/ha and native woodland, affects the water levels for conceptual wellfield layouts. The results of these changes can be compared to the effects of the existing forest cover as shown in Figure 48 (Simulation 20).

In Simulation 25, existing forest cover is changed to that with an average basal area of 15-20m^2/ha. While this raises water levels by about 1.0m in some areas (eg. south of Melaleuca Park MPA) it causes a general lowering of water levels from 0.5 to 2.0m in the area from Lake Pinjar to Wabling MPA. High basal areas may significantly affect the sensitive Yeal Swamp area.

In Simulation 23 all existing forests are changed to a basal area of between 7-15m^2/ha. This has the positive effect of raising water levels south of Melaleuca Park MPA and near the market garden area west of Lake Pinjar, but produces a lower water level near Yeal Swamp, because existing basal areas near Yeal Swamp are between 7-15m^2/ha.

Simulation 24 indicates the large rise in water levels which would occur if existing forests were thinned to approximate the recharge condition under native woodland. Water levels south of Melaleuca Park MPA could rise by up to 3.5m, while west of Lake Pinjar water levels could rise by up to 1.5m. A rise in water level of 1.0m also occurs in Wabling MPA.

These three simulations demonstrate the effects that thinning mature pines have on water levels. Of particular importance are those areas near Lake Jandabup and west of Lake Pinjar where competing uses of groundwater have stressed the groundwater system. The simulations have shown that forest management may affect water levels in these important areas and thinning and slash removal may be necessary in order to optimise use of the groundwater resource. A portion of the predicted drawdown attributed to the proposed Pinjar Scheme (Figure 43) may be reduced if the mature plantations south and west of Lake Pinjar are thinned to a basal area between 7-15m^2/ha.

Simulations 24 and 23 are compared in Figure 47, and show the direct effect of canopy cover changes on water levels by comparing native woodland to pine forests with a basal area between 7-15m^2/ha. Changing the area from native woodland to pine forest causes a 0.5-1.0m drop in water levels over much of the State forest.

These five simulations show the effects of forest management on water levels. Public and private groundwater abstraction and plantation density need to be jointly managed to ensure adequate protection of the environment. The thinning of pine plantations immediately west of Lake Pinjar may allow for increased groundwater abstraction, while still protecting the environment.

Water balances for the simulations involving forest management are shown in Table 23. The parameters of the water balances affected by forest management are interception and evapotranspiration, as a result of the changes in canopy cover. As thinning of pines occurs, both interception and evapotranspiration are reduced. For example, if the existing pine forest is thinned to the equivalent of native woodland, interception and evapotranspiration are reduced by $27 \times 10^6 m^3/yr$.

8.2.6 Climatic Factors

In order to evaluate the magnitude of water level changes resulting from climatic factors, two extreme climatic variations were simulated.

Simulation 28 used a sequence of high rainfall with the average over the Gnangara Mound area being 943mm (142mm higher than average). Water levels on a regional basis rose by about 1.0 to 1.5m. The effect of proposed public water supply schemes and private development was largely mitigated.

Simulation 29 used a sequence of low rainfall with the average over the Gnangara Mound being 675mm (126mm lower than average). Water levels fell on a regional basis between 1.0 and 3.0m. When combined with proposed public water supply schemes and private development, the water level decline in the western chain lakes was about 1.0m while in the eastern lakes was up to 3.0m. Water levels in the existing urban areas fall by up to 2.0m.

8.2.7 Combined Groundwater Abstraction and Land Use Effects

While the effects of the individual paramaters considered above are important in determining water levels within the Gnangara Mound area, it is the combined effects of all these parameters which is most important to the management of the water resource of the area. A balance between public and private abstraction, forestry and the environment is required.

Figure 49 shows three combined effect scenarios.

Simulation 15 shows the effect of combining the original conceptual wellfields, private abstraction at Wanneroo (21 x $10^6 m^3/yr$) and Pinjar/Carabooda (15 x $10^6 m^3/yr$) and current forest canopy cover. This combination of parameters appears unfavourable because:

- o drawdowns up to 1.0m occur near Lake Carabooda,
- o drawdowns of 0.5-1.0m occur in the Wabling MPA, and
- o drawdowns up to 3.0m occur under the western line of the Pinjar wellfield which deleteriously effect shallow circular lakes (eg. Jandabup) south of Lake Pinjar.

The combination of parameters used in Simulation 15 is not preferred in the long term.

Simulation 20 (Figure 49) combines a modified wellfield layout and pumping distribution with current forest cover. This combination of parameters is more favourable than Simulation 15 because less drawdown occurs in sensitive locations within the area.

Drawdowns are reduced in the Wabling MPA, an important wetland area containing Yeal Swamp. The size and depth of the drawdown trough has been reduced because of the redistribution of pumping within the Pinjar Scheme (ie. the reduction of pumping in the southwest line). The combination of unthinned pines and public and private abstraction results in drawdowns of 0.5m in the Lake Carabooda and Lake Jandabup areas. While this simulation is an improvement over Simulation 15, it may still result in undesirable effects.

Simulation 23 is similar to Simulation 20 except that all forest cover has changed from the current density to one that is equivalent to pines with a basal area of between 7-15m^2/ha. The close link between forest and water management is demonstrated by the general rise in water levels. In particular, the area around the Lexia and Wanneroo wellfields shows a 1.5-2.0m rise in water levels which results in higher water levels in Lake Jandabup. The drawdown trough under the western leg of the Pinjar Scheme has also been reduced, with a consequent reduction on the effect on market garden areas to the west. By reducing forest cover in the northern portion of State Forest No. 65, the water level decline in Wabling MPA has been further reduced to less than 0.5m.

Simulation 30 (Figure 50) provides even more favourable drawdown results by changing forest cover in the southern portion of pine plantations of the area. These are reduced to a basal area equivalent to 7-15m^2/ha while the young plantations to the north are maintained at their present equivalent density. This simulation results in a reduction in drawdowns near Yeal Swamp and in the circular lakes south of Lake Pinjar.

Water balances for these three simulations are shown in Table 23. Because forest cover is the parameter which is varied the most, evapotranspiration and interception show the greatest change. This parameter decreases as the simulations progress towards the preferred scenario in Simulation 30. Pumping does not vary because wellfield location rather than the volume of abstraction is varied.

The combined scenarios presented in this section indicate that a large portion of the potential effects of the proposed Pinjar, Yeal and Barragoon Schemes can be mitigated if forest management and public and private pumping are conjunctively managed.

This means that thinning of pine plantations can provide sufficiently large gains in recharge to service the needs of public and private abstraction without significantly affecting the environment. Furthermore, such thinning results in improved sawlog quality thus benefitting timber production as well as groundwater utilisation.

9.0 PREFERRED DEVELOPMENT STRATEGY FOR THE PINJAR AREA

A Preferred Development Strategy has been defined, incorporating management plans for the region's groundwater resources. This Preferred Development Strategy is a modification of the conceptual Pinjar Scheme as outlined in the North-West Corridor Report (MRPA, 1978). The preferred strategy considers public supplies, private supplies and land use management options.

9.1 PUBLIC WATER SUPPLIES

Both wellfield layout and the abstraction rates from individual wells were varied in the modelling.

9.1.1 Preferred Wellfield Layout

Two lines, each of 14 wells into the superficial formations, will be located in State Forest No. 65 and vacant Crown Land, one on either side of Lake Pinjar (Figure 51). Wells into the Leederville and Yarragadee Formations will be located beside selected wells into the superficial formations as originally proposed. Assessment of various layouts and abstraction strategies has shown that benefits can be derived by modifying pumping rates, within the original conceptual layout. Alternative layouts resulted in little reduction of effect in sensitive areas.

9.1.2 Abstraction Rates

Simulated abstraction rates for public supply were varied to reduce conflict with private abstraction and environmental demands in the Pinjar/Carabooda area. The southern seven wells on the western line will each produce $0.165 \times 10^6 m^3/yr$, while the northern seven wells of this line will each produce $0.5 \times 10^6 m^3/yr$. The 14 wells on the eastern line will each produce $0.67 \times 10^6 m^3/yr$ to provide a scheme quota of $14 \times 10^6 m^3/yr$ from the superficial formations. The balance of production from the Pinjar Scheme will come from wells into the Leederville and Yarragadee Formations. Total production from the scheme will be $32 \times 10^6 m^3/yr$.

9.2 PRIVATE WATER SUPPLIES

Significant expansion in the demand for private groundwater abstraction is expected in the Wanneroo Groundwater Area (Figure 9). To accommodate this demand, without jeopardising nearby wetlands, the following quotas are preferred.

- In the area north of Flynn Drive, a 67% increase over the estimated use in 1985 of $9 \times 10^6 m^3/yr$ to a quota of $15 \times 10^6 m^3/yr$.
- In the area south of Flynn Drive, the existing quota should be retained at $21 \times 10^6 m^3/yr$, which is about a 40% increase over the present licenced allocation of $15 \times 10^6 m^3/yr$.

Overall usage in both areas will be distributed, taking into account the likely impact on wetlands, so as to avoid local over-pumping.

9.3 PINE PLANTATION MANAGEMENT

In order to help stabilise water levels in the shallow lakes of the Wanneroo Eastern Chain, the Preferred Development Strategy includes reducing the density of pines in the southern portion of State Forest No. 65 and west of Lake Pinjar (Figure 51) to a basal area that optimises groundwater recharge and timber production. Based on a preliminary assessment, about $11 m^2/ha$ is considered to be appropriate. The preferred strategy also includes maintaining the density of pines in the northern portion of State Forest No. 65 (Figure 51) at levels equivalent to either the current density or not more than $11 m^2/ha$, whichever is less. In conjunction with this thinning, regular control burning is required to remove the thinned slash and the leaf litter which builds up between thinning operations.

10.0 ENVIRONMENTAL EFFECTS AND MITIGATION

The Preferred Development Strategy for proposed public water supply developments has been specifically located largely within pine plantations to reduce the effects of drawdown on conservation areas and potential conflict with private users. Furthermore, management of private groundwater abstraction and plantation density are proposed to control effects on the natural environment, protect the water resource to ensure continuity of supply to the private groundwater users and to provide maximum benefit to the community at large.

This section evaluates the likely environmental effects of the proposed developments and groundwater management strategies. Actions to mitigate these effects are discussed at the same time, to put the effects into context and assist in defining the commitments to be outlined in Section 11. The key effects of each scheme are identified and a separate summary of the likely effects of the Pinjar Scheme is provide in Table 25 at the end of this section.

10.1 ASSESSING ENVIRONMENTAL EFFECTS

The location of wellfields within pine plantations is designed to reduce the potential for water level changes to affect natural habitats or conflict with other groundwater users. There may still be some water level changes outside the plantation so an assessment must be made on what may be a "significant" effect. To effectively manage the groundwater resource it is necessary to judge the degree of drawdown that may cause adverse environmental effects.

Groundwater levels fluctuate naturally, both seasonally and from year to year. Seasonal fluctuations range from less than 0.5m to over 3.0m. Wetlands are a surface expression of the water table and fluctuate in sympathy with changes in groundwater level.

In certain situations where the lake bed sediments are less permeable than the surrounding aquifer, the water level in the lake may be buffered against the effect of changes in local water levels. Lakes in the Wanneroo Eastern Chain show typical seasonal fluctuations in water levels of about 1.0m, while local groundwater levels have seasonal fluctuations of about 1.5m. Any permanent reduction in groundwater level will be superimposed on the natural fluctuations.

Swamps, shallow lakes and deep lakes display a range of water depths. A large decline in the water level of a deep lake for example will reduce the habitat for species such as diving ducks (eg. Musk Duck) but will provide habitat for waders requiring shallow water or plants which provide nesting sites. The critical water level decline for any lake will depend on the normal level and original depth of that lake. For example, if a lake is less than one metre deep in winter and dries completely in summer there is a risk of invading bulrushes (Typha sp.) completely covering the lake.

Defining a perceptible and significant change therefore requires some judgement based on past experience and careful future monitoring. Changes in other land uses may increase water levels even leading to a local rise, for example, thinning a pine plantation adjacent to a lake.

To facilitate management of the water resource, target water levels for the region are required which take into account both seasonal and longer term climatic variations and the sensitivity of specific areas to water level change. Following consultation with DCE and CALM it is apparent that while considerable effort is being directed towards determining environmentally acceptable water level changes for the region, such criteria are not yet available.

Without these criteria, it has been necessary to subjectively determine acceptable impacts within the region. Following discussions with officers of DCE and CALM, a guideline of 0.5m change in water level has been adopted for the most environmentally sensitive areas because changes less than this are within the natural seasonal fluctuation and are unlikely to result in significant effects. This guideline will be revised as further input is received from the relevant authorities.

Natural water table fluctuations of up to three metres have been recorded below swamps, hence the swamp vegetation is adapted to wide fluctuations. Drawdowns of the order of half a metre are thus not expected to have major effects on swamps.

On upland sites the natural water table variation is also high. The vegetation on upland sites is largely independent of the water table and hence low impacts are expected in these areas. Some tree deaths have occurred on upland sites within a few tens of metres of a production well. Close to wells, water contained in the upper soil is likely to be depleted rapidly, before the vegetation adapts to the changing soil moisture regime.

Monitoring of tree vitality near production wells indicated that the rate of drawdown, as well as the magnitude, may be important (Dodd and Bell, 1982). If drawdown is imposed slowly (over a season say), as occurs remote from the wells, then vegetation may well adapt to the changed conditions. However, re-establishment of seedlings of the affected species has been observed (Mattiske, pers. comm.) indicating that the species are likely to re-establish under the adjusted conditions. Where vegetation growing on the lower slopes depends on the water table, it is likely that there will be a shift in species composition to those able to tolerate drier site conditions. Once again, changes in the order of half a metre are not expected to cause perceptible changes provided they are imposed gradually.

Further monitoring of water levels, lake biota and vegetation will be undertaken in sensitive areas and the need to amend the abstraction strategy reviewed if necessary.

10.2 EFFECTS ON LANDFORM/VEGETATION ASSOCIATIONS

The environmental effects of any change in water level and its management will depend on the landform involved and the dependence of the associated vegetation on the water table. The following section considers the specific effects of the Preferred Development Strategy on wetland and upland associations within existing and proposed conservation reserves.

Lowering of the water table will reduce evapotranspiration in two ways. The greater depth to water table will result in reduced direct evaporation as the overlying dry soil acts as a mulching layer. If the water table falls below the extent of plant roots then direct transpiration by plants will be reduced.

The sensitivity of the landform - vegetation associations represented in System 6 conservation reserves is summarised in Table 24. This sensitivity is based on the dependence of the association on the water table. Lakes, particularly shallow ones, are likely to be the most sensitive.

No other System 6 reserves on the Gnangara Mound will be influenced by the proposed developments as their water levels will not be affected.

TABLE 24

POTENTIAL IMPACT OF PREFERRED GNANGARA MOUND DEVELOPMENT ALTERNATIVE ON SYSTEM 6 CONSERVATION RESERVES

RESERVE	SYSTEM 6 NUMBER	KEY LANDFORM/ FEATURES	SENSITIVITY	COMMENTS	PREDICTED DRAWDOWN (m)**	POTENTIAL IMPACT
Caraban MPA	C12	Spearwood Dunes	Insensitive	Dunes, Limestone	<0.5	Very low
Wabling MPA	C13	Karrakatta/Bassendean/ Swamps	Sensitive in Part	Bindiar Lake	0-0.5	Low-Med in Swamp
Two Rocks	M1	Quindalup/Spearwood	Insensitive	High Dunes	<0.5	Very Low
Yeal Nature Reserve	M5	Bassendean	Sensitive in Part	Yeal Swamp	0-<0.5	High in Swamp
Yeal Proposed extension	-	Bassendean/High Dunes	Sensitive in Part	High Dunes/Swamp	0-1.5	Low/Med in Swamps
Gingin Stock Route proposed	-	Karrakatta/Alluvial Terrain	Low	Mound contributes minor flow only to Gingin Brook	0-0.5	Very Low
Ridges MPA	M4	Spearwood	Low	Some swamps	0-<1.0	Very Low
Yanchep National Park	M3	Spearwood/Herdsman	Low/Medium	Low for deep lakes & caves in limestone, medium in shallow lakes to south	0-0.5	Very Low
Neerabup National Park	M6	Spearwood/Herdsman	Low/Medium	Deep & shallow lakes	<0.5	Low
Lakes Joondalup & Goollelal	M7	Karrakatta/Spearwood/ Herdsman	Low/Medium	Deep lakes	0-0.5	Nil
Wanneroo Wetlands Eastern Chain*	M8	Bassendean/Joel	Sensitive	Shallow Lakes, existing abstraction in the area		
- Jandabup Lake					0-<0.5	Low
- Wetlands N of Jandabup Lake					0-<0.5	Low
- Mariginiup Lake					0.5	Low
- Little Mariginiup Lake					0.5	Low
- Gnangara Lake					+0.5 rise	Positive
- Wetlands SW Gnangara Lake					+0.5 rise	Positive
- Badgerup Lake					+0.5 rise	Positive
- Little Badgerup Lake					+0.5 rise	Positive
- Lenzo Rd Wetlands					+0.5 rise	Positive
- Snake Swamp					+0.5 rise	Positive
- Lake Adams				Disturbed	<0.5	Nil
- Swamps S and E of Lake Adams					0	Nil
- Lake Pinjar				Very Disturbed	0.5-2.0	Low
Melaleuca Park	M9	Bassendean	Low/Medium	Some Swamps	0-1.0 rise	Nil/Positive
Whiteman Park	M13	Bassendean/Southern River	Low/Sensitive	Levels controlled by Brook	0-0.5 rise	Nil
Pearce Aerodrome	M15	Alluvial Terrain	Sensitive	East of Ellen Brook	0	Nil
Ellen Brook/Twin Swamps	M17	Alluvial Terrain	Sensitive	East & North of Brooks Short-necked Tortoise	0	Nil
Bennett Brook	M41	Bassendean/Southern River	Sensitive	Baseflow from mound	0	Nil
Mound Springs	M25	Alluvial Terrain	Sensitive	Baseflow from mound	0	Nil

* Wanneroo Wetlands - Eastern Chain - Lakes in order of conservation importance as listed by DCE, 1983.

** Predicted drawdown for preferred option (Refer to Figure 50).

10.2.1 Wetlands

Wetland ecosystems are the most vulnerable to declining water levels. Accordingly, these areas are afforded high priority in the Water Authority's groundwater management strategies and have received special attention in the overall planning of groundwater developments.

Considerable effort therefore has gone into modifying the locations and operation of the proposed Gnangara Mound developments, to reduce the potential effects on wetlands on the Gnangara Mound, particularly within existing and proposed conservation reserves.

10.2.1.1 Shallow Lakes and Swamps

The Pinjar Scheme has been located within pine forest, away from environmentally sensitive shallow lakes. It straddles Lake Pinjar which is largely disturbed by agricultural development. Agricultural productivity has suffered in most years due to winter flooding, to the extent that landholders have requested improved drainage. While Lake Pinjar forms part of the Wanneroo Wetlands - Eastern Chain (M8) recommendation of the EPA, it has been afforded the lowest conservation status (DCE, 1983) due to the disturbance for agriculture. The other shallow lakes within M8 would be subjected to less than half a metre of additional drawdown if the Pinjar Scheme were developed without modification to the existing density of pine plantations south of Lake Pinjar and east of Lake Jandabup. Small reductions in water level could result in a greater area of each lake drying out earlier each summer and refilling later each winter. Thinning of the forests to a basal area of about $11m^2$/ha could reverse the situation leading to an increase of up to 1.5m in water level to the east of Lake Jandabup, resulting in stabilisation or even a slight increase in lake levels. Drawdown of about half a metre along the western edge of the low lying part of Yeal extension is not expected to have a major effect on the vegetation of that area. There will be no drawdown in the Mound Springs reserve (C25) and hence no impacts on the habitat of the undescribed Darwinia sp. there. Similarly there will be no drawdown in the Twin Swamps and Ellen Brook reserves and hence no impact on the Short-necked Tortoise.

The conceptual wellfield layout of the Lexia Scheme (Figure 50) with appropriate thinning of pine plantations east of Lake Jandabup, would not affect any shallow lakes or swamps in the Melaleuca Park (M9), Whiteman Park (M13), Ellen Brook and Twin Swamps (M17) or Bennett Brook (M41) conservation reserves.

The conceptual wellfield layout of the Yeal Scheme has been located downflow, rather than straddling, Yeal Swamp to reduce its environmental effects on the swamp. Pines already planted in the area would normally be expected to reduce the water table in the swamp by up to one metre as they grow. The effect on water levels in the swamp could be limited to half a metre with the conceptual wellfield layout if the basal area of the pines were maintained at the present low level.

The conceptual wellfield configuration of the Barragoon Scheme (Figure 50) may lead to drawdowns in the order of half to one metre beneath Barragoon Lake.

Prior to construction, the layout of the Lexia, Yeal and Barragoon Schemes will be further reviewed and separate environmental studies conducted which fully consider options for further reducing the effects of water table drawdown on sensitive areas.

10.2.1.2 Deep Lakes

Only the Pinjar and Yeal Schemes have deep lakes nearby. Of particular importance are the lakes and caves of the Yanchep National Park, however, neither scheme is likely to cause significant drawdowns in this area. High transmissivities of the limestone will tend to mitigate drawdowns as water will rapidly flow into the area. Drawdown effects of less than half a metre may occur in the lakes within Neerabup National Park. Drawdowns of this magnitude are not expected to have major effects on these wetland habitats.

No perceptible drawdown is anticipated throughout the remaining deep linear lakes, including Lake Joondalup and those to the south (Figure 50). If the proposed thinning of pine plantations east of Lake Jandabup occurs, there may even be a slight rise in water levels in these lakes.

10.2.1.3 Streams and Drainage Lines

Brooks rising in groundwater discharge areas (eg. Bennett Brook) rely on water of the Gnangara Mound for their baseflow. Developments which affect outflow from the mound in the vicinity of the brooks may influence their baseflow. Bennett Brook rises in the Whiteman Park conservation reserve with the lower reaches of the Brook also designated as a conservation reserve (DCE, 1983). No changes in water levels are predicted in the vicinity of Bennett Brook (Figure 50) and hence no impacts are expected as a result of the proposed schemes.

Two similar brooks drain into Ellen Brook in the vicinity of the Twin Swamps and Ellen Brook reserves, which are set aside for conservation of the Short-necked Tortoise. There are not expected to be any changes in groundwater levels in the vicinity of these reserves due to the proposed schemes and hence no effect on their conservation status.

The Gnangara Mound also discharges into Gingin and Ellen Brooks, providing a component of their baseflow. These two much larger streams are also fed by runoff from the Darling Scarp, making them much less susceptible to changes in outflow from the Gnangara Mound. No changes in baseflow to these brooks are predicted as a result of the proposed schemes.

10.2.2 Uplands

On upland sites, a lowering of the water table may result in plant growth rates declining or the deep rooted species being replaced by shallow rooted types which are not dependent on the water table. Many species, such as Eucalyptus calophylla, Banksia menziesii and Banksia attenuatta show decreasing transpiration as the soil dries out each year (Grieve, 1957). Such species are adapted to a dry period each year and provided the fall is gradual, seem well adapted to fluctuating water levels. Fluctuating water levels are part of the natural seasonal cycle on the sandy coastal plain.

About eight wells in the Pinjar Scheme, along the north-eastern leg, will be adjacent to upland vegetation in the proposed Yeal Nature Reserve extension. Some tree deaths may occur within a few tens of metres of these wells.

Drawdowns of up to 1.5m along the western edge of the proposed Yeal Nature Reserve extension may cause a gradual shift from Banksia ilicifolia to B. menziesii and B. attenuata on the small area of the Jandakot-Steep unit which fringes the area. The much larger area of Jandakot-Steep unit to the east of this site is unlikely to be affected, due to the low predicted drawdowns in this area. It is possible that a reduction in the number of Banksia species on a site may limit the span of flowering times and hence resources available to nectar feeding birds and insects. However this effect is not expected to have a significant effect on the fauna, given that the banksia woodland habitat is widespread and the area affected is small. The overall woodland character of the vegetation will re-establish if older intolerant trees are replaced by seedlings which adapt to the modified soil moisture regime. The upland ecosystems as a whole are regarded as unlikely to be significantly affected by groundwater drawdown in the longer term.

Water table drawdowns beneath much of the upland vegetation in existing and proposed reserves will be limited to less than half a metre. Drawdowns of about half a metre due to the Yeal Scheme in Caraban MPA (C12), Wabling MPA (C13) and Yanchep National Park (M3) and the proposed Yeal Nature Reserve extension are unlikely to affect upland vegetation in these areas (Figure 50) due to their small magnitude and remoteness from well sites. Drawdowns of between 0.5 and 1.0m in Ridges MPA (M4) are not expected to affect the vegetation growing over limestone as it does not rely on the water table.

No significant impacts on upland ecosystems in conservation reserves are expected due to the proposed Lexia and Barragoon Schemes. Limited drawdown of about half a metre in the Lexia area and one metre in the Barragoon area, is not expected to have a regional effect on upland vegetation. Local effects may occur within a few tens of metres of wells located adjacent to areas of native upland vegetation.

10.2.3 Pine Plantations

The pine plantations of State Forest No. 65 essentially occupy upland sites. Their extent and effect on recharge however, means that they influence water levels in wetlands as well as beneath the uplands. As they do not generally rely on the water table but rather on soil moisture stored in the upper profile, they are not affected by a reduction in water levels except on some lowland sites. Some deleterious effects on pines may occur if water tables rise in low lying sites.

Management of pine plantation density and the control of leaf litter by burning are potentially powerful tools for the optimisation of groundwater recharge and sawlog quality. Effective groundwater management will require manipulation of several elements of the water cycle; not just abstraction alone. Effective groundwater management requires effective land use management as a whole. The Water Authority recognises CALM's responsibility for land management in State Forest No. 65. The Authority further recognises the need for multiple land use as outlined in the 1981 Forests Department Land Use Management Plan for the Swan Coastal Plain (North) and emphasises that the priority land use is water production. The Authority has taken account of this priority in its water management strategies for the area.

The Preferred Development Strategy involves land use management by CALM in co-operation with the Water Authority, as well as private landholders. In order for the Water Authority to carry out its responsibility to manage groundwater with due regard for environmental, social and economic considerations, it will be necessary for the Authority to participate in the preparation of plantation management strategies.

To mitigate environmental effects on Yeal Swamp and Bindiar Lake and the wetlands of the proposed Yeal Nature Reserve extension, it will be necessary to manage plantation density as well as groundwater abstraction east of Yanchep. Modelling has shown that a plantation density equivalent to that now existing could achieve this. It is proposed that CALM, with appropriate input from the Water Authority, plan suitable forest management strategies for the plantations east of Yanchep, which recognise the joint needs of water production, the environment and timber production. The positive effects of thinning and regular control burning in the plantations can contribute significantly to returns from both water and timber production in this area.

Declining water levels have been recorded in Lake Jandabup over the last 16 years, probably as a consequence of below average rainfall and increased evapotranspiration by the adjacent pine forest (Figure 36). Thinning of the pine plantations east of Lake Jandabup and north of Lake Adams could partially reverse this situation to the benefit of all the shallow Wanneroo - Eastern Chain Lakes (M8), as well as sawlog production. It is proposed that CALM, with appropriate input from the Water Authority, manage State Forest No. 65 east of Lake Jandabup and north of Lake Adams, to maintain a plantation density suited to the maintenance of recharge at levels appropriate to the joint needs of public and private water production, environmental protection and timber production.

The Authority will provide advice to CALM to assist with the management of pine plantations in accordance with the water production priority land use for the area.

10.3 SOCIAL ISSUES

Much of the Gnangara Mound north of Lake Pinjar is sparsely populated and likely to stay so under the present Corridor Plan for metropolitan development. The area of State Forest No. 65 will make an important contribution to regional open space, conservation, water and timber production. The Water Authority has based its planning on the retention of State Forest No. 65 for its present range of multiple land uses.

On the other hand, there is a dense and rapidly expanding population west and south of the existing water production areas. The proposed Pinjar Scheme will remain relatively remote from urban development. Part of the wellfield will be located adjacent to rural land on Lake Pinjar but will be one to three kilometres from rural land between Lake Carabooda and State Forest No. 65.

10.3.1 Livelihood

The Water Authority is responsible for the management of groundwater resources for the good of the whole community. Such management takes account of the need for private abstraction to service market gardens and other commercial enterprises from which people derive their livelihood. Given the limited availability of groundwater, the Authority must allow for allocation of supplies today as well as plan for the future security of supplies, by preventing short term over-exploitation of the resource.

There is presently significant private abstraction of groundwater in the Carabooda area and increasing development of the resource.

To avoid conflicts and maximise the availability of groundwater for use, the Water Authority has modified its proposed abstraction rate from seven southwestern wells of the Pinjar Scheme. It is proposed that these seven wells will operate at $0.167 \times 10^6 m^3/yr$ instead of the original $0.5 \times 10^6 m^3/yr$ proposed in the conceptual plan. The resulting loss in water production for public supply can be offset by increased abstraction from wells deeper within the pine plantations further north. Such re-distribution of abstraction will not affect the rural areas or lakes to the west of the forest.

To protect future security of private supplies and provide for adequate protection of Lakes Carabooda, Nowergup and Neerabup, allocation of quotas for private abstraction are incorporated in the guidelines for the Wanneroo Groundwater Area. The Groundwater Advisory Committee, with local representation, makes recommendations to the Water Authority for the issue of licences for private abstraction.

The Lexia proposal, in association with appropriate pine plantation thinning, would have a limited effect on regional groundwater levels and is not expected to conflict with existing private abstraction in the Swan Valley or nearby.

The Yeal and Barragoon proposals are remote from present private abstraction areas. No conflicts with private abstraction are envisaged. The northern section of the Barragoon Scheme is within the Gingin Groundwater Area.

10.3.2 Lifestyle

Many people are choosing a rural lifestyle while deriving their income from sources outside the property on which they live. This lifestyle is facilitated by the Special Rural zoning concept. The Water Authority's groundwater management strategies recognise that Special Rural zones are designed to accommodate a rural lifestyle but are not appropriate for the provision of a livelihood which relies on access to commercial quantities of groundwater. This is because the density of Special Rural zones is such that there is inadequate groundwater available, from the limited area involved, to supply more than normal domestic quantities without serious local depletion of the resource.

Under normal circumstances, the water requirements for Special Rural living are not great and do not conflict with public abstraction or other uses. There is a need for management of the density and quantity of water use to avoid interference with neighbours and the environment on which Special Rural developments are usually based. There is also a particular need to protect the quality of supplies in these areas of relatively dense settlement where groundwater may service potable supplies.

The Water Authority will continue with the present policy of allocating $1500m^3/yr$ for Special Rural lots and will continue to liaise with the State Planning Commission about proposals for the modification of zoning in rural areas.

The quantities of groundwater required to irrigate public facilities such as ovals, parks and gardens is limited and does not normally conflict with the needs of other users or the environment and no particular conflict with any of the proposed public abstraction schemes has been identified. However each case needs to be considered with respect to neighbouring users and the Water Authority will continue to provide advice to intending users prior to the allocation of licenses.

10.3.3 Aesthetic Values

The conservation of lakes, other natural areas, parks and gardens was considered an important social issue by both urban and rural respondents to the Public Awareness and Attitudes Study. This finding reinforces the Water Authority's objective for management of groundwater with due regard to social and environmental considerations. The important need for groundwater management to provide for supplies to maintain lakes and provide for irrigation of public facilities is apparent.

The Water Authority has considered the likely effects of new groundwater developments on wetlands, leading to modification of the proposals to mitigate effects on these water dependent environments. Once again, plantation thinning and control burning can make a major contribution to the maintenance of wetlands and aesthetic values, especially in the vicinity of Lakes Jandabup, Gnangara and the associated lakes of the Wanneroo Wetlands - Eastern Chain (M8).

Pipelines and powerlines to wells may have a potential aesthetic impact. As far as possible, these sources will be routed along existing roads in the Pinjar Scheme. Laying of the pipelines below ground will further mitigate against additional aesthetic effects.

10.3.4 History and Archaeology

A number of historic European houses are located in the vicinity of the Pinjar Scheme:

- Sinagra House (Lake Pinjar).
- Arrigo House (Lake Pinjar).
- Chitty House (Lake Pinjar).
- Pig Farm House (Lake Pinjar).
- Ostle House (East Pinjar).

None of these sites will be affected by development of the Pinjar Scheme.

The Pinjar Scheme is located within pine forest and therefore, the area has already been highly disturbed. The survey for Aboriginal archaeological sites did not identify any cultural material and consequently there will be no impacts as a result of development or management of the Pinjar Scheme. Additional surveys will be conducted for the proposed Lexia, Yeal and Barragoon Schemes after detailed investigations have defined the preferred layouts.

TABLE 25

SUMMARY OF ENVIRONMENTAL EFFECTS OF PINJAR SCHEME

ISSUE	FACTOR	IMPACT	EFFECT	COMMENTS
Shallow Lakes and Swamps - M8	Lake Pinjar	0.5 - 2m drawdown	Some effect on degraded natural ecosystem Aids winter utilisation of agricultural land, may lower summer productivity	Lowest priority for conservation in M8 Landowners have requested drainage
	Lakes Adams, Mariginiup, Jandabup, Badgerup and Gnangara	<0.5m drawdown	Low - none	Meets guideline Pine thinning may actually increase levels
	Mound Springs - C25	No drawdown	None	Meets guideline No impact on <u>Darwinia</u>
	Twin Swamps/Ellen Brook Reserves - M17	No drawdown	None	Meets guideline No impact on Short-necked Tortoise
Deep Lakes - M6	Neerabup National Park	<0.5m drawdown	Low - none	Meets guideline •
	Lake Joondalup	<0.5m drawdown	Low - none	Meets guideline
	Yanchep Caves	No drawdown	None	Meets guideline No impact on cave fauna
Streams & Drainage Lines	Ellen Brook	No drawdown	None	Meets guideline No impact on aquatic fauna
Uplands	<u>Banksia</u> woodland in SW of proposed Yeal Nature Reserve extension	0.5-1m drawdown adjacent to 8 wells in NE leg	Some localised tree deaths possible immediately adjacent to wells	<u>Banksia</u> woodland widespread, affected area small, overall impact unlikely to be significant Area also proposed as extension to State Forest No. 65
Pine Plantations	Pines on uplands	0-2m drawdown	Little effect on productivity of pines on uplands	Pines not dependent on water table on uplands
	Pines on lowlands	0-2m drawdown	Some reduction in pine productivity possible on lowlands	Thinning and control burning important to water level management
Private Groundwater Use	Pinjar/Carabooda Horticultural area	0.5-2m drawdown	2m drawdon at eastern end of Carabooda Road No change in quota south of Flynn Drive -21 x $10^6 m^3/yr$ Quota of 15 x $10^6 m^3/yr$ north of Flynn Drive	Private production wells likely to extend more than 2m below water table Quota 40% greater than existing use Quota 67% greater than existing use
	Special rural users	<0.5m drawdown in special rural zones at Flynn Drive and Lake Adams	None	Private domestic wells unaffected
Aesthetic Values	Lakes and environs Pipelines Powerlines	As above Below ground Along existing roads	Low - none None Low	Lakes etc. maintained
History and Archaeology	Historic Buildings Archaeological sites	None None	None None	None adjacent to development Site integrity disturbed by previous clearing

11.0 ENVIRONMENTAL MANAGEMENT COMMITMENTS

11.1 NEED FOR MANAGEMENT

Water Authority commitments, made as a condition of environmental approval of the developments and groundwater management strategies outlined in this ERMP, are presented in bold type for easier reference. These commitments are summarised in Table 27.

11.1.1 Philosophy

With continuing growth in population, there is an increasing demand for public and private water supplies for household, agricultural, commercial, industrial and local government use. In the North-West Corridor, the water resources which can be developed at least cost, are the groundwater resources of the Gnangara Mound.

Appropriate management is required so that these resources can be developed whilst avoiding effects such as:

- over-exploitation of the resource,
- degradation of water quality,
- lowering of lake water levels and degradation of native flora and fauna, and
- salt water intrusion.

The need for management is recognised by the Water Authority which has as one of its primary objectives:

> "To assess, plan, manage and co-ordinate the utilisation and conservation of the State's water resources for the optimum overall benefit of the community in both the short and long term."

Groundwater management is implemented with the objectives of avoiding long term depletion of the resource and maintaining the community assets that rely on groundwater (Ventriss and Green, 1986). In accordance with these objectives, management is aimed at allocating available resources for beneficial public and private purposes and maintenance of the environment.

The Authority recognises that the need for management may be more acute in some areas than in others and that the type and degree of management will vary. To achieve the above objectives, a four stage management strategy has been adopted:

Stage 1: Maintain an awareness of potential developments likely to place the groundwater resource under stress, or to adversly affect an established user or the environment.

Stage 2: Proclamation of areas and licensing of wells where it is necessary to more closely monitor increasing use of the resource and the response of the aquifer.

Stage 3: Introduction of active management where monitoring indicates that annual water abstraction is approaching the level of annual availability established to protect existing users and the environment.

Stage 4: Monitor the effectiveness of the management strategy in terms of the objectives for the area and modify management as appropriate.

When allocating groundwater within proclaimed areas, historical levels of usage by established irrigators and other users is generally permitted to continue in recognition of the demonstrated commitment of the users. Unless such allocations prejudice the long term security of the resource, there is a reluctance to reduce them. Subsequent applications are generally treated on a first come - first served basis, although applications for a significant portion of the resource to a single user or to a small number of users are carefully assessed on the basis of hydrogeological, social and environmental considerations.

Applications by persons demonstrating an immediate justifiable use are considered to have a stronger claim than those who have a possible future requirement. In this way water "in the bank" allocations are discouraged. Licences are regularly reviewed to ensure that the resource is being used fairly and that unused allocations, where appropriate, are made available for others with an immediate need for water.

Licences are issued with conditions that relate to well construction, permitted use and allocated volume. Licence conditions can be varied at any time. Apart from isolated areas where the resource is seriously limited, allocations for domestic and stock purposes are granted automatically. In several areas where the resource is not in danger of being over-exploited, there is no requirement to apply for a licence for these uses. There is no charge associated with applying for or holding a licence. Licensing allows the groundwater usage in an area to be determined, which is important for management.

Groundwater licences are not automatically transferrable, but in most instances new owners are granted licences under similar conditions to those which previously applied. Purchasers are encouraged to make their offers to buy land subject to the Water Authority approving the transfer of the groundwater licence.

These procedures have been generally satisfactory but are subject to on-going review. The current management system considers each application on its merits and so is reactive to the needs of the applicants.

Advisory Committees, incorporating local representatives, have been established in some areas to provide advice to the Water Authority on matters relating to groundwater management. These Committees have been an important forum in enabling the local community to have input to the management of groundwater resources. The Wanneroo Groundwater Area is administered with the assistance of an Advisory Committee.

Public awareness is an essential part of groundwater management. People respond better to controls when they appreciate the potential problems and so understand the need for management.

The philosophy of introducing management to avoid problems rather than attempting to manage problems once they have arisen, together with an information programme to ensure that those affected understand the need for management, has enabled groundwater resources in Western Australia to be effectively managed. This approach is contrary to that adopted in many other areas where groundwater management is not introduced until problems occur. The Government in these situations is then often committed to a rescue operation at considerable community cost. The philosophy adopted in Western Australia aims to avoid problems on the basis that 'prevention is better than cure'.

11.1.2 Legislation

All groundwater in Western Australia is "vested in the crown" and its management is the responsibility of the Water Authority on behalf of the Western Australian Government.

The legislative basis for the management of groundwater in Western Australia is contained in provisions of the Rights in Water and Irrigation Act, 1914 and the Metropolitan Water Authority Act, 1982. This legislation, which is currently being consolidated into the Water Authority Act, is administered by the Water Authority of Western Australia.

The legislation enables the Government and its administrators to allocate and manage groundwater for both public water supplies and private use. All artesian wells throughout Western Australia require licensing and groundwater management areas have been proclaimed in areas where non-artesian and sub-artesian groundwater require management.

The Rights in Water and Irrigation Act, 1914 provides for the establishment of Advisory Committees to advise the Water Authority on groundwater management matters. This includes the issue of licences and the associated licence conditions. The legislation provides for the establishment of an Appeal Tribunal to hear an appeal by any applicant who is aggrieved by any decision made by the Water Authority. The tribunal consists of three members; an independent chairman (usually a retired magistrate), a nominee of the appellant and a nominee of the Water Authority. The tribunal makes a recommendation to the Minister for Water Resources who subsequently advises of his decision in respect to the appeal.

The Metropolitan Water Authority Act, 1982 provides for an appeal to a local court by any person aggrieved by a decision of the Water Authority.

Outside proclaimed groundwater management areas, landowners have common law rights to non-artesian groundwater. In this situation a landowner has a common law right to exploit the water below his property irrespective of the purpose and the effects of such exploitation. A neighbouring landowner adversely affected by the exercise of this right is unable to sue. In addition there is no provision in this situation to provide for protection of the environment.

Clearly, effective management of the resource by the Water Authority is required to protect public water supplies, to ensure equitable allocation in the case of competition between private users, to protect existing users in areas of major agricultural, industrial or mineral developments and to protect the environment.

11.2 CURRENT MANAGEMENT

Within the region adjacent to the North-West Corridor there are four proclaimed groundwater management areas, the Gnangara Water Reserve, the Wanneroo Public Water Supply Area (PWSA), the Wanneroo Underground Water Pollution Control Area (UWPCA) and the Wanneroo Groundwater Area (WGA) (Figure 9).

11.2.1 Gnangara Water Reserve

The Gnangara Water Reserve was proclaimed in 1973 under provisions of the Metropolitan Water Supply, Sewerage and Drainage Act, 1909. The proclamation of the Reserve indicated the Authority's long term proposals for development of the water resources of the region for public water supplies. The Reserve covers land that is generally under the control of various Government Departments. The provisions of the Act enable the Authority to develop the water resources of the Reserve and requires that the approval of the Authority be obtained before anyone develops any water resources within the Reserve. The Act and associated by-laws contain provisions that relate to the prevention of the pollution of water resources within the Reserve.

11.2.2 Wanneroo Public Water Supply Area

The Wanneroo PWSA was proclaimed in 1975 under provisions of the Metropolitan Water Supply, Sewerage and Drainage Act, 1909. In 1982 the boundary was amended under the Metropolitan Water Authority Act, 1982, to avoid overlaps between the PWSA and the UWPCA.

Abstraction for public water supplies from the superficial formations in the Wanneroo Public Water Supply Area commenced in 1976 and reached full production in 1978. The production quota for the superficial wells is $12.2 \times 10^6 m^3/yr$.

Management of the groundwater resource has involved the monitoring of water levels and annual reporting to the EPA on scheme performance. A comprehensive triennial report is prepared for the EPA detailing all aspects of the management of the resource. The next triennial review is due for submission to the EPA in 1987.

A recent review of groundwater management within the Wanneroo region identified significant factors affecting the lakes and wetlands (Metropolitan Water Authority, 1985b). It recommended that the annual quota of three production wells in the superficial formations near Lake Jandabup be significantly reduced and that the possibility of thinning an area of adjacent pine forest be investigated. Production from the three wells has been reduced and discussions regarding the thinning of a small area of pine forest have been initiated with CALM. The effect of reducing this abstraction is being monitored.

11.2.3 Wanneroo Underground Water Pollution Control Area

The Wanneroo UWPCA was proclaimed in 1975 under provisions of the Metropolitan Water Supply, Sewerage and Drainage Act, 1909. By-laws have been proclaimed under provisions of the Act to protect groundwater from pollution. The by-laws, in general, require that the approval of the Authority be obtained before any activity likely to lead to pollution of groundwater is undertaken.

11.2.4 Wanneroo Groundwater Area

On March 26, 1982 the Wanneroo Groundwater Area (WGA) was proclaimed under the Rights in Water and Irrigation Act and a water management programme developed which recognised the Wanneroo wetlands area and the special management policy needed to ensure that the groundwater resource continues to meet the reasonable requirements of land owners in the area, as well as the environment. The Wanneroo Groundwater Area was recently amended to include the rural areas north of Flynn Drive (Figure 9).

An Advisory Committee has been established to assist the Water Authority to manage the groundwater resources of the area. The Committee, which held its inaugural meeting in July 1982, advises the Water Authority on guidelines for groundwater management within the Wanneroo Groundwater Area including the issue of well licences. The Committee, which consists of three local representatives nominated by the City of Wanneroo, and three Government representatives, has met on 24 occasions.

Applicants for licences or local landowners wishing to discuss groundwater management issues are invited to attend and address the Committee. To date, about 50 deputations have been received by the Committee.

Licence applicants who are aggrieved by a decision of the Advisory Committee may give notice to the Minister of their wish to appeal against such a decision. The Minister will subsequently convene an Appeals Tribunal. The tribunal will then make a recommendation to the Minister who makes a decision with respect to the appeal.

To date two appeals have been made to the Minister with respect to decisions made by the Water Authority. One appeal was unsuccessful and the other resolved before being considered by the Tribunal.

All landowners and real estate agents active in the area, have been advised of the well licensing requirements. This helps foster a sense of community responsibility, which is necessary for careful management of the resource. In addition, signs have been erected within the area advising landowners of the requirements for well licensing. Information about well licensing is also displayed at the City offices. With the assistance and co-operation of the City of Wanneroo and real estate agents, prospective landowners are informed of the well licensing requirements. These requirements may affect the activities that can be carried out on land in the area. This is particularly relevant to Special Rural Zones, where commercial activities may not be compatible with groundwater availability.

There are currently (1986) 839 licences issued within the area south of Flynn Drive. These wells have a total licenced allocation of about 15 x $10^6 m^3$/yr. The estimated usage north of Flynn Drive is 9 x $10^6 m^3$/yr.

11.3 PROPOSED MANAGEMENT

Management of the groundwater resource must take into account the need to balance competing demands. The strategy adopted must take into account the degree of utilisation of the resource as well as the cost or practicality of its implementation. Of necessity, management must be directed at those elements of the water cycle which can practically be manipulated. For example, it is possible to vary the abstraction rate from wells or the density of a plantation but it is not possible to alter rainfall. The following management actions are feasible.

- o Modification of wellfield layouts.
- o Modification of the abstraction rate from public schemes.
- o Management of abstraction for private use.
- o Management of plantations, reserves and other large scale land uses.
- o Demand management.

Combinations of the first four actions have been modelled to define a management strategy which accomodates the range of demands, whilst minimising the effects on wetlands. A summary of the Proposed Management Strategy is shown in Table 26.

11.3.1 Layout of Schemes for Public Water Supply

Conceptual wellfield layouts have been shown for the proposed Lexia, Yeal and Barragoon Schemes. These layouts and variations of them have been modelled to show the general nature of water level changes throughout the Gnangara Mound area. They indicate that drawdown locations can be affected by wellfield layout. **The layouts of these proposed schemes will be further assessed as part of detailed investigation prior to selection of the preferred strategies for management of the groundwater resource.**

Alternative layouts of the Pinjar Scheme result in little benefit to sensitive areas. Benefits accrue from modifying pumping rates as discussed below. The proposed wellfield layout is shown on Figure 51.

11.3.2 Abstraction Strategies for Public Water Supply Schemes

Detailed abstraction rates from the proposed Lexia, Yeal and Barragoon Schemes will be assessed as part of the preparation of environmental documentation for those projects. Planned rates are shown in Table 19. Rates will be determined with due regard for the need to achieve a balance with private and environmental demands. The originally proposed abstraction rates from the western line of wells of the Pinjar Scheme have been modified to accommodate private abstraction and the environment in the Carabooda area. **Groundwater levels will be monitored using the existing network of over 900 monitoring points in conjunction with measurements from the production wells. The abstraction strategy will be reviewed, and if necessary, modified taking into account the results of monitoring and the need to maintain the resource to meet public, private and environmental needs. The Water Authority will not exceed the quota or substantially modify the abstraction strategy from the scheme without prior Environmental Protection Authority approval.**

TABLE 26

PROPOSED MANAGEMENT STRATEGY,
GNANGARA MOUND AREA

EXISTING OR PROPOSED ITEM	MANAGEMENT STRATEGY	REASON
Public Water Supply Schemes	o Bores in southwest line of Pinjar Scheme reduced in yield	o Prevent lowering of water levels at the small circular lakes south of Lake Pinjar o Reduce the drawdown effect on the linear lakes in the Lake Carabooda and Lake Neerabup area
	o Yeal and Barragoon wellfields moved to the west and bore lines moved closer together	o Protect conservation areas in the northern part of the area particularly Yeal Swamp.
Private Water Supply	o Maintain maximum quota of $21 \times 10^6 m^3$/yr at Wanneroo (south of Flynn Drive)	o Based on available water resources within the Wanneroo Groundwater Area and effects on small circular lakes
	o Maximum quota of $15 \times 10^6 m^3$/yr at Pinjar/Carabooda area (north of Flynn Drive)	o Control effects on lakes in the area, particularly the linear lakes in the Lake Carabooda and Lake Neerabup area o Match available supply with realistic demand.
Forest Cover	o Thin and maintain basal area of pines at about $11 m^2$/ha	o Maintain or improve recharge to the superficial formations
	o Maintain basal area in young pine areas north of Lake Pinjar at present levels or not more than $11 m^2$/ha, whichever is less	o Improve sawlog quality o Prevent lowering of water levels in the proposed Yeal Nature Reserve extension.
	o Control burn pine slash and leaf litter	
Lakes and Wetlands	o Minimise water level declines under these features to less than 0.5m in environmentally sensitive areas	o Mitigate effects on these features to maintain the exisiting environment.

11.3.3 Management of Private Water Use

The management of private water use is undertaken under the provisions of the relevant legislation. Within the WGA all wells must be licenced. Licences generally contain conditions relating to well construction, permitted use and allocated volume. Although the legislation provides for the fitting of meters to wells, such action has not been necessary within the WGA to date.

The Water Authority will manage private abstraction within the Wanneroo Groundwater Area, so as not to exceed the private groundwater abstraction quota. This quota will be reviewed as part of the annual reporting procedure for the Environmental Protection Authority. Provision will be made for the Wanneroo Groundwater Advisory Committee to have appropriate public representation from the entire Wanneroo Groundwater Area.

11.3.4 Co-Operative Land Management

Effective groundwater management requires effective land management so that both groundwater recharge and use may be manipulated. The Water Authority recognises that such land management will require the co-operation of the various vesting authorities, in particular CALM which is now responsible for the management of both pine plantations and conservation on reserves. **The Water Authority will liaise with the Department of Conservation and Land Management so that plans for thinning, control burning and future management of pine plantations recognise the effect of plantation management on the groundwater resource.**

The Authority proposes that management of pine plantations in State Forest No. 65 be consistent with the water production priority allocated to such areas by CALM. It is proposed that the basal area of pine plantations in the southern portion of State Forest No. 65, as shown on Figure 51, be maintained at about $11m^2$/ha and that basal area in the northern portion be maintained at the present level, or about $11m^2$/ha, whichever is less. In addition, control burning of thinning slash and leaf litter, consistent with increasing groundwater recharge, is proposed.

Management of reserves and MPA's for conservation is consistent with protection of the groundwater resource and the Water Authority's management objectives. Management of MPA's for active recreation is generally consistent with water protection but activities such as motorised recreation have groundwater pollution implications. **The Water Authority will provide advice during preparation of management plans for conservation areas and recreational activities to ensure protection of water quality.**

The Water Authority recognises that zoning issues dealt with by the State Planning Commission may have implications for water management and supply, particularly if there are major changes to the current corridor plan for development. **The Water Authority will continue to liaise with the State Planning Commission to ensure that appropriate consideration is given to water resource management when land planning issues are being considered.**

An interim guideline of 0.5m drawdown has been adopted for sensitive wetlands in conservation reserves, but this guideline needs to be kept under review on a case by case basis, as knowledge of wetlands improves.

The Water Authority suggests that the expertise of the DCE and CALM is required to set guidelines for the maintenance of water levels appropriate to conservation of representative ecosystems in conservation reserves. **The Water Authority will continue to liaise with the Departments of Conservation and Environment, and Conservation and Land Management to assist them in developing guidelines for water level changes which take into account the need for environmental conservation.**

Mining activities in the Gnangara Mound area could have significant implications for groundwater management. **The Water Authority will continue to liaise with the Mines Department and the Department of Conservation and Environment to ensure that consideration is given to water resource management when mining applications are evaluated.**

The proposed Yeal Nature Reserve extension is vacant Crown Land, supporting native vegetation. The intended future management of the area has particularly important implications for groundwater management. If the area is to become a conservation reserve, then conservative groundwater management may be required. If the site were cleared and planted to pines, then it would be logical to concentrate groundwater abstraction there.

Resolution of the intended future management of the area is required so that the Water Authority can plan accordingly. **The Water Authority will take account of future land management in the area of the proposed Yeal Nature Reserve extension when planning future groundwater management in the area, by liaison with the Department of Conservation and Land Management.**

11.3.5 Demand Management

Demand management is an essential and increasingly important part of the Water Authority's strategy to effectively manage water use from all sources, in all parts of the State. **The Water Authority will prepare a demand management strategy.**

A draft Demand Management Strategy is being prepared and is planned for finalisation in 1987. The three essential elements of the strategy are:

- continuation and refinement of the pay-for-use system of water charges,
- improved standards of appliance design, and
- an education programme to encourage water conservation.

11.3.6 On-going Review

Further assessment of predicted changes in water levels with varying patterns of use and land management will be essential for management of the groundwater resource. **Monitoring of water levels will be used to assess the effectiveness of management strategies which will be reviewed as appropriate.**

11.4 MONITORING

Groundwater investigations and vegetation monitoring commenced in the Gnangara Mound area in the 1960's. A comprehensive monitoring programme is now conducted throughout the area. It is data from this on-going programme which has provided the information used to plan, model and evaluate the existing and proposed schemes discussed in this ERMP. **This programme of monitoring will continue, forming the basis for the monitoring to be undertaken in connection with existing and future developments on the Gnangara Mound area generally and the Pinjar Scheme in particular.**

11.4.1 Water Monitoring

11.4.1.1 Current Water Monitoring

Water levels are recorded each month at about 900 sites throughout the Gnangara Mound. Levels are recorded from bores, lakes and swamps to monitor the effects of seasonal as well as land use changes. All data is stored on a computer data base and reported in a variety of formats. It is this data which forms the basis of annual and triennial reporting to the EPA, as well as providing input to the modelling and management programmes described above.

Water quality is monitored from about 400 of the sites on a rolling five year programme. Water quality is monitored less frequently than water levels as it changes less rapidly. This monitoring will assist in identifying the factors causing these changes and enable appropriate management strategies to be developed.

More intensive monitoring programmes have been undertaken in selected areas to assist overall understanding of groundwater processes or where specific issues require investigation. Such monitoring has been undertaken as part of intensive studies of Lakes Jandabup (Allen, 1980) and Mariginiup (Hall, 1983) and as part of the net recharge study at Melaleuca Park. Detailed monitoring is continuing at the former liquid waste disposal site on Gnangara Road.

11.4.1.2 Proposed Water Monitoring

Regular monitoring of groundwater levels will be carried out within the Pinjar area. This will include observation bores at the site of proposed production wells to monitor the local drawdown effects and selected lakes and swamps. These lakes will include Lakes Carabooda, Nowergup, Neerabup, Pinjar, Adams, Mariginiup, Jandabup and Loch McNess. Water level monitoring from over 900 other existing stations will continue. The existing regional groundwater quality monitoring programme will continue. The quality of water produced by the Pinjar Scheme will be monitored frequently to ensure that the water meets potable standards.

The quality of water produced from each Water Authority production well is metered and recorded on a monthly basis. Monitoring of private abstraction is assessed on the basis of the area irrigated by each user.

The need for specific water monitoring data in conjunction with vegetation and fauna monitoring, will be evaluated in consultation with the Departments of Conservation and Environment, and Conservation and Land Management.

11.4.2 Vegetation Monitoring

11.4.2.1 Current Vegetation Monitoring

Vegetation monitoring is carried out to follow changes induced by natural causes as well as changes which may be associated with alterations in land use such as groundwater abstraction.

Several botanical studies predate the development of the groundwater schemes on the Gnangara Mound. One of these was instigated in 1966 by Havel (1968), and now provides the most detailed longer-term successional study on native vegetation in the areas of proposed abstraction. In addition to providing base-line data on the response of native species to drought conditions in the 1970s, it has also formed the basis for monitoring the effects of changing land use in the region.

Vegetation monitoring has been carried out both within existing and proposed abstraction areas, and in control areas remote from the abstraction. This has provided an understanding of the native plant communities and how they respond to changes in localised environmental conditions. Species composition, densities and condition are recorded. Other detailed studies have investigated the root morphologies of selected perennial native species which have assisted in delineating those species which may be dependent on water from the shallow aquifers. Significant findings have been published and referred to in the annual or triennial reports to the EPA as appropriate.

11.4.2.2 Proposed Vegetation Monitoring

The Department of Conservation and Land Management has suggested that the need for further vegetation monitoring requires evaluation. **The Water Authority will prepare an appropriate vegetation monitoring programme in consultation with the Departments of Conservation and Land Management, and Conservation and Environment.**

The following aspects will be considered in the design of any new monitoring programme.

- o Regular monitoring of the aquatic and fringing communities, in conjunction with water level and quality monitoring.
- o Maintenance of established monitoring programmes in areas both within and beyond the projected zones of influence.
- o Expansion of monitoring to landforms and native communities not currently studied (eg. Spearwood Dune System, particulary near the wetlands and swamps).
- o Inclusion of representative sensitive conservation areas in a monitoring programme, eg. Yeal Nature Reserve (M5), Eastern Chain of Wanneroo Wetlands (M8), Wabling MPA (C13), and Ellen Brook and Twin Swamps (M17).
- o Expansion of monitoring to include areas where predicted effects may occur (eg. near pumping wells and in areas where local water levels may vary).
- o Search of habitats likely to support the orchid Thelymitra carnea during future vegetation monitoring.

The adequacy of current monitoring activities will be re-evaluated following appropriate input from the Water Authority, CALM and DCE. It has been recognised that such monitoring should include unaffected control areas as well as potential areas of influence from the present and future proposed schemes.

11.4.3 Pine Plantation Monitoring

The Department of Conservation and Land Management currently monitor the basal area of the plantations every three years.

The Water Authority will liaise with the Department of Conservation and Land Management regarding future monitoring of the basal area of pine plantations in State Forest No. 65.

11.4.4 Fauna Monitoring

11.4.4.1 Current Fauna Monitoring

In collaboration with DCE, the Water Authority is supporting on-going monitoring of the invertebrate fauna of wetlands on the Swan Coastal Plain. Presently Lakes Jandabup and Joondalup are monitored in the Gnangara Mound area. Invertebrates often have specific habitat requirements allowing them to be used as indicators of the biological health of an ecological community. Invertebrate species density and distribution is being monitored in response to seasonal water level and quality changes. In addition, invertebrates contribute to the diet of higher order members of the food chain, such as fish and birds, so their abundance can be used as an indicator of the suitability of a wetland for other higher animals.

Details of the present studies will be presented in a DCE Bulletin later in 1986 and the results presented in future reports to the EPA.

11.4.4.2 Proposed Fauna Monitoring

The existing wetland invertebrate monitoring programme will continue and be expanded to include Lake Goollelal and Loch McNess. The Water Authority will continue to support this programme.

The Water Authority will consult the Departments of Conservation and Environment, and Conservation and Land Management on the need for essential monitoring of other animals. It is important that any additional monitoring be incorporated within the framework of exisiting programmes being undertaken by these Departments.

11.4.5 Social Monitoring

11.4.5.1 Current Social Monitoring

An important component of the ERMP investigations was the Public Awareness and Attitudes Survey. The study was aimed at informing the public of the Water Authority's conceptual proposals for the Gnangara Mound and identifying the social issues associated with the proposals. These issues were then taken into account in the development of the Preferred Development Strategy.

Public involvement in the decision making process will be invited by the EPA following the release of this document for a public review period. **The Water Authority will participate in public meetings during the ERMP review period.**

The social issues associated with the management of groundwater resources are currently being studied by the WAWRC's Groundwater Management Project which presently focuses on the Jandakot area. The study team comprises personnel from CSIRO, academic institutions and Government Authorities. The study will contribute to the Water Authority's future management of the resource.

The existing Groundwater Advisory Committees also provide an important source of public input to the Water Authority's planning and management processes.

11.4.5.2 Proposed Social Monitoring

Further evaluation of social issues will occur when the WAWRC study of groundwater management is completed. **The Water Authority will continue to liaise with and provide support to the Western Australian Water Resources Council study team.**

The existing Groundwater Advisory Committees will continue to provide a forum for public input and monitoring of important social issues. **The Water Authority will continue to take into account the advice of the Groundwater Advisory Committees as an important contribution to the management of the resource.**

Public comment on the proposed Lexia, Yeal and Barragoon Schemes will also form a very important component of input to the Water Authority's planning process.

11.5 REPORTING AND ASSESSMENT

The results of the management and monitoring programmes will be reported regularly for review by the Environmental Protection Authority and the programmes modified where appropriate. Reporting on the existing Wanneroo and Mirrabooka Schemes will continue in the established format with brief annual reports complemented by comprehensive triennial reviews for submission to the Environmental Protection Authority.

11.5.1 Pinjar Developments

The existing reporting to the Environmental Protection Authority will be extended to cover the proposed Pinjar Scheme, together with a review of private groundwater usage in the area.

A brief annual report will be submitted to the Environmental Protection Authority. It will contain:

- a review of operations and production volumes,
- a summary of well, lake level and water quality monitoring,
- brief reviews of the vegetation and fauna monitoring programmes, and
- an overview of any other developments which may be significant to the operation of the scheme, have potential environmental effects or may be of relevance to management of the groundwater resource.

A comprehensive triennial review of the Pinjar Scheme will also be submitted, covering similar topics to the annual reports but in more detail, with the emphasis on any important changes in the resource and the implications for any alterations required to future management. Management strategies will be reviewed and modified as appropriate.

11.5.2 Future Developments

This ERMP relates to long term groundwater resource management and development of the groundwater resources of the Gnangara Mound. The next proposed development for public water supply is the Pinjar Groundwater Scheme.

The Water Authority will provide appropriate environmental documentation to enable the Environmental Protection Authority to assess future groundwater developments on the Gnangara Mound.

TABLE 27

GNANGARA MOUND GROUNDWATER RESOURCE - SUMMARY OF ENVIRONMENTAL MANAGEMENT PROCEDURES

SUBJECT	ERMP SECTION	COMMITMENT
Proposed Wellfield Layouts	11.3.1	o Layout and abstraction pattern of the proposed Pinjar Scheme will be as described in this ERMP o Layouts of proposed Lexia, Yeal and Barragoon Schemes will be further assessed in detail
Abstraction Strategies	11.3.2	o Monitoring of groundwater levels o Regular review of abstraction strategy and modification if necessary o Well quotas not to be substantially exceeded without EPA approval
Private Water Use	11.3.3	o Private abstraction will be managed so as not to exceed the quota o Annual review of quota reported to EPA o Public representation on Wanneroo Groundwater Advisory Committee will continue
Co-operative Land Management	11.3.4	Liaise with: - CALM on pine plantation and groundwater management - SPC to ensure land planning proposals are consistent with water resource management - DCE and CALM to assist in development of guidelines for environmental conservation - Department of Mines and DCE with regard to mining applications
Demand Management	11.3.5	o Prepare a demand management strategy
On-going Review	11.3.6	o Assessment of the effectiveness of management strategies, using water level monitoring results o Predict changes in water levels with varying land use and management strategies; review as appropriate
Water Monitoring	11.4.1	Regular monitoring of: - Groundwater level including levels in selected wetlands - Regional groundwater quality - Water quality from Pinjar Scheme
Vegetation Monitoring	11.4.2	o Prepare an appropriate vegetation monitoring programme in consultation with CALM and DCE
Pine Plantation Monitoring	11.4.3	o Liaise with CALM on monitoring of basal area of pines in State Forest No. 65.
Fauna Monitoring	11.4.4	o The wetland invertebrate monitoring programme will continue and be expanded to include Lake Goollelal and Loch McNess o Consult with DCE and CALM on monitoring of fauna
Social Monitoring	11.4.5	o The Water Authority will participate in public meetings during the ERMP public review period o Liaise with and support the WAWRC groundwater management study team o Public input through the Groundwater Advisory Committees will continue
Reporting and Assessment - Existing Schemes	11.5	o Brief annual and comprehensive triennial reports to EPA on the Wanneroo and East Mirrabooka Schemes will continue
- Pinjar Scheme	11.5.1	o Brief annual and comprehensive triennial reports to EPA incorporating operations data, water quality, vegetation and fauna monitoring results and an overview of scheme management o Management strategies reviewed and modified if necessary
- Future Schemes	11.5.2	o Liaise with EPA on groundwater developments on the Gnangara Mound

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14.0 AUTHORITIES CONSULTED

Australian Bureau of Statistics

Bureau of Meteorology

City of Wanneroo

Commonwealth Scientific and Industrial Research Organisation

Department of Agriculture

Department of Conservation and Environment

Department of Conservation and Land Management

Department of Lands and Surveys

Department of Mines - Geological Survey of WA

Shire of Chittering

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State Planning Commission

Western Australian Herbarium

Western Australian Museum

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15.0 ABBREVIATIONS

Water Authority	Water Authority of Western Australia
ERMP	Environmental Review and Management Programme
TSS	Total Soluble Salts
$\times 10^6 m^3/yr$	million cubic metres per year
%	percentage
CALM	Department of Conservation and Land Management
EPA	Environmental Protection Authority
SPC	State Planning Commission
LGA	Local Government Authority
PWSA	Public Water Supply Area
UWPCA	Underground Water Pollution Control Area
DCE	Department of Conservation and Environment
MWA	Metropolitan Water Authority
MRPA	Metropolitan Region Planning Authority
ABS	Australian Bureau of Statistics
WGA	Wanneroo Groundwater Area
WAWRC	Western Australian Water Resources Council
km^2	square kilometres
$\$/m^3$	dollars per cubic metre
NH & MRC	National Health and Medical Research Council
TDS	Total Dissolved Solids
PAAS	Public Awareness and Attitudes Survey
mm	millimetres
L	litres
^oC	degrees Celsius
m	metres
m/d	metres per day
MPA	Management Priority Area
AHD	Australian Height Datum
m^2/ha	square metres per hectare
ha	hectares
AAGR	Average Annual Growth Rate
MWB	Metropolitan Water Board
$<$	less than
$>$	greater than
mg/L	milligrams per litre

16.0 GLOSSARY

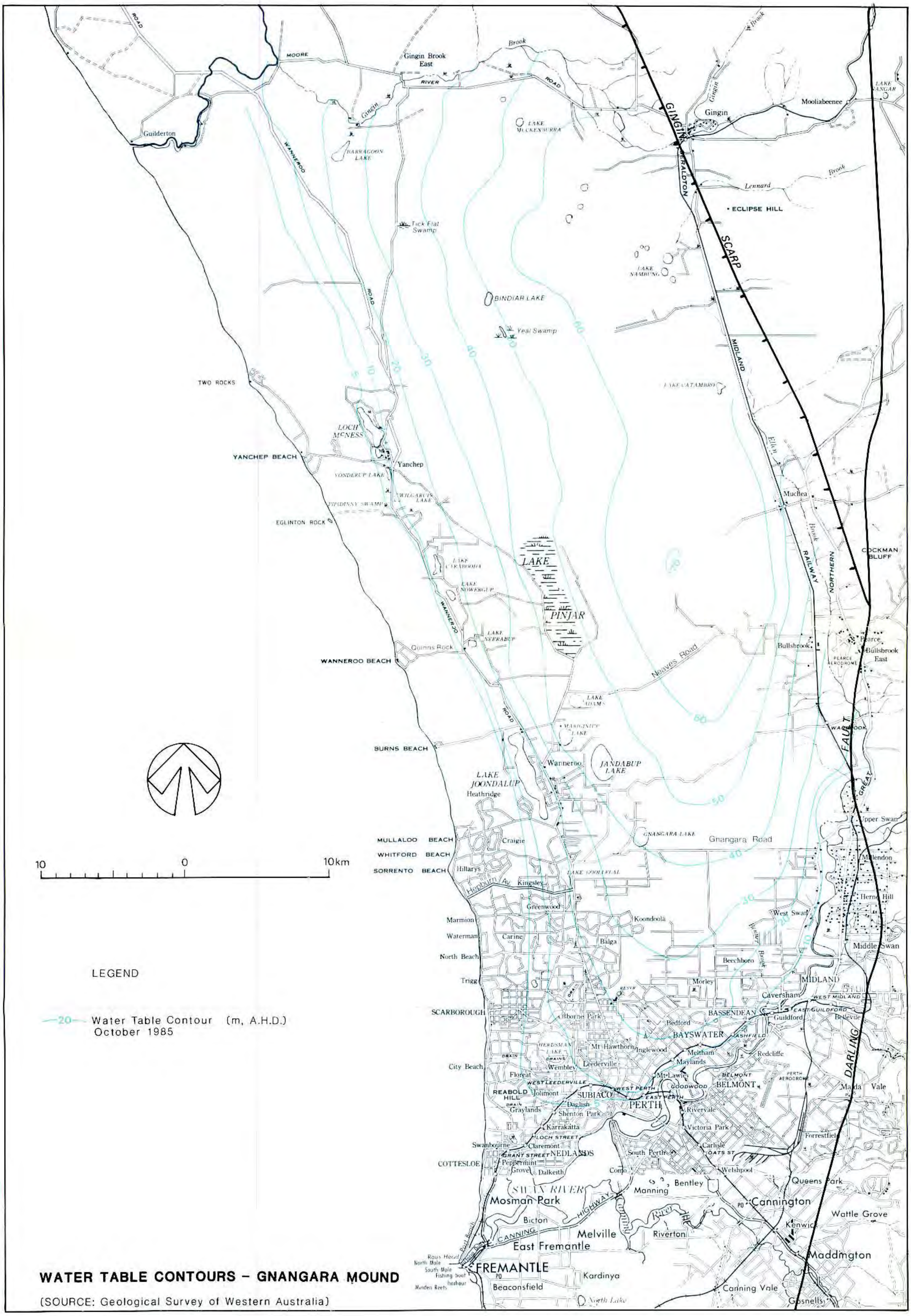
Aeolian:	Wind-blown; describes a deposit formed by wind action.
Algorithm:	A set of formalised steps designed to solve a problem, especially in computing.
Alluvial:	Referring to stream or river deposits.
Amphipods:	An order of Crustacea including the freshwater shrimps.
Anaerobic:	Living or active only in the absence of gaseous or dissolved oxygen.
Annual System Demand:	The total volume of water expected to be used by consumers serviced by the Metropolitan Water Supply System in a year without restrictions.
Annual Yield:	The total amount of water that can be abstracted in a given year.
Aquifer:	A geological formation or group of formations capable of receiving, storing and transmitting significant quantities of water.
Arboreal:	Pertaining to trees.
Archaean:	Referring to rocks older than 2600 million years.
Arenaceous:	Sandy, or composed of sandy material.
Artesian:	Artesian and sub-artesian both describe groundwater confined under hydrostatic pressure. Artesian flows at the surface, sub-artesian rises above the confining layer but does not flow.
Basal Area:	The sum of the cross-sectional area of stems (measured at 1.3m above ground) per unit land area.
Bassendean Dune System:	The furthest inland and oldest dune system on the coastal plain.
Biota:	All plants and animals within a specified area.
Bore:	A hole drilled into the ground and lined with a suitable casing to monitor water levels.
Botulism:	A disease produced by the bacterium Clostridium botulinum, which periodically causes bird deaths in wetlands.
Calcarenite:	A limestone consisting predominantly of detrital calcite particles of sand size.

Capillary fringe:	The lower subdivision of the zone of aeration immediately above the water table in which the interstices are filled with water at a pressure less than atmospheric, being continuous with the water below the water table, but held above it by surface tension.
Carbonaceous:	Said of a rock or sediment that is rich in carbon.
Confined aquifer:	A permeable bed saturated with water under pressure and underlying a relatively impervious layer.
Conformably:	Deposited in a continuous sequence without a break.
Cretaceous:	Referring to rocks 65 million to 140 million years old.
Crystalline:	Rocks composed of interlocking crystals eg. granite.
Demand Management:	A programme which is adopted to achieve effective management of the use of water resources in order to meet the general objectives of economic efficiency, environmental conservation, community and consumer satisfaction.
Desalination:	The removal of dissolved salts from sea or brackish water to make it potable.
Diatomite:	A light, porous, chalk-like substance, composed of microscopic siliceous plant remains.
Dieback:	An exotic plant disease caused by the fungus Phytophthora cinnamomi.
Downfaulted:	Said of the rocks on the down thrown side of a fault.
Drawdown:	The decline in water level due to abstraction.
Ecosystem:	A community of interdependent plants and animals together with the physical environment which they inhabit and with which they interact.
Evapotranspiration:	The actual loss of water by evaporation from soil, vegetation and water bodies, and transpiration from vegetation.
Feldspathic:	Said of a rock containing the mineral feldspar.
Ferruginous:	Pertaining to or containing iron.
Flocculated:	Describing a loose, open-structured aggregation of fine particles.
Formations:	A group of rocks which have certain characteristics in common and which were deposited about the same geological period and constitute a convenient until for description: eg. Leederville Formation, Yarragadee Formation.

Glauconitic:	Said of a mineral aggregate that contains glauconite, resulting in a characteristic green colour.
Goethitic:	Said of a mineral aggregate that contains the yellowish, reddish or brownish-black mineral goethite.
Habitat:	The particular type of environment occupied by an organism.
Hardness:	The measure of the ability of water to lather with soap. Soft water readily lathers with soap.
Herpetofauna:	A collective term for reptiles and amphibians.
Hydraulic Conductivity:	The rate of flow of water in units per day through a unit cross section, under a unit hydraulic gradient.
Interception:	Rainfall caught and held on the leaves of trees and vegetation before reaching the ground and returned to the atmosphere by evaporation.
Impermeable:	Describing a rock mass that will not allow the transmission of water under the head differences ordinarily found in groundwater.
Isopods:	An order of Crustacea including woodlice, water and shore slaters.
Jurassic:	Referring to rocks 140 million to 195 million years old.
Karst:	A type of topography that forms over limestone by dissolving or solution and that is characterised by depressions or sink holes, caves and underground drainage.
Littoral:	Area between high and low water lines.
Macropods:	Larger terrestrial animals, eg. Kangaroos.
Mesozoic:	Referring to rocks 65 million to 230 million years old.
Micaceous:	Consisting of, containing, or pertaining to the group of minerals known as mica.
Myrtaceous:	Pertaining to those plants belonging to the family Myrtaceae.
Net Recharge:	Resultant groundwater recharge to an aquifer.
Peak Demand:	The absolute maximum demand expected over a short hot, dry period of weather, nominally assumed to be one week.
Perched water table:	A water table which occurs above an impermeable zone, which is underlain by unsaturated materials.

Percolating groundwater:	A legal term for groundwater that oozes, seeps or filters through the soil without a definite channel in a course that is unknown or not discoverable.
Permeability:	The ease of movement of groundwater through a conductive unit. It represents the rate of flow through a unit cross section under a unit hydraulic head.
Permian:	Referring to rocks 230 million to 280 million years old.
Phreatophytes:	A plant that obtains its water suppy from the zone of saturation or from the capillary fringe.
Pipehead:	A small dam which would collect river flow in winter and pump it back to large existing storage reservoirs or supply it directly into the water supply system.
Potable:	Drinkable.
Proteaceous:	Pertaining to those plants belonging to the family Proteaceae.
Pyritic:	Said of a mineral aggregate that contains any of various metallic-looking sulfides of which pyrite ("iron pyrites") is the commonest.
Quaternary:	Referring to rocks up to 2 million years old.
Quindalup Dune System:	The furthest west and the youngest dune system on the coastal plain, composed of unconsolidated calcareous sands.
Quota:	The maximum volume of water that can be abstracted in a year.
Raptors:	Birds of prey.
Recharge:	Water arriving at the water table.
Riparian:	Pertaining to or situated on the bank of a body of water, especially of a water course such as a river.
Safe Yield:	(of an aquifer) The rate at which groundwater can be withdrawn without causing unacceptable drawdown or deterioration of water quality.
Saline:	Salty.
Saturated Zone:	A subsurface zone in which all the interstices are filled with water.
Sedimentary:	Descriptive term for an accumulation of material deposited by wind, water or gravity.
Shale:	A compacted clay or mud with some silt.

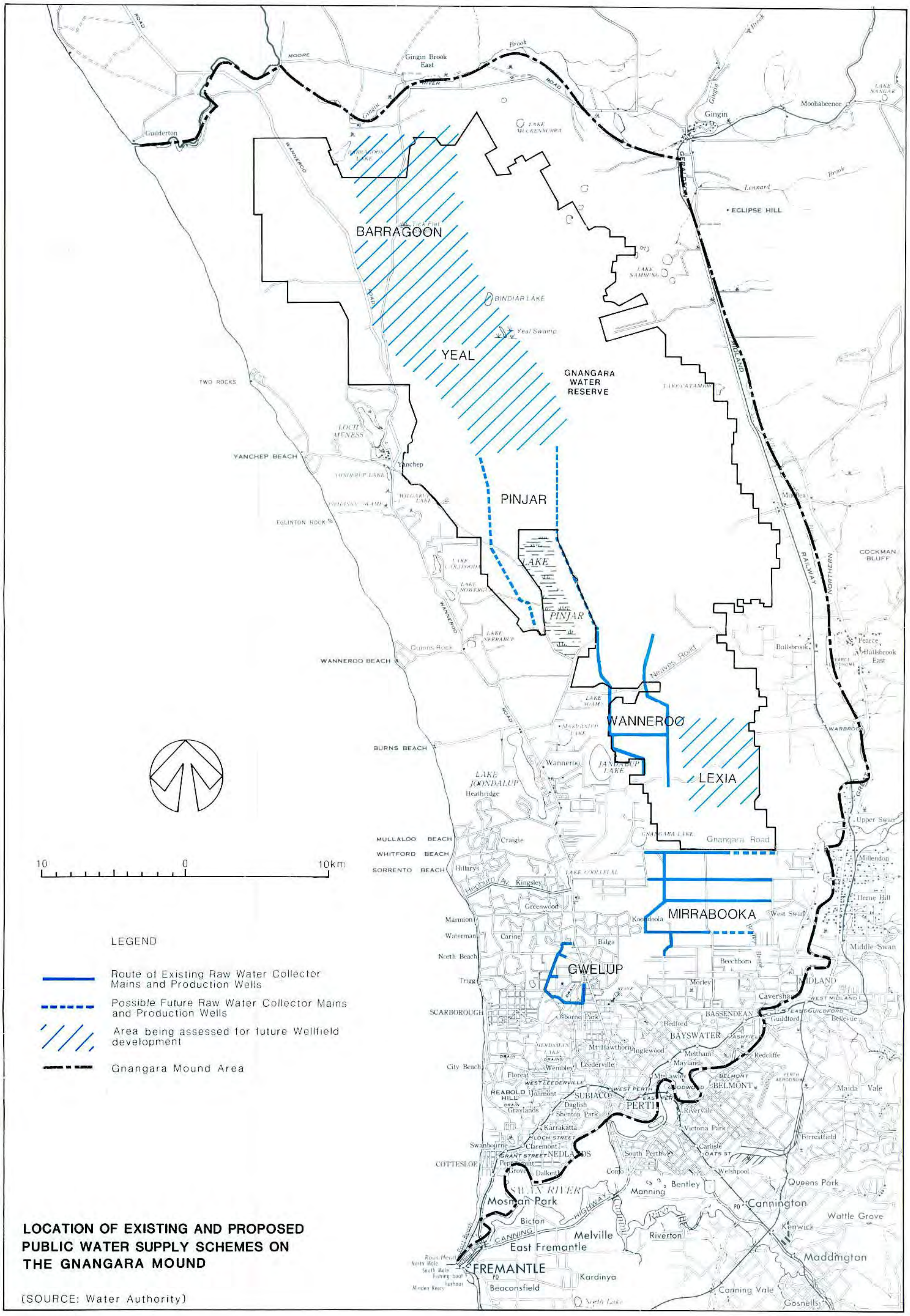
Siliceous:	Said of a rock containing abundant silica.
Siltstone:	Composed mainly of particles of silt size, ie. between 0.02 and 0.002mm.
Silviculture:	The cultivation of a forest, in this case pine forest.
Sources Development Timetable:	A schedule for the chronological development of new water sources to supply projected demand.
Spearwood Dune System:	This system lies between the Bassendean and Quindalup Dune System, comprising soft sandy limestones.
Superficial:	Pertaining to, occuring in, or affecting only, a surface or surface layer.
Superficial Formations:	Collective term for near surface geological formations.
Tertiary:	Referring to rocks 2 million to 65 million years old.
Total Dissolved Solids:	Amount of dissolved salts in a given volume of water.
Total Soluble Salts:	A measure of soluble chemical constituents of groundwater.
Transmissivity:	In an aquifer, the rate at which water is transmitted through a unit width under a unit hydraulic gradient.
Transpiration:	The loss of water vapour from a plant, mainly through the leaves.
Uncomformably:	Time break in sequence of deposition.
Unconfined aquifer:	A permeable bed only partly filled with water and overlying a relatively impervious layer. Its upper boundary is formed by a free water table or phreatic level under atmospheric pressure.
Vascular plants:	The higher plants, characterised by the possession of true roots, stems and leaves containing specialised vascular tissue through which liquids are conducted.
Viticulture:	The cultivation of vines, in this case grapevines.
Water balance:	An account of all water entering and leaving a system over a specific period.
Water table:	That surface within the saturated zone at which the pressure is atmospheric. Level at which water stands in uncased or screened shallow well in an unconfined aquifer.
Well:	A hole drilled into the ground and suitably developed and lined with casing from which usable quantities of water are produced.
Yilgarn Block:	Name given to a large Proterozoic and Archaean rock mass underlying most of south Western Australia. It represents the remnants of a stable continental craton.



WATER TABLE CONTOURS – GNANGARA MOUND

(SOURCE: Geological Survey of Western Australia)

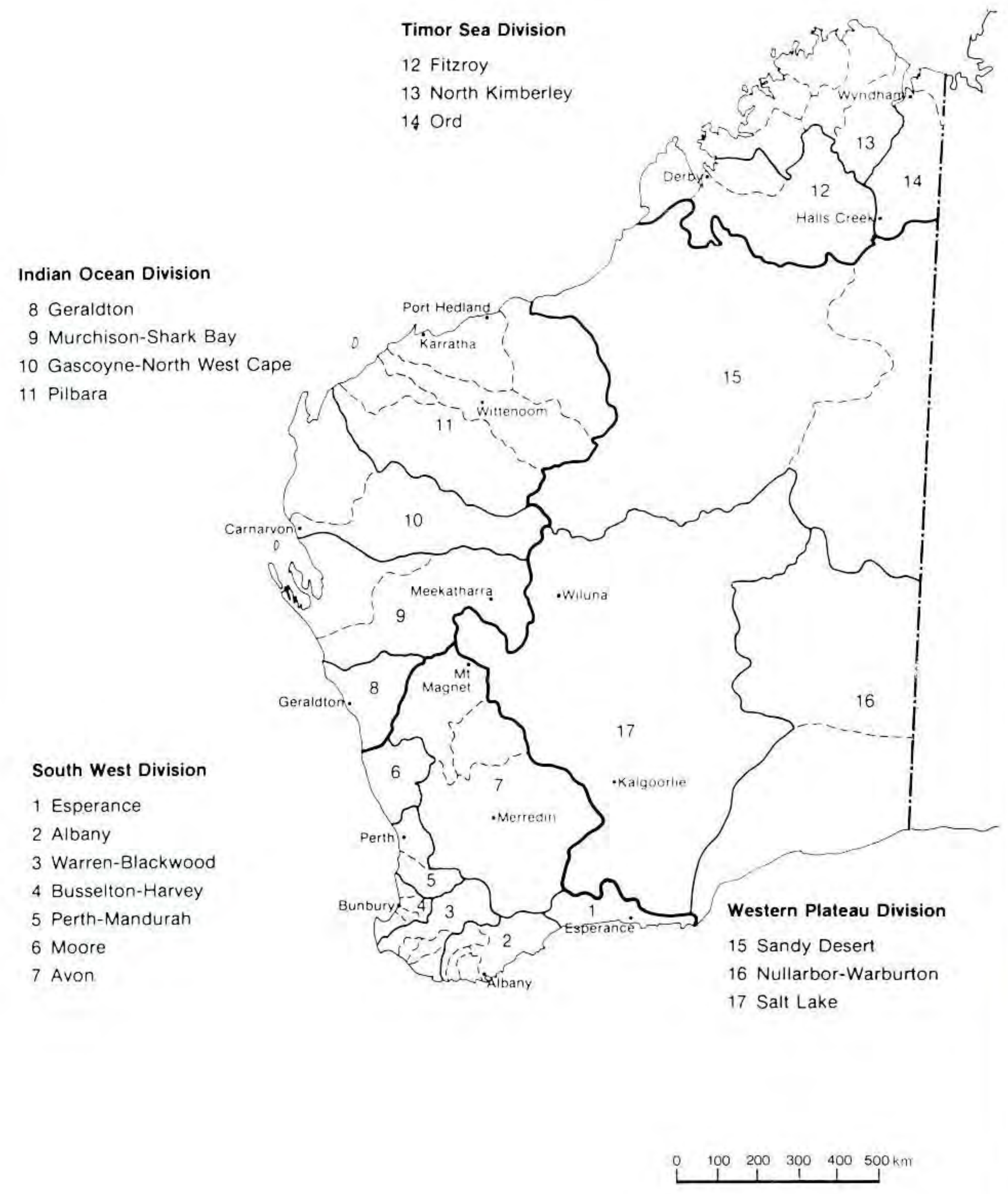
Figure 1
Dames & Moore



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

(SOURCE: Water Authority)

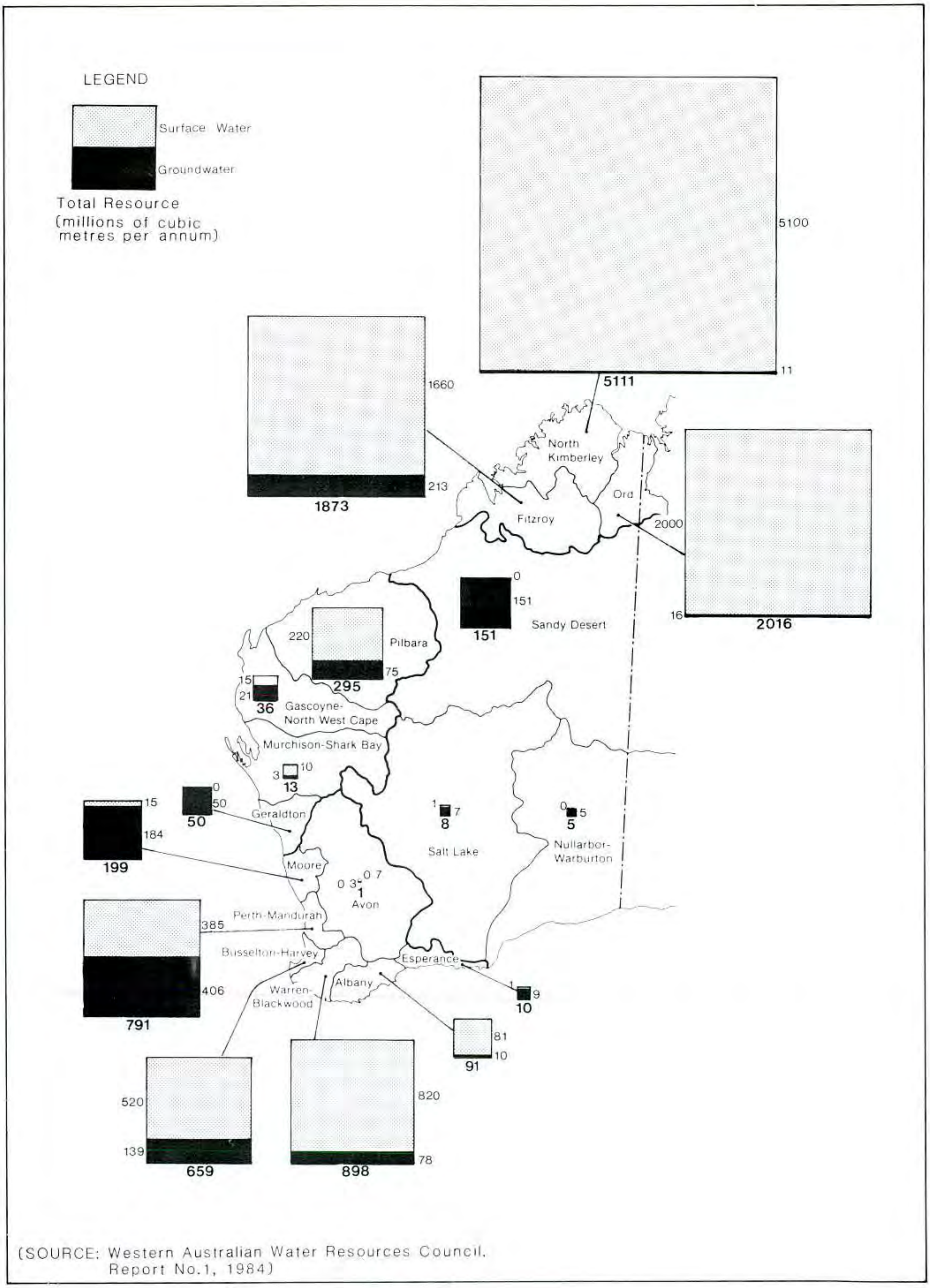
Figure 2
Dames & Moore



(SOURCE: Western Australian Water Resources Council.
Report No.1, 1984)

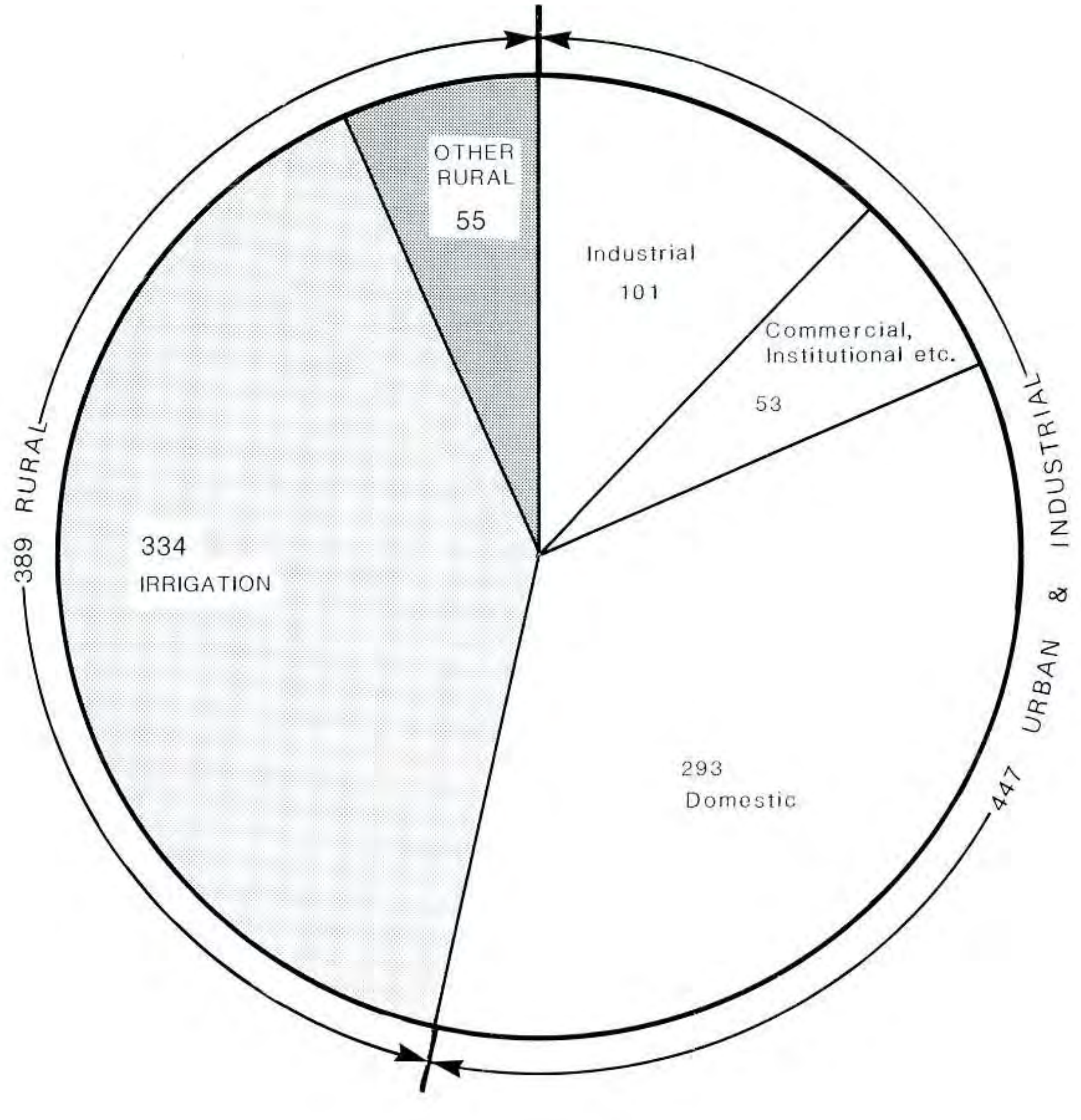
LOCATION OF WATER RESOURCE REGIONS

Figure 3
Dames & Moore



REGIONAL DIVERTIBLE FRESH AND MARGINAL WATER RESOURCES

Figure 4
Dames & Moore



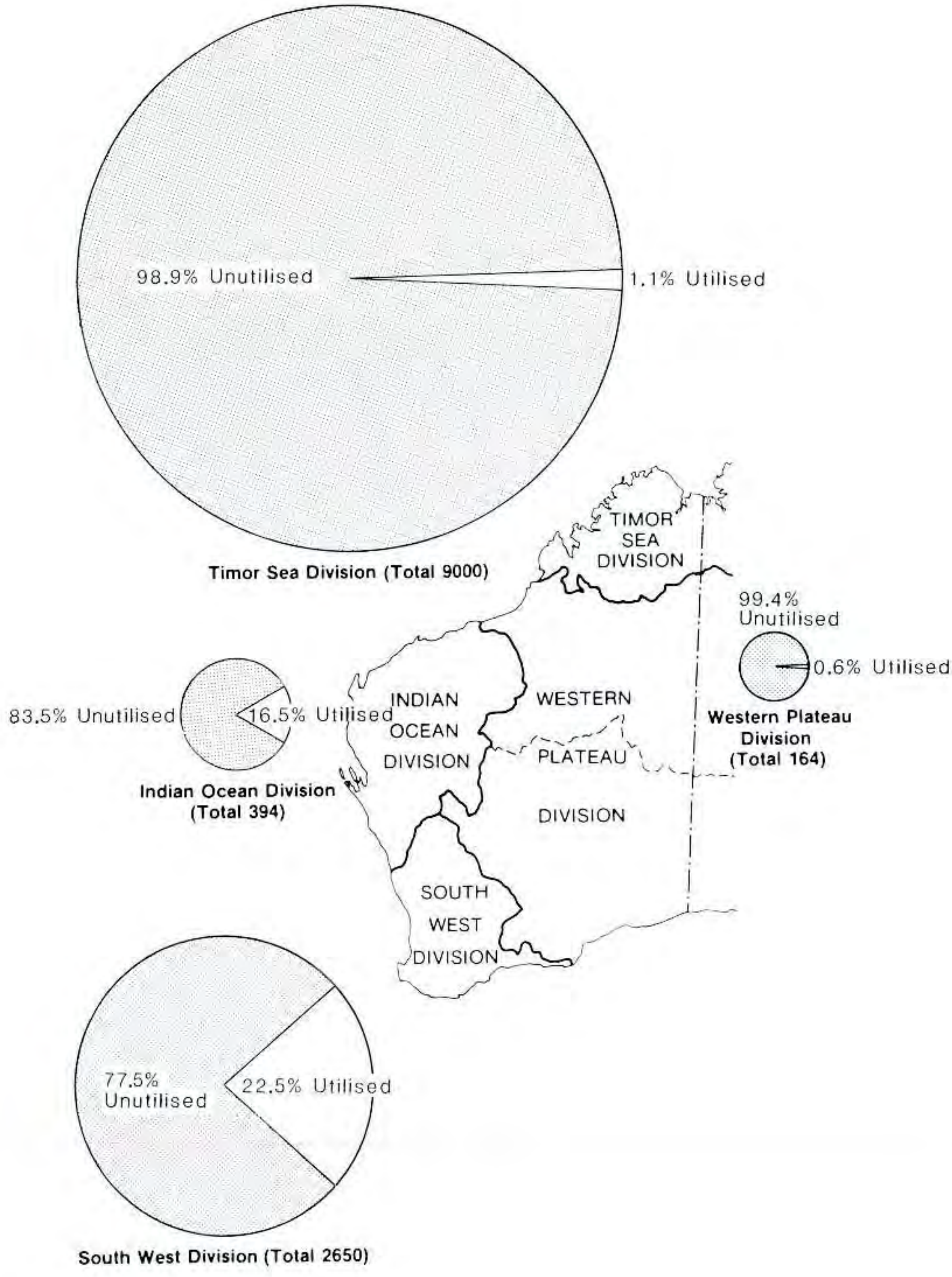
TOTAL 836

(SOURCE: Western Australian Water Resources Council
Report No.1, 1984)

WATER CONSUMPTION IN WESTERN AUSTRALIA (1981)

Millions of cubic metres per annum

Figure 5
Dames & Moore



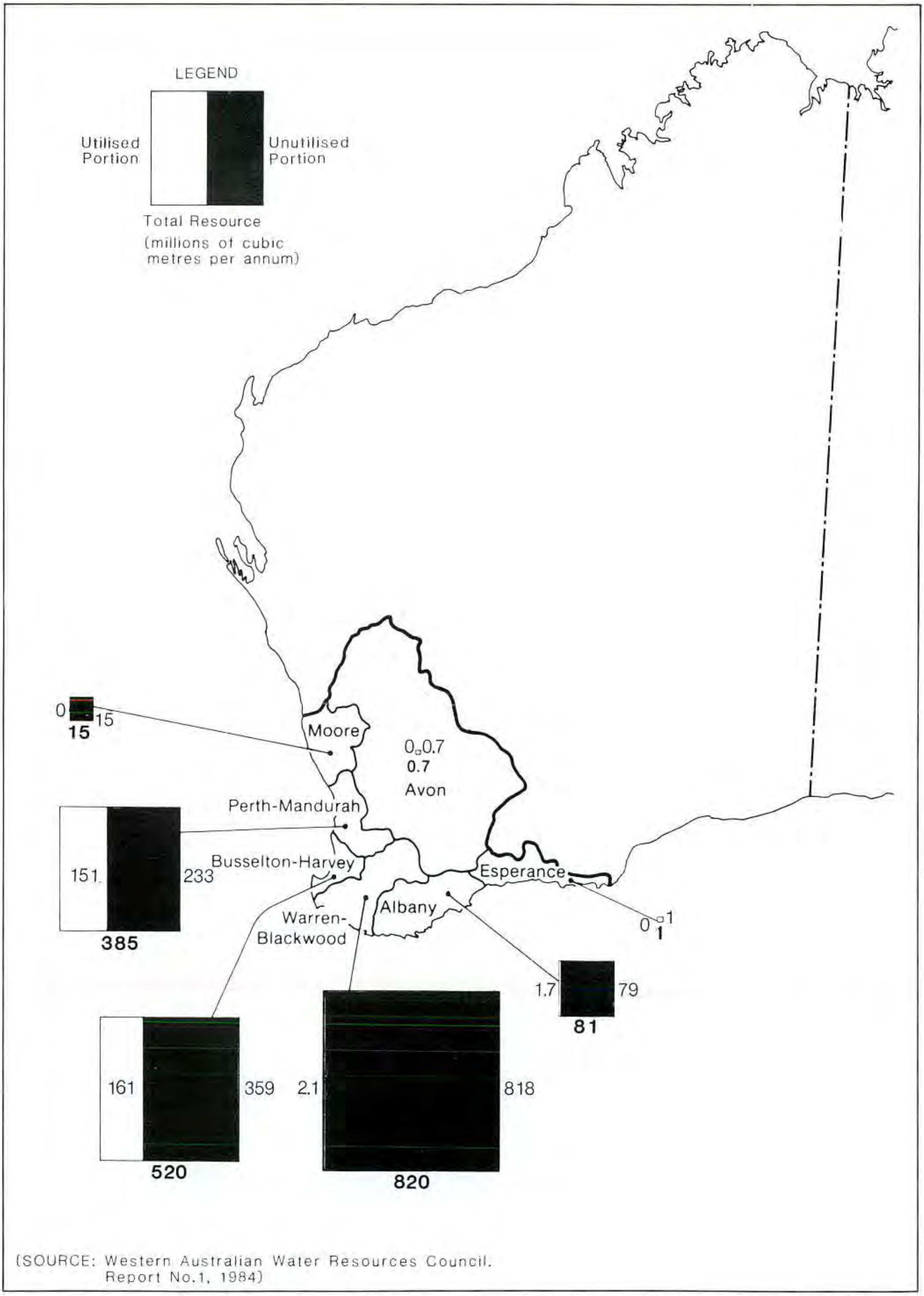
(SOURCE: Western Australian Water Resources Council. Report No.1, 1984)

UTILISATION OF DIVERTIBLE WATER RESOURCES IN WESTERN AUSTRALIA

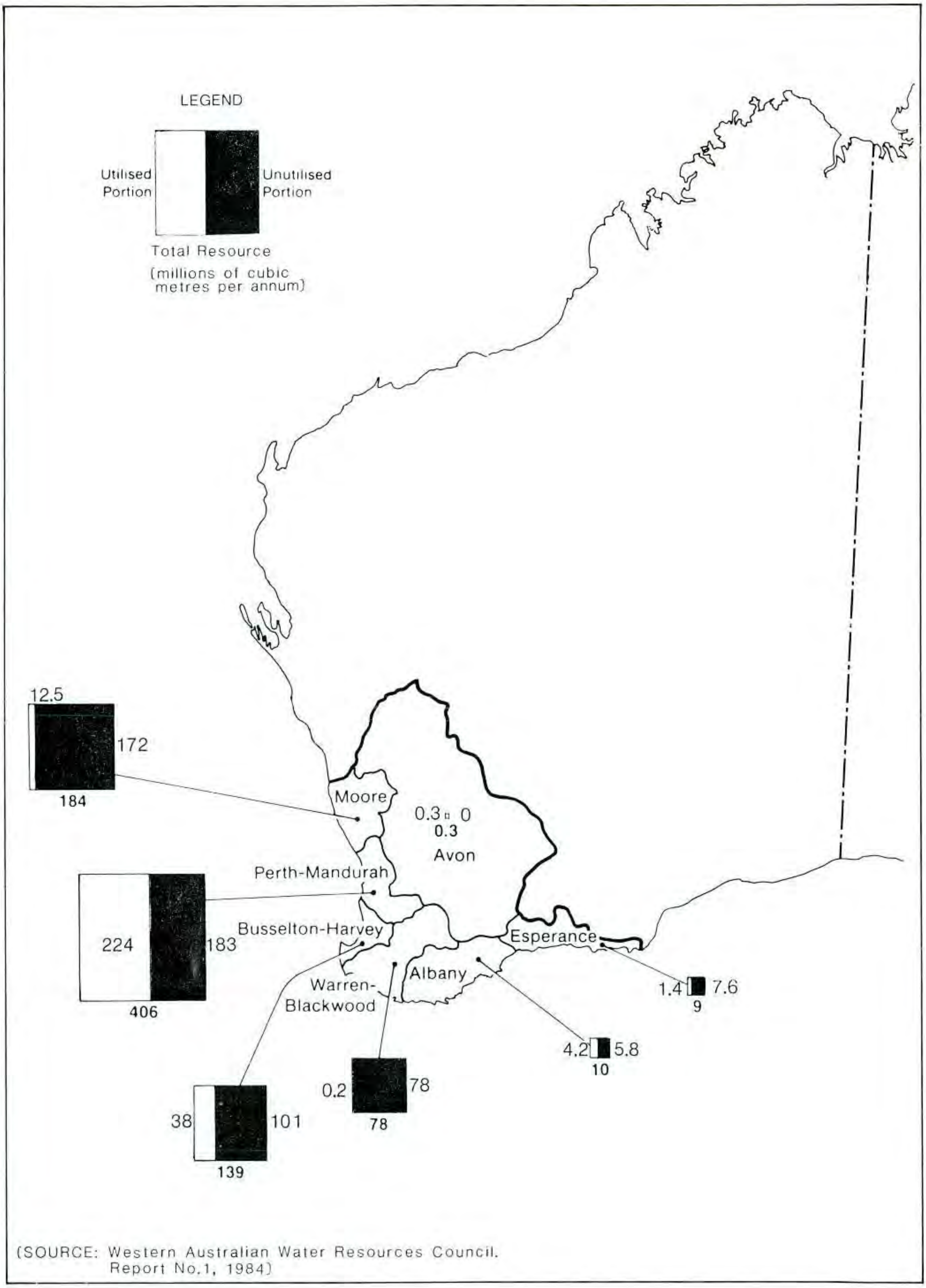
Millions of cubic metres per annum

Figure 6

Dames & Moore



UTILISATION OF REGIONAL SURFACE WATER RESOURCES



UTILISATION OF REGIONAL GROUNDWATER RESOURCES

Figure 8
Dames & Moore

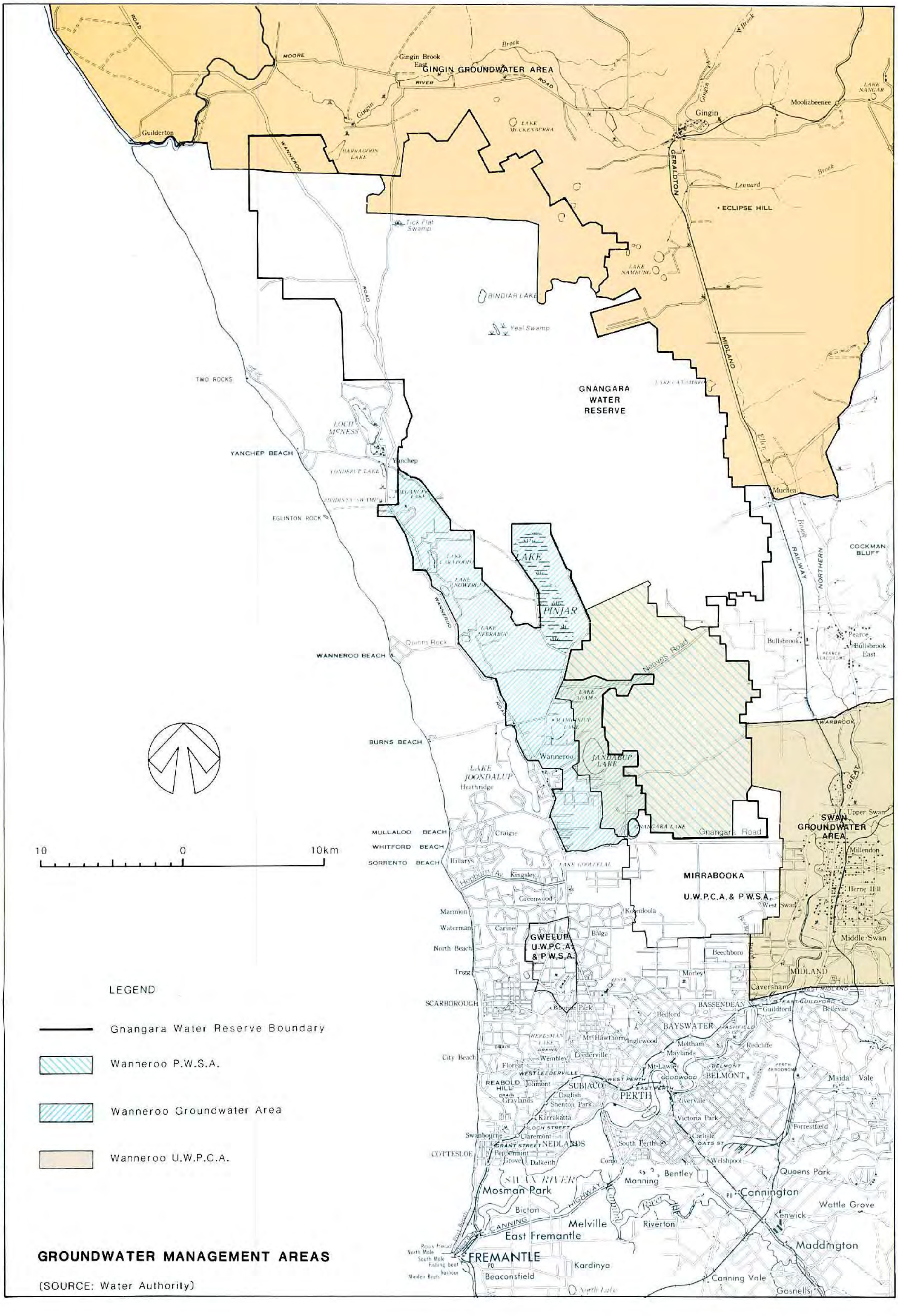
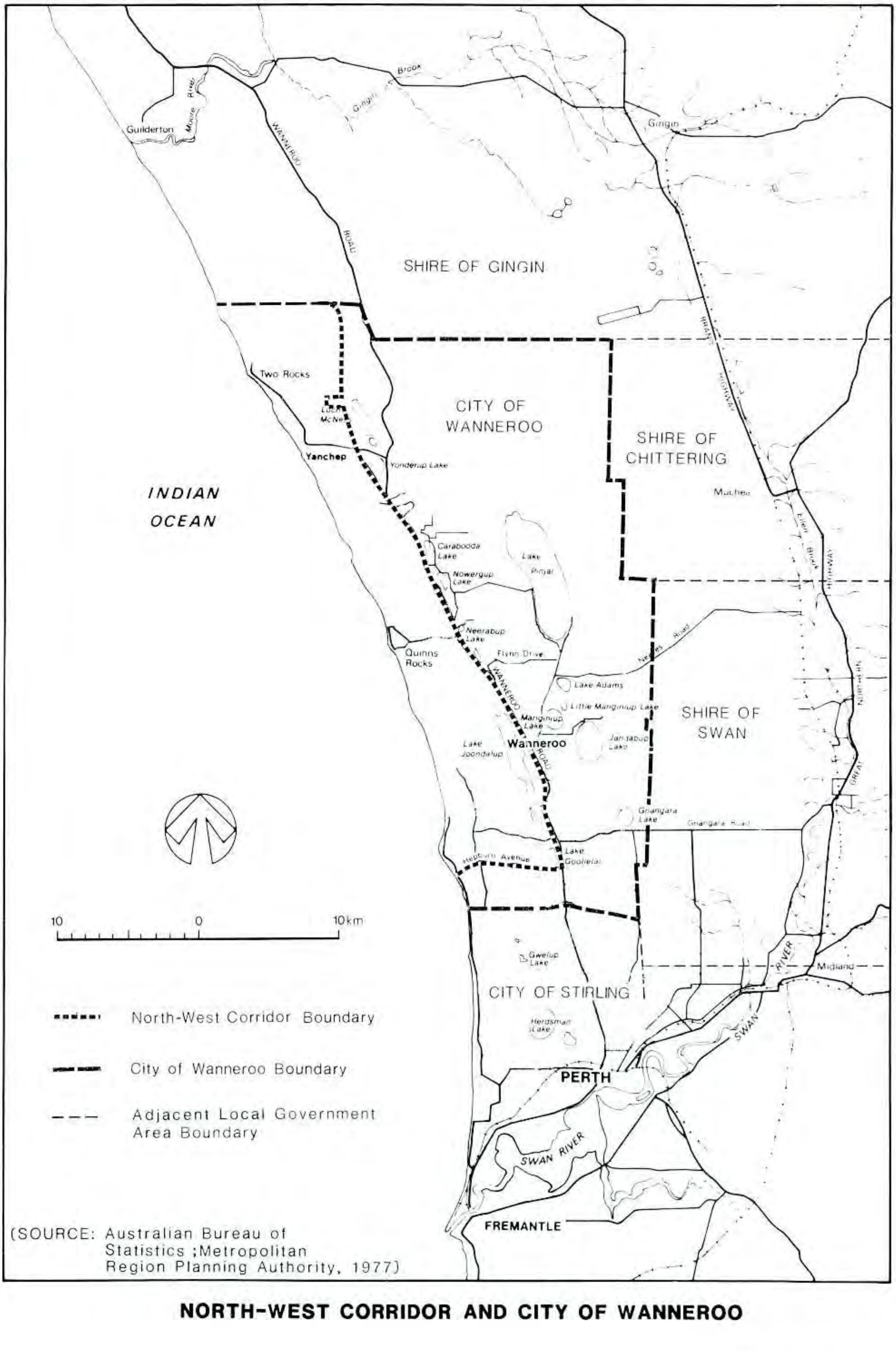
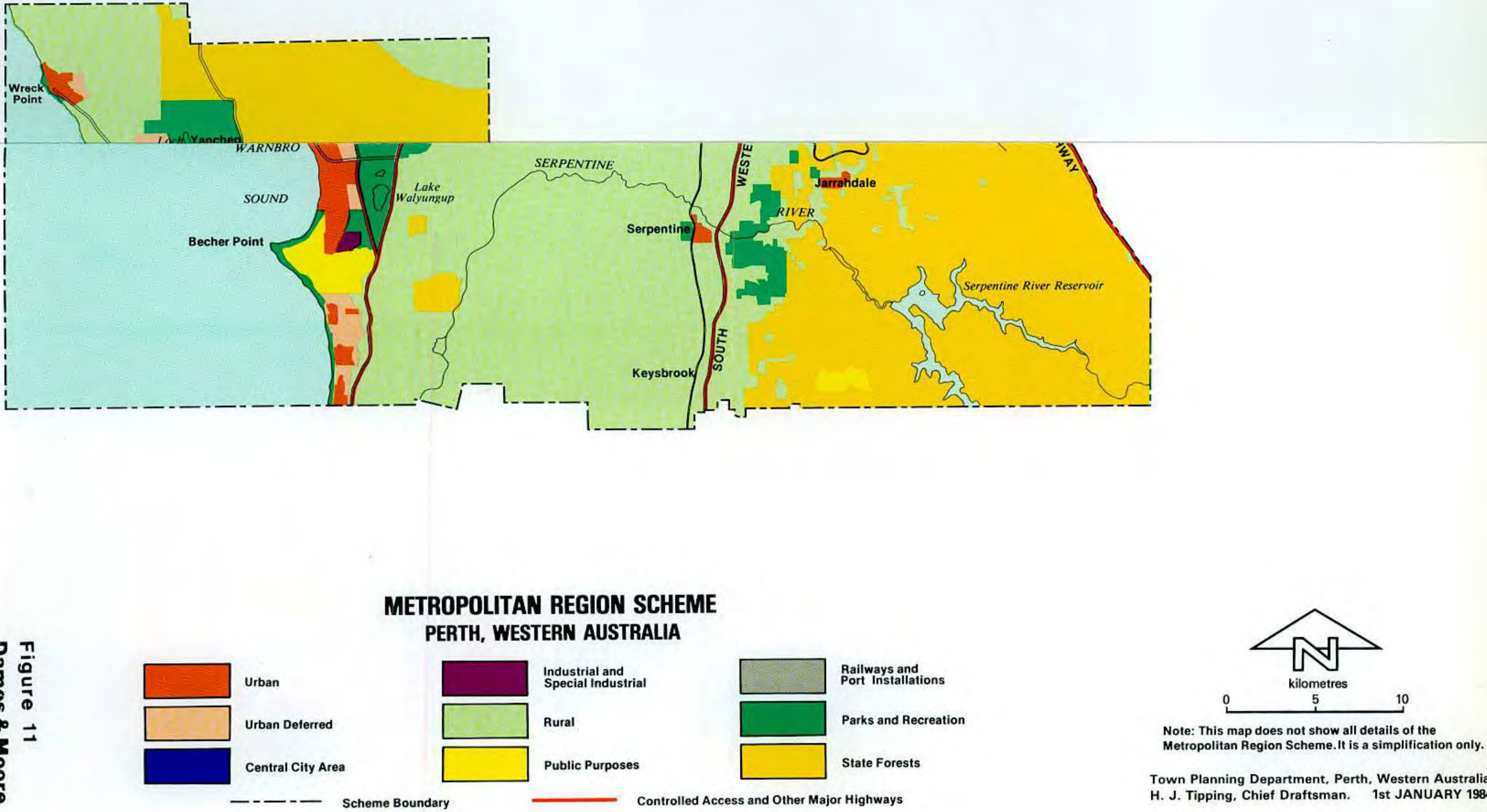


Figure 9
Dames & Moore



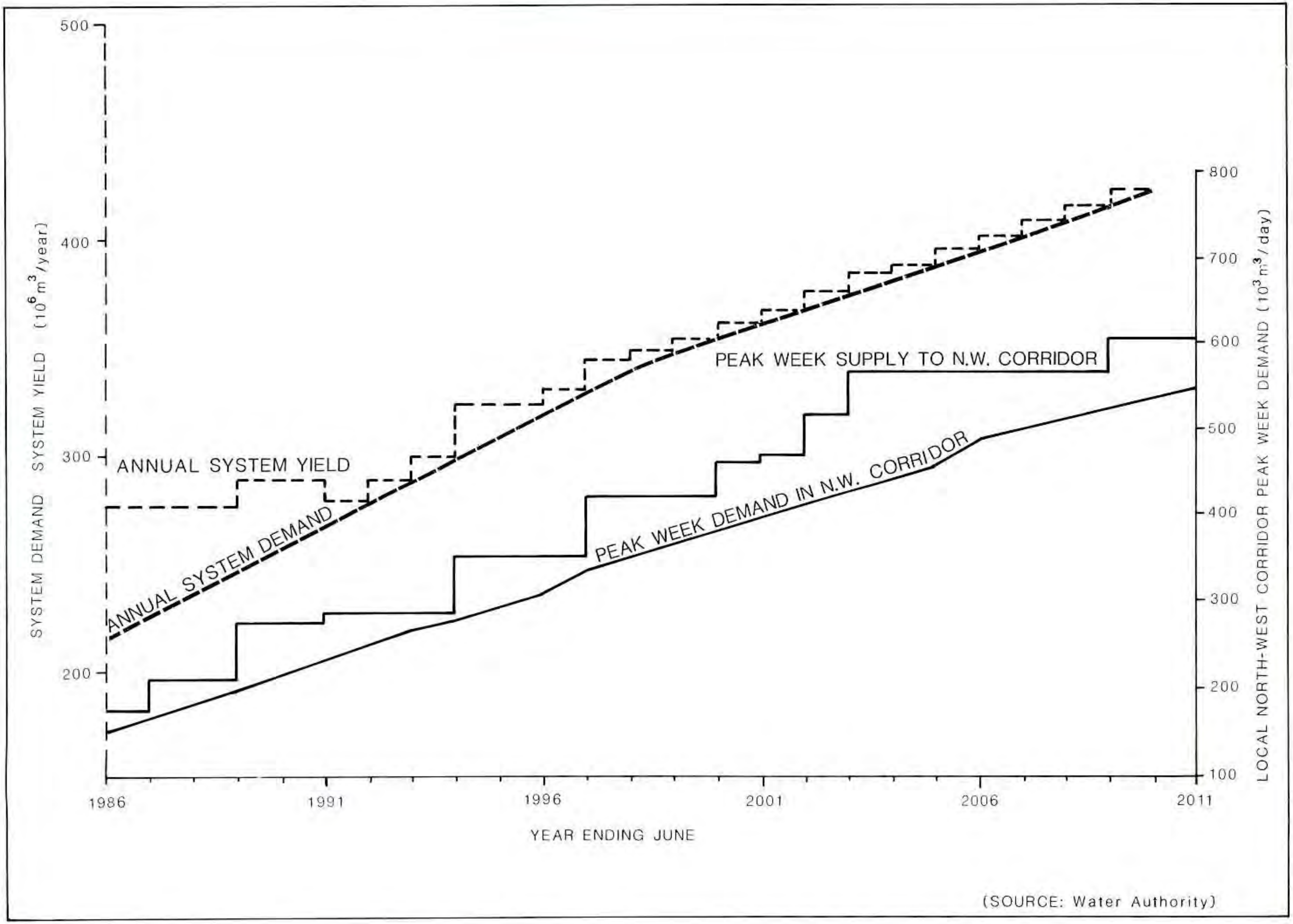
NORTH-WEST CORRIDOR AND CITY OF WANNEROO

Figure 10
Dames & Moore



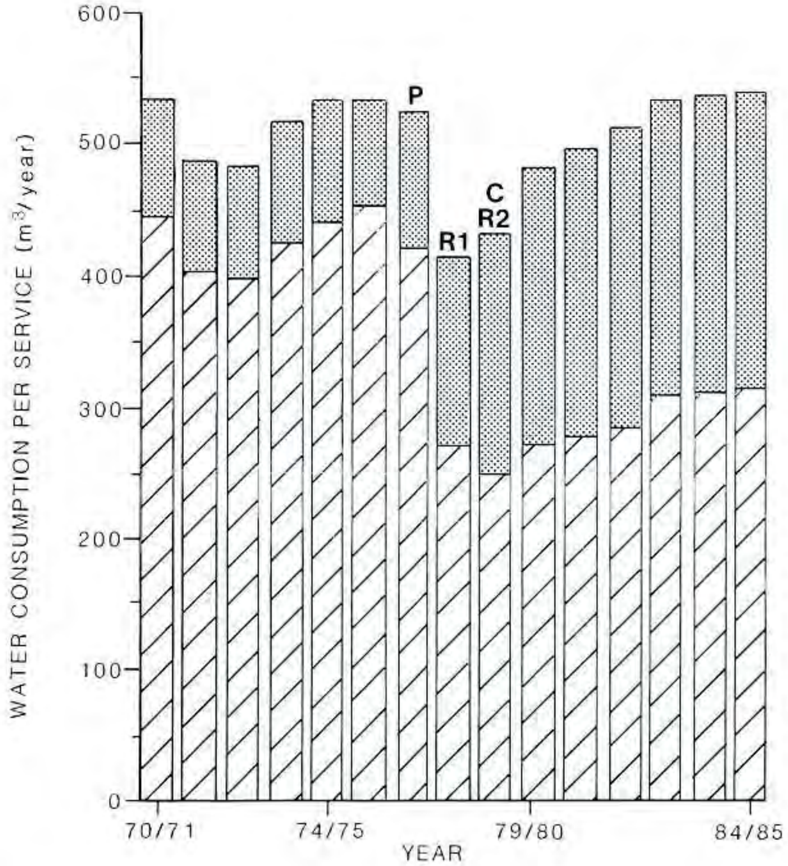
NOTE: Reproduce

Figure 11
Dames & Moore



WATER SUPPLY AND DEMAND–
PERTH AND NORTH-WEST CORRIDOR

Figure 12
Dames & Moore



PUBLIC WATER SUPPLY

PRIVATE WELLS

P = Promotion Campaign urging Water Conservation

R1 = Total sprinkler ban 28/7/77 to 30/9/78

R2 = Sprinklers only 6am to 7am and 6pm to 9pm
Alternate days 1/10/78 to 20/12/78

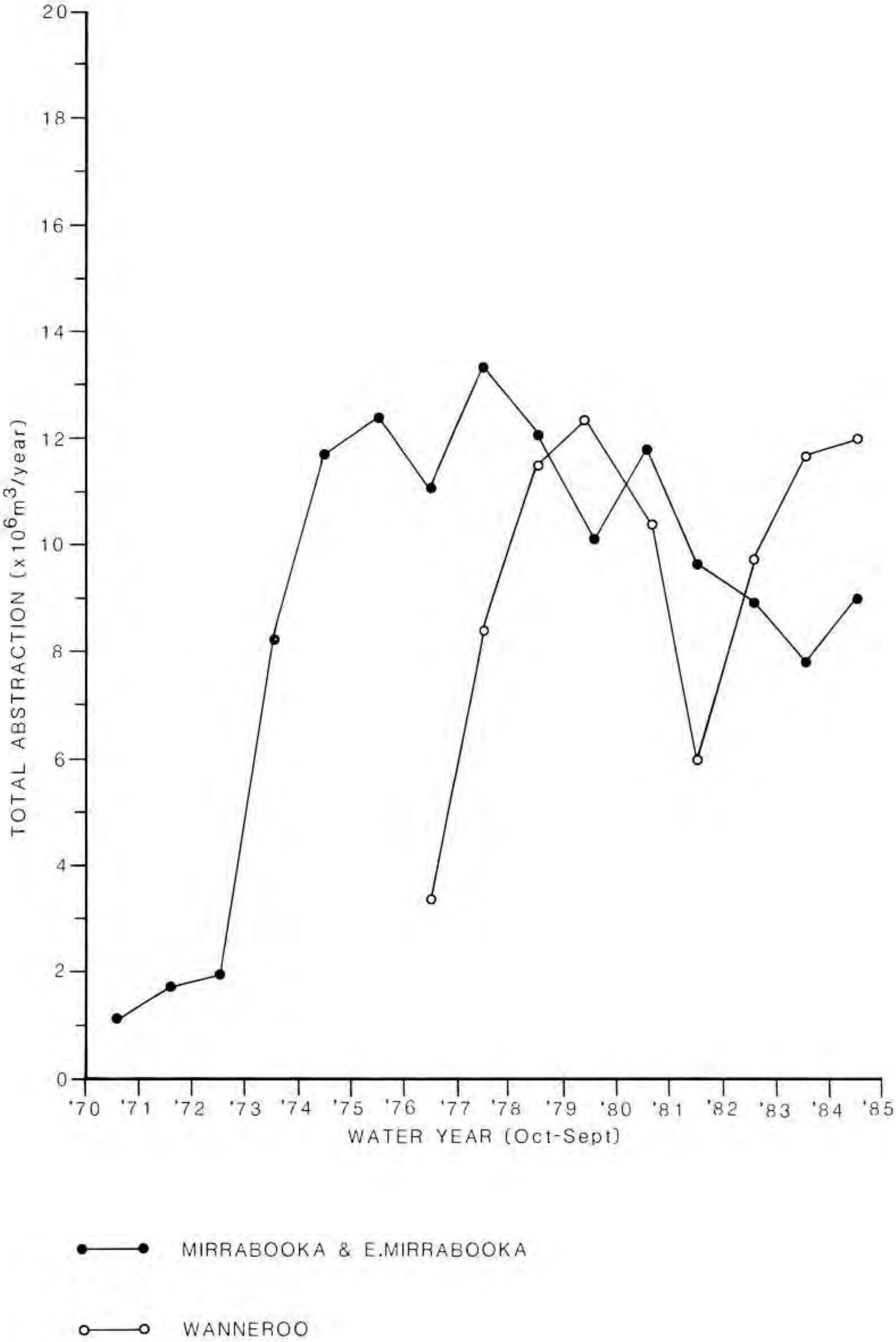
= Sprinklers only 6pm to 7pm from 21/12/78 to 21/5/79

C = Pay for use introduced on 1/7/78

(SOURCE: Australian Water Resources Council, 1986)

ANNUAL CONSUMPTION PER DOMESTIC SERVICE
PERTH METROPOLITAN AREA

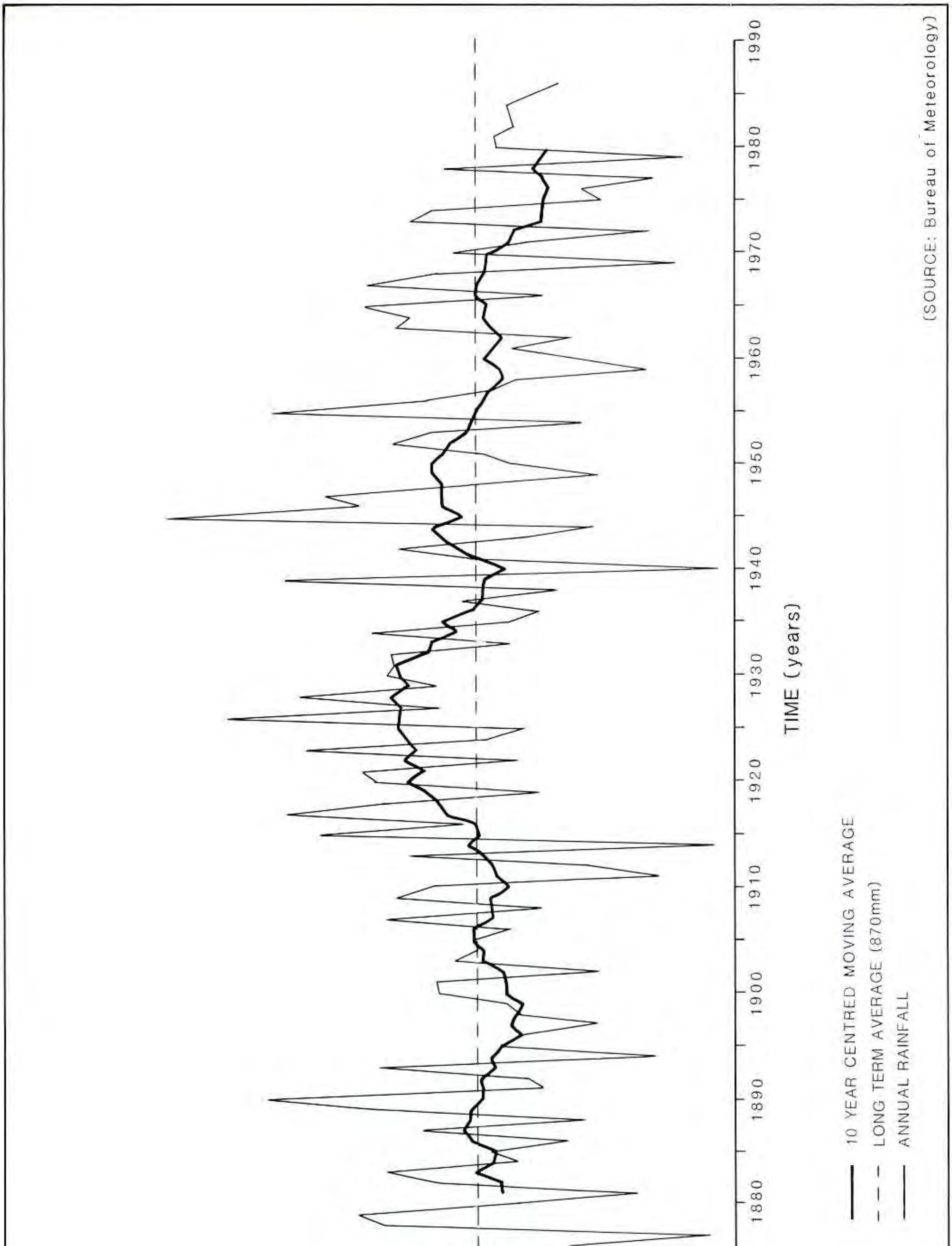
Figure 13
Dames & Moore



(SOURCE: Water Authority)

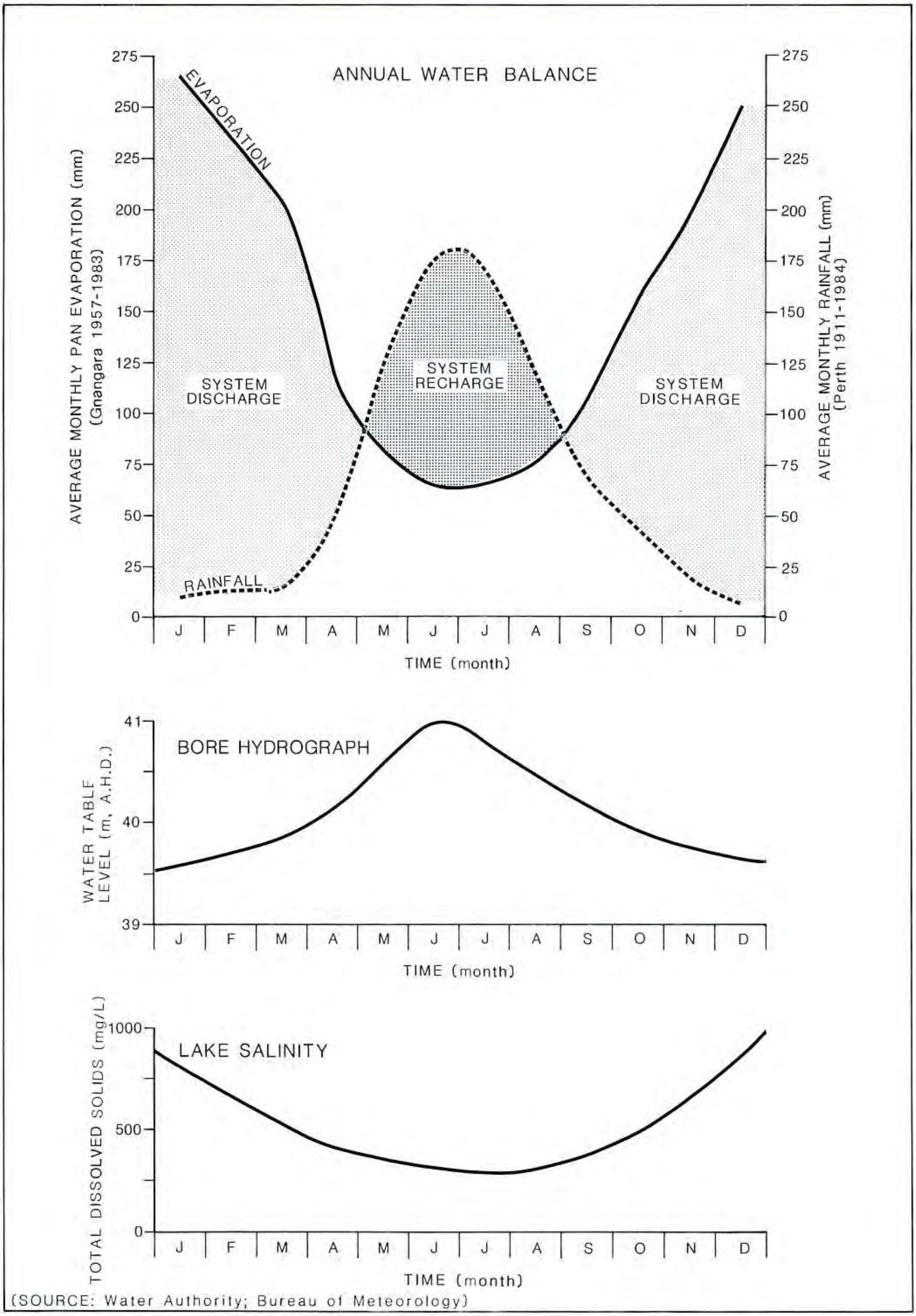
ABSTRACTION OF GROUNDWATER FROM SUPERFICIAL FORMATIONS 1970-1985 FOR MIRRABOOKA AND WANNEROO SCHEMES

Figure 14
Dames & Moore



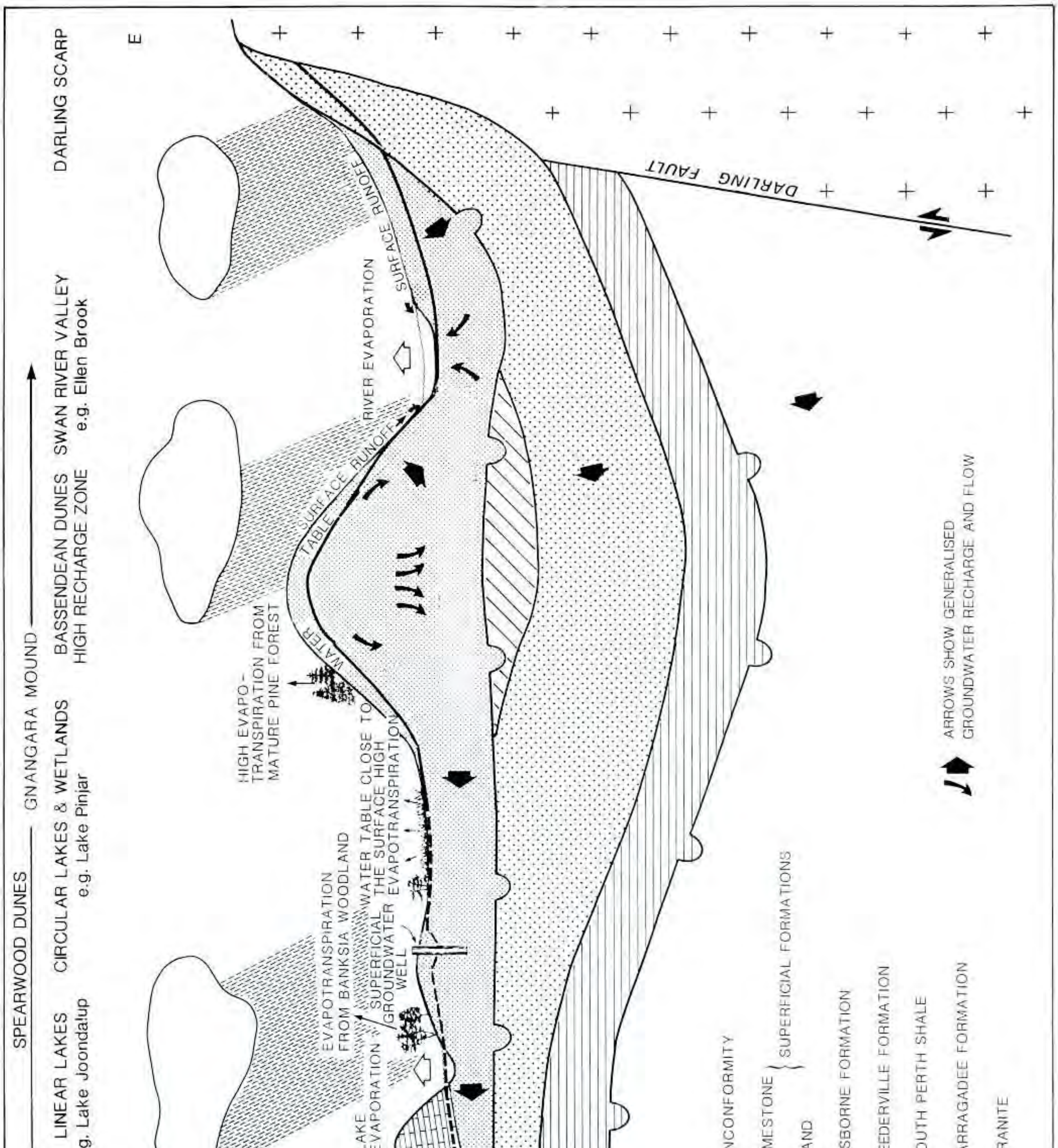
PERTH ANNUAL RAINFALL (mm) 1876 - 1985

Figure 15
Dames & Moore



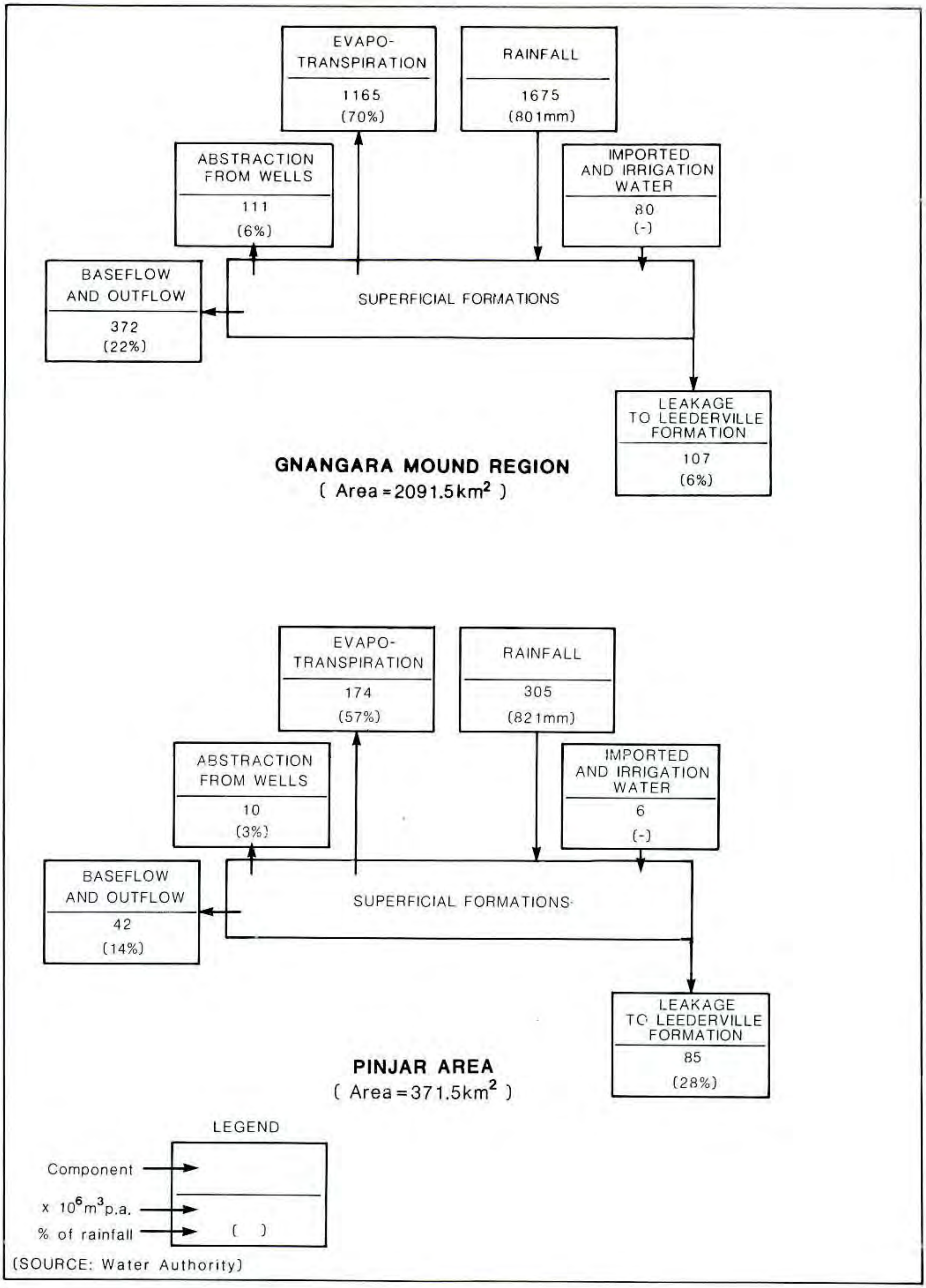
CLIMATIC, WATER TABLE AND LAKE WATER SALINITY VARIATION

Figure 16
Dames & Moore



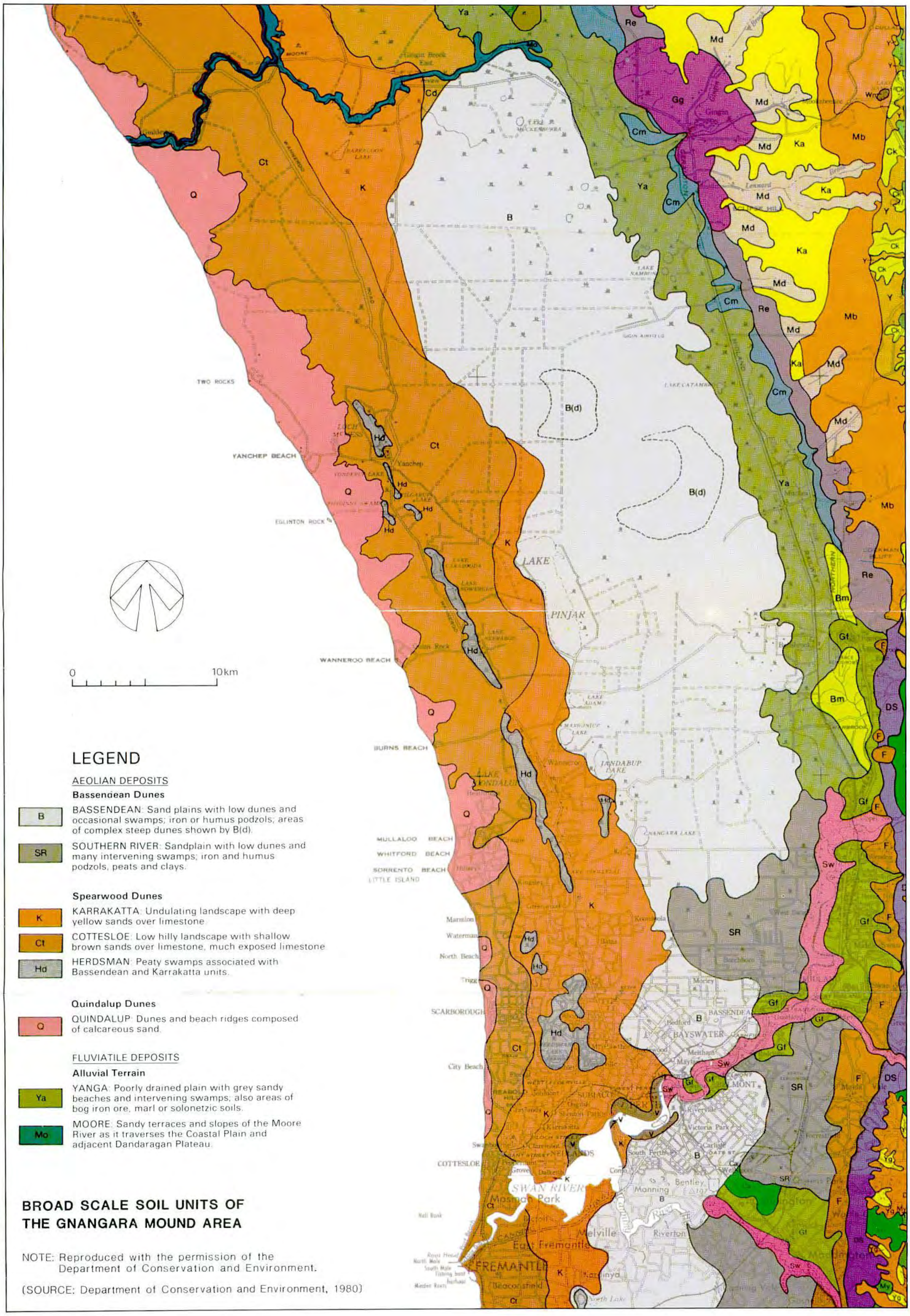
GNANGARA MOUND
SCHEMATIC HYDROGEOLOGICAL CROSS SECTION
(PINJAR AREA)

Figure 17
Dames & Moore



SIMPLIFIED WATER BALANCE FOR THE GNANGARA MOUND AND PINJAR AREAS

Figure 18
Dames & Moore

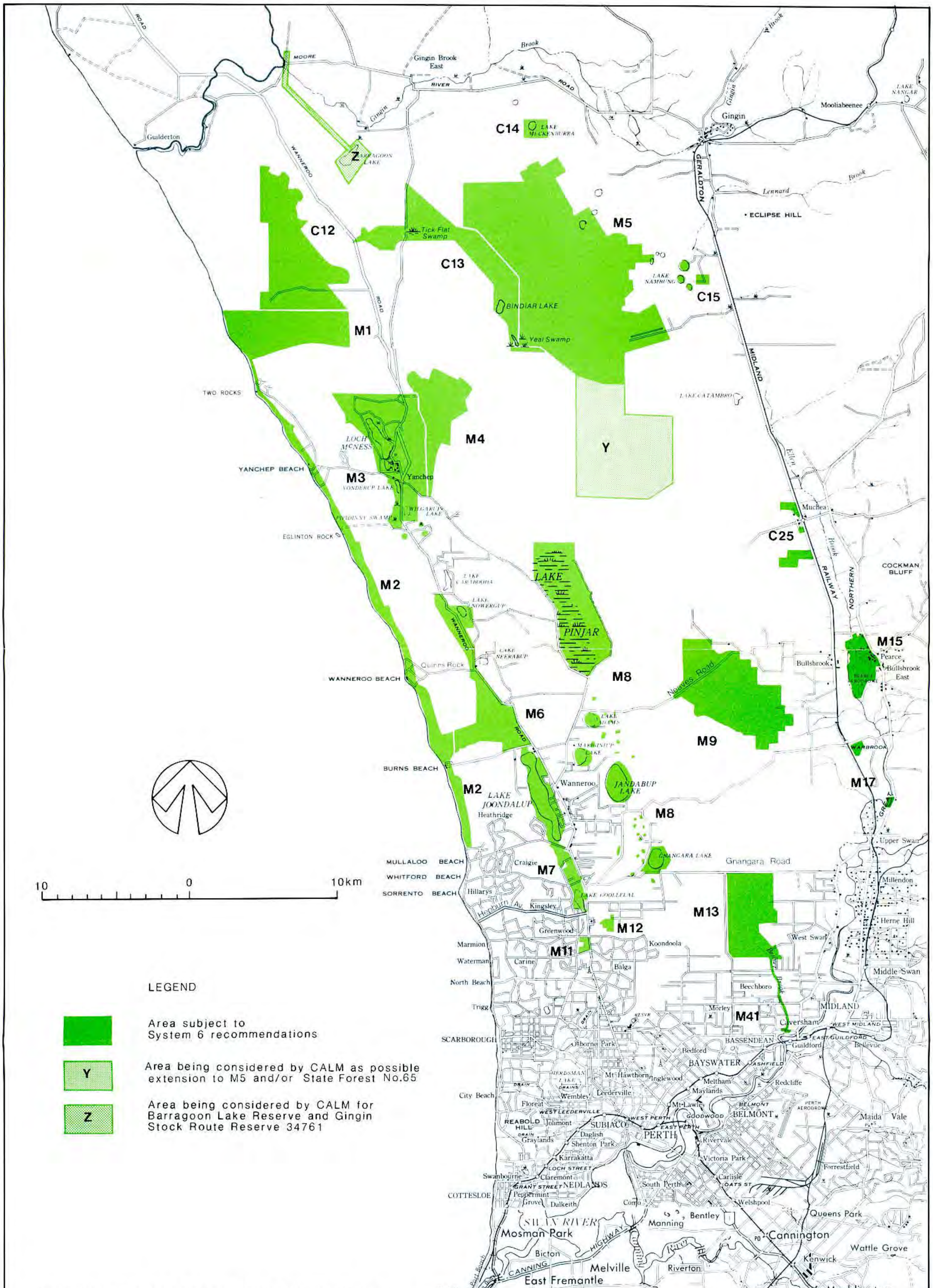


BROAD SCALE SOIL UNITS OF THE GNANGARA MOUND AREA

NOTE: Reproduced with the permission of the Department of Conservation and Environment.

(SOURCE: Department of Conservation and Environment, 1980)

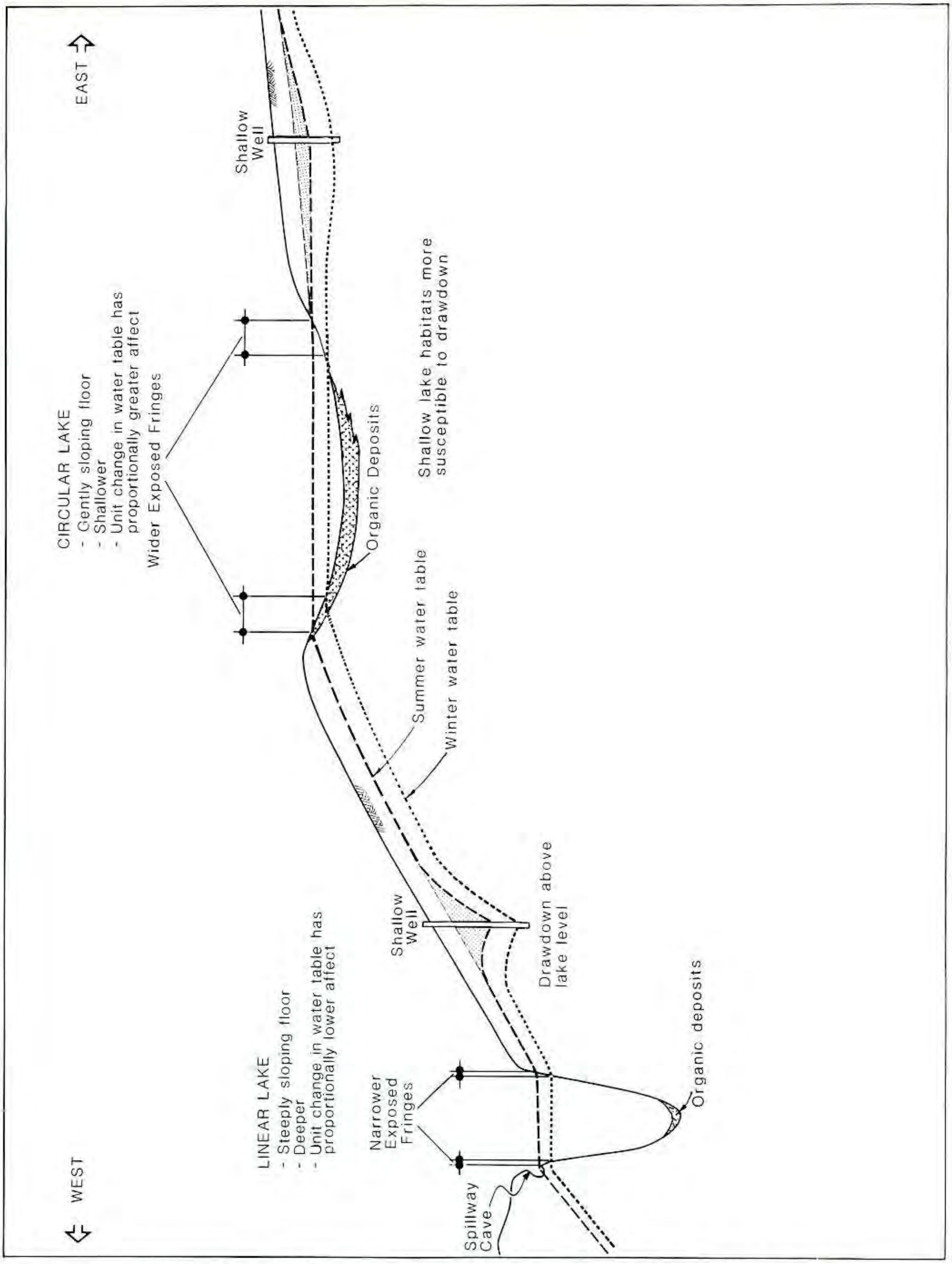
Figure 19
Dames & Moore



EXISTING AND PROPOSED CONSERVATION AREAS

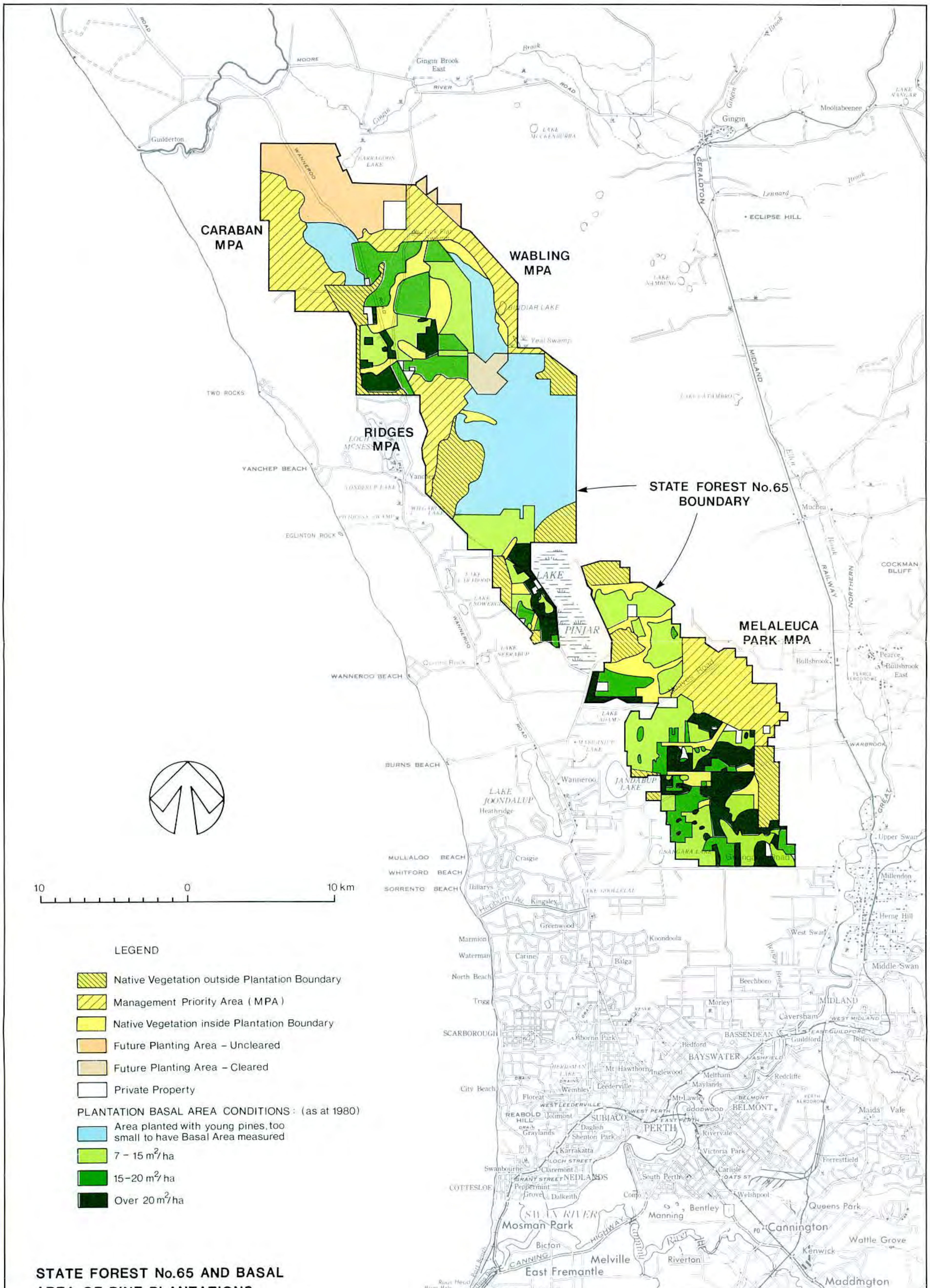
(SOURCE: Department of Conservation and Land Management; Department of Conservation and Environment, 1983)

Figure 20
Dames & Moore



SCHEMATIC EFFECT OF WATER TABLE CHANGES ON LAKES

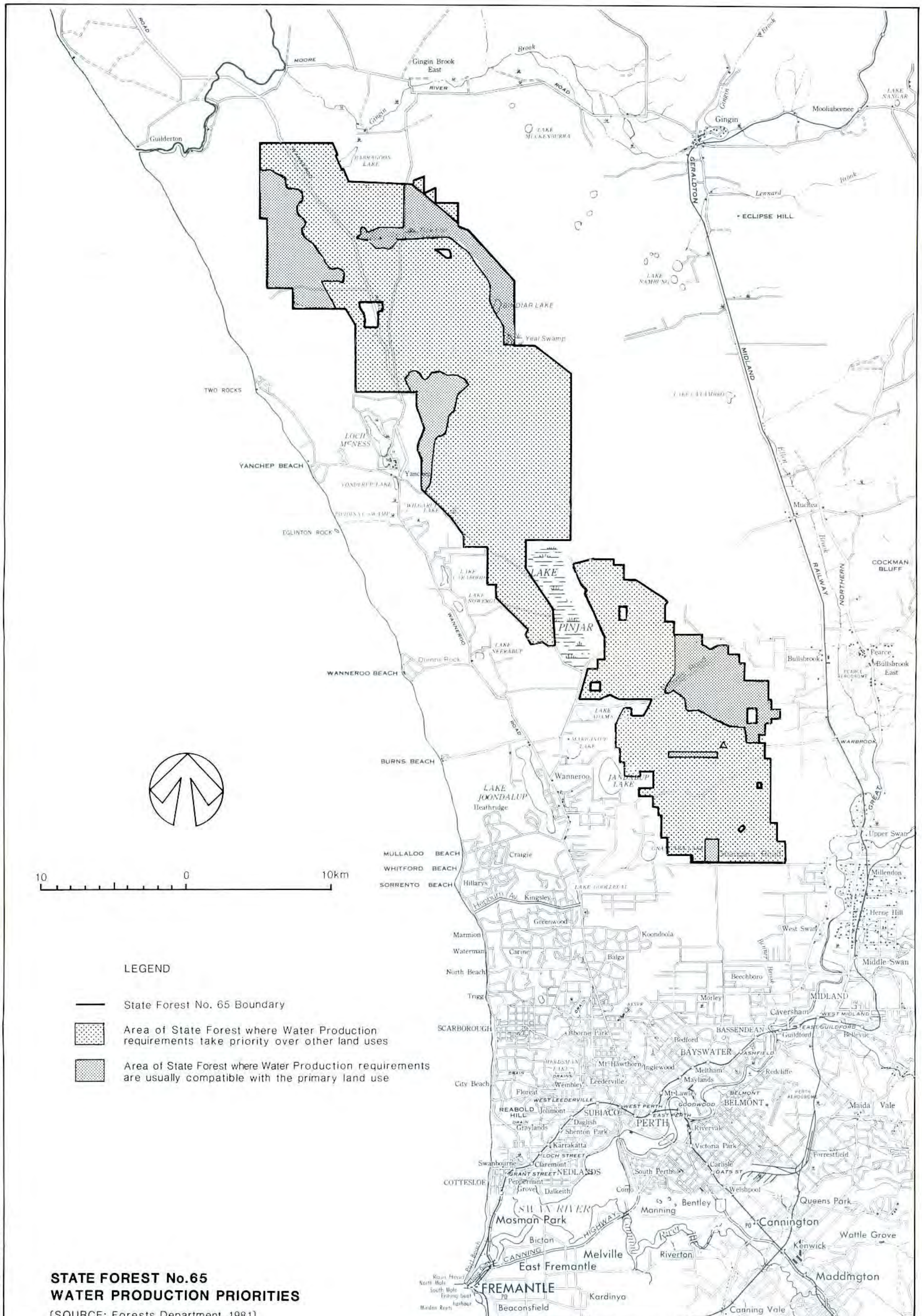
Figure 21
Dames & Moore



STATE FOREST No.65 AND BASAL AREA OF PINE PLANTATIONS

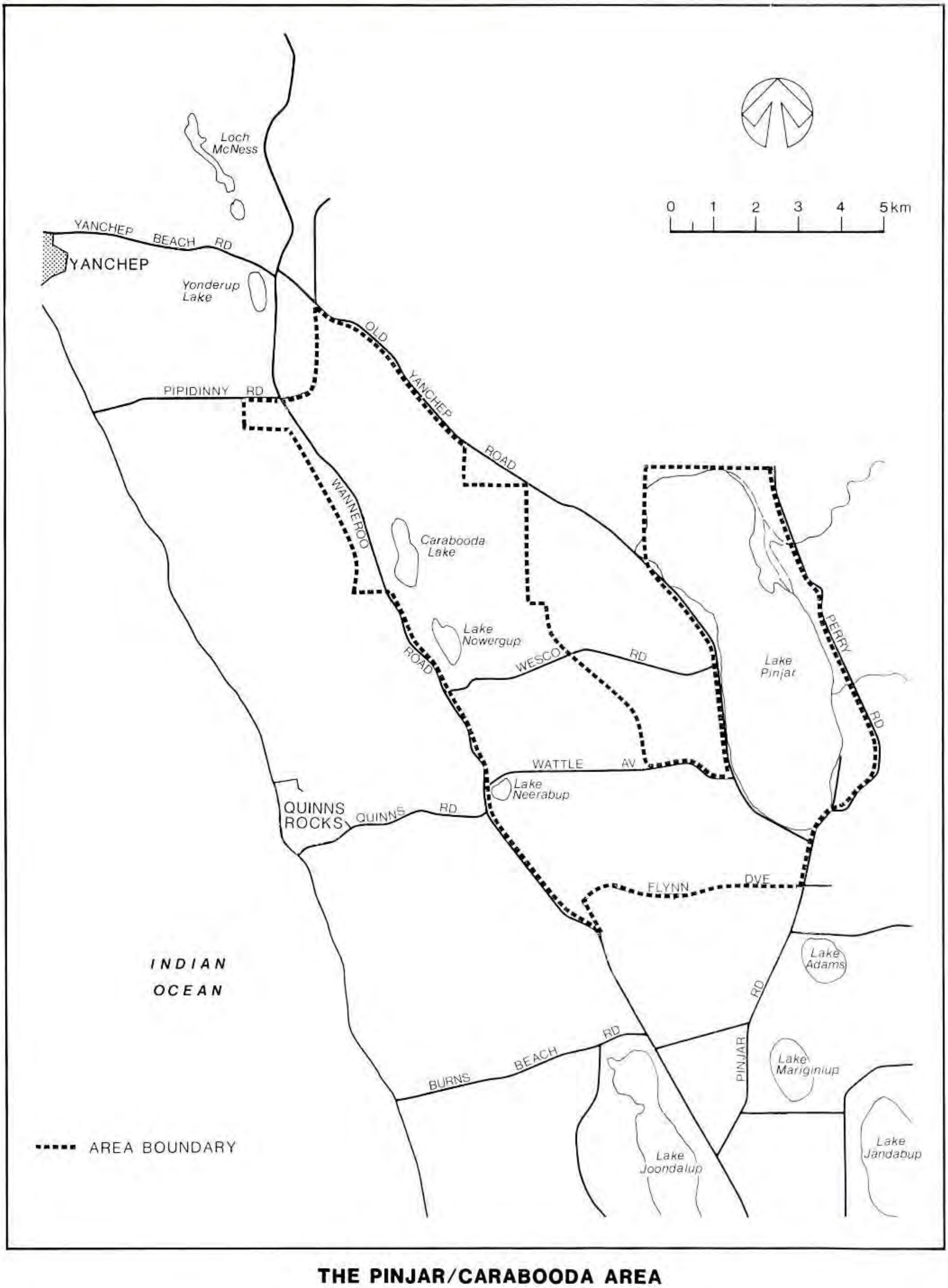
(SOURCE: Department of Conservation and Land Management)

Figure 22
Dames & Moore



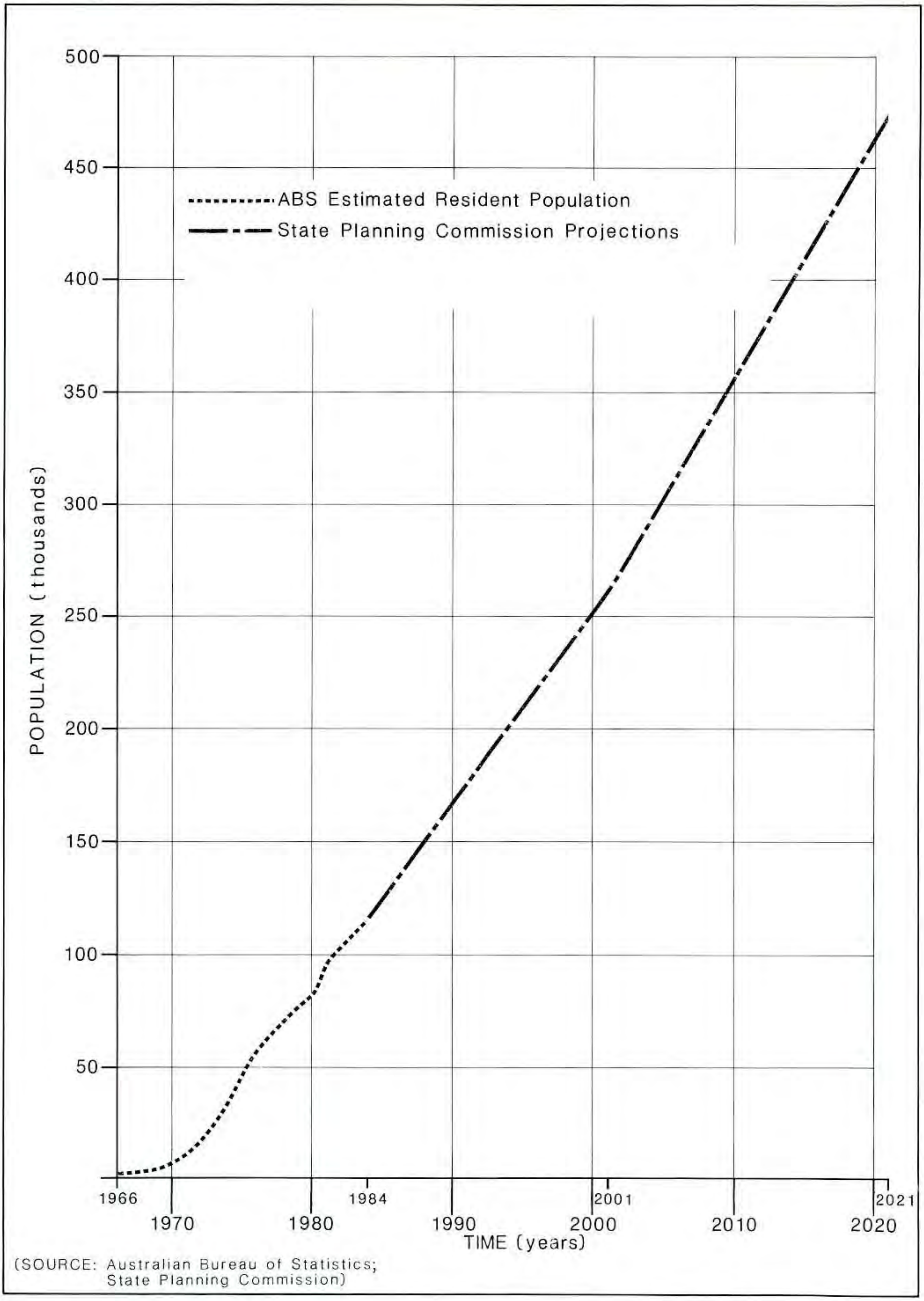
STATE FOREST No.65
WATER PRODUCTION PRIORITIES
(SOURCE: Forests Department, 1981)

Figure 23
Dames & Moore



THE PINJAR/CARABOODA AREA

Figure 24
Dames & Moore

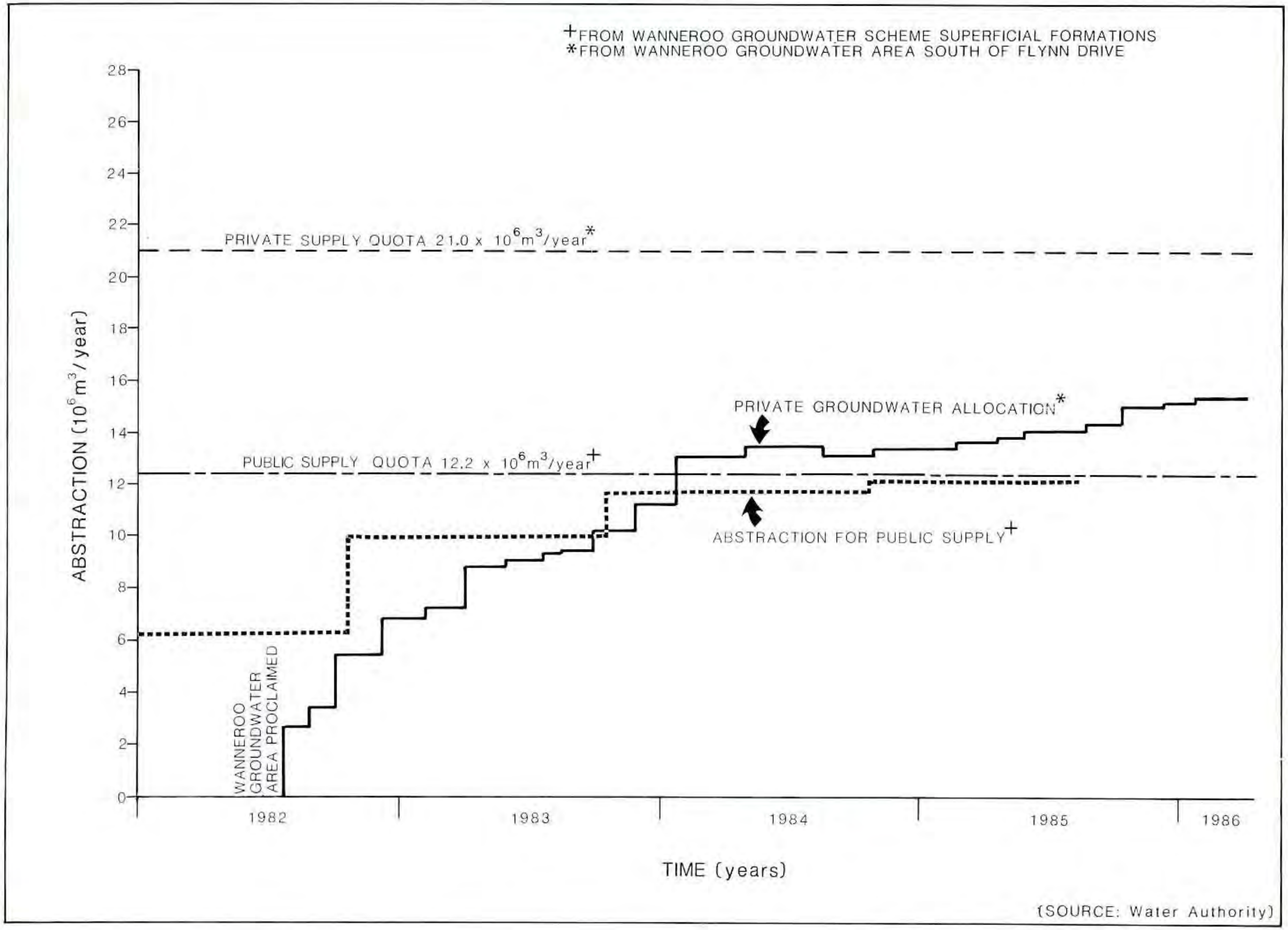


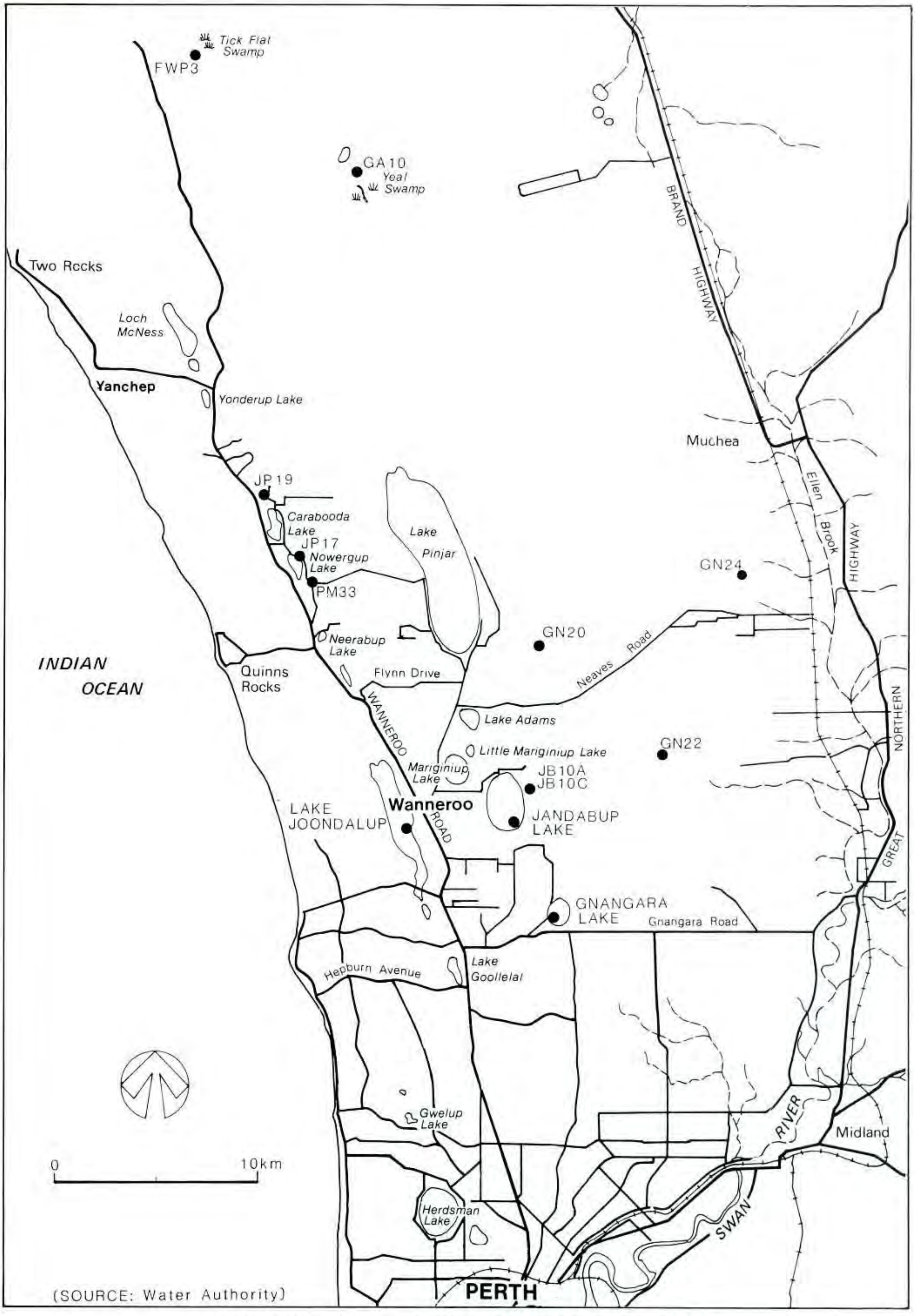
CITY OF WANNEROO POPULATION TRENDS

Figure 25
Dames & Moore

Figure 26
Dames & Moore

ALLOCATIONS FOR PUBLIC AND PRIVATE SUPPLY FROM SUPERFICIAL FORMATIONS





LOCATION OF SELECTED MONITORING BORES

Figure 27
Dames & Moore

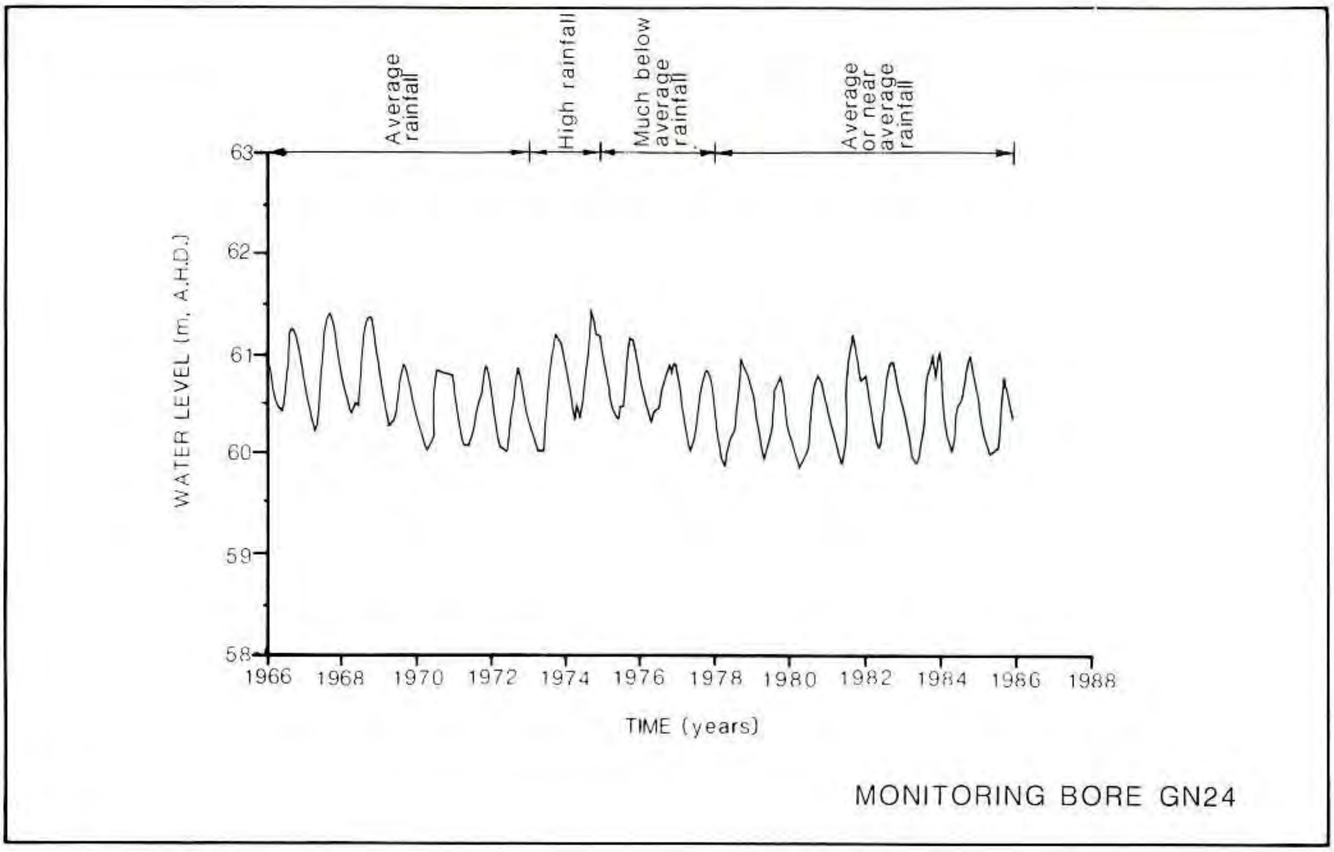


Figure 28 – WATER LEVEL TRENDS DUE TO CLIMATE WITH UNCHANGED LAND USE

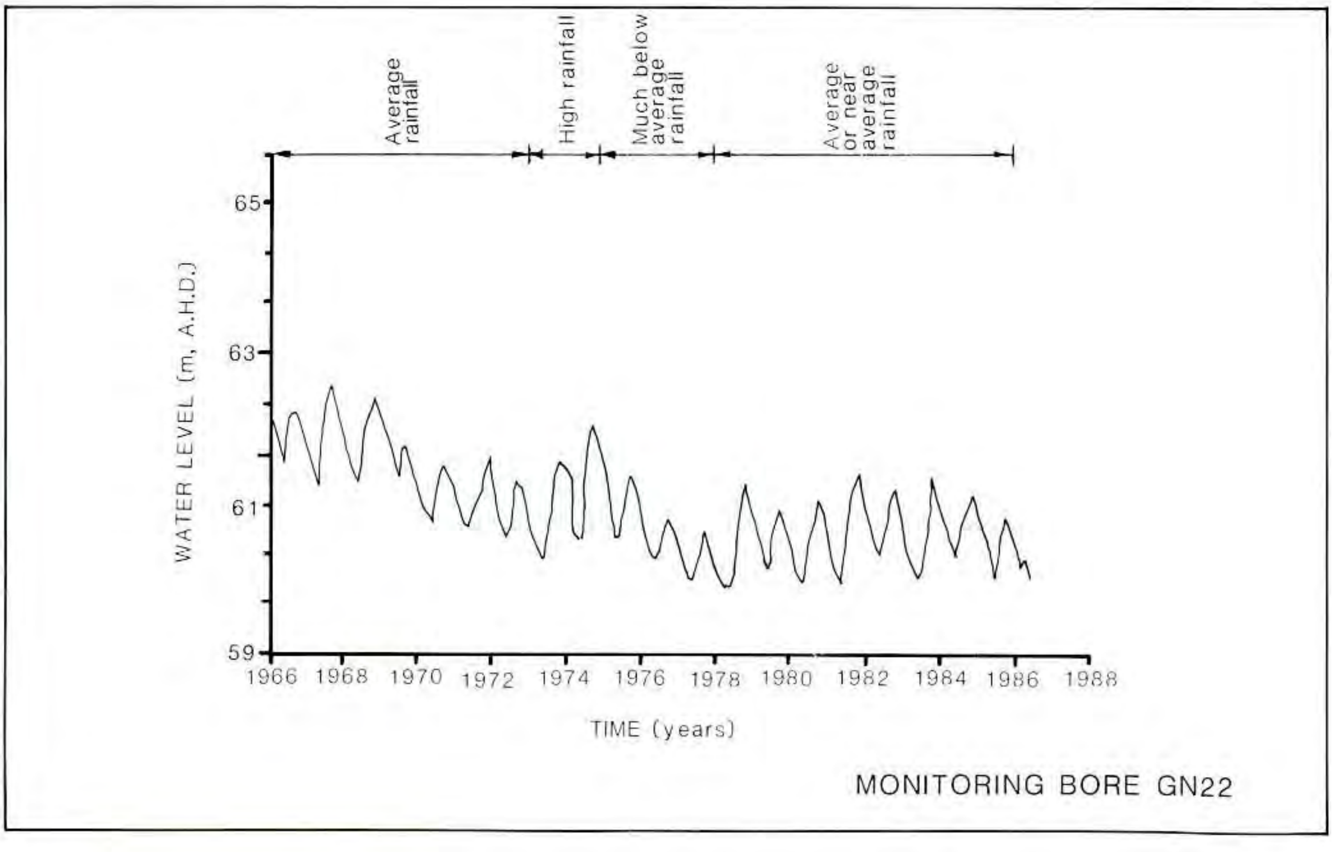
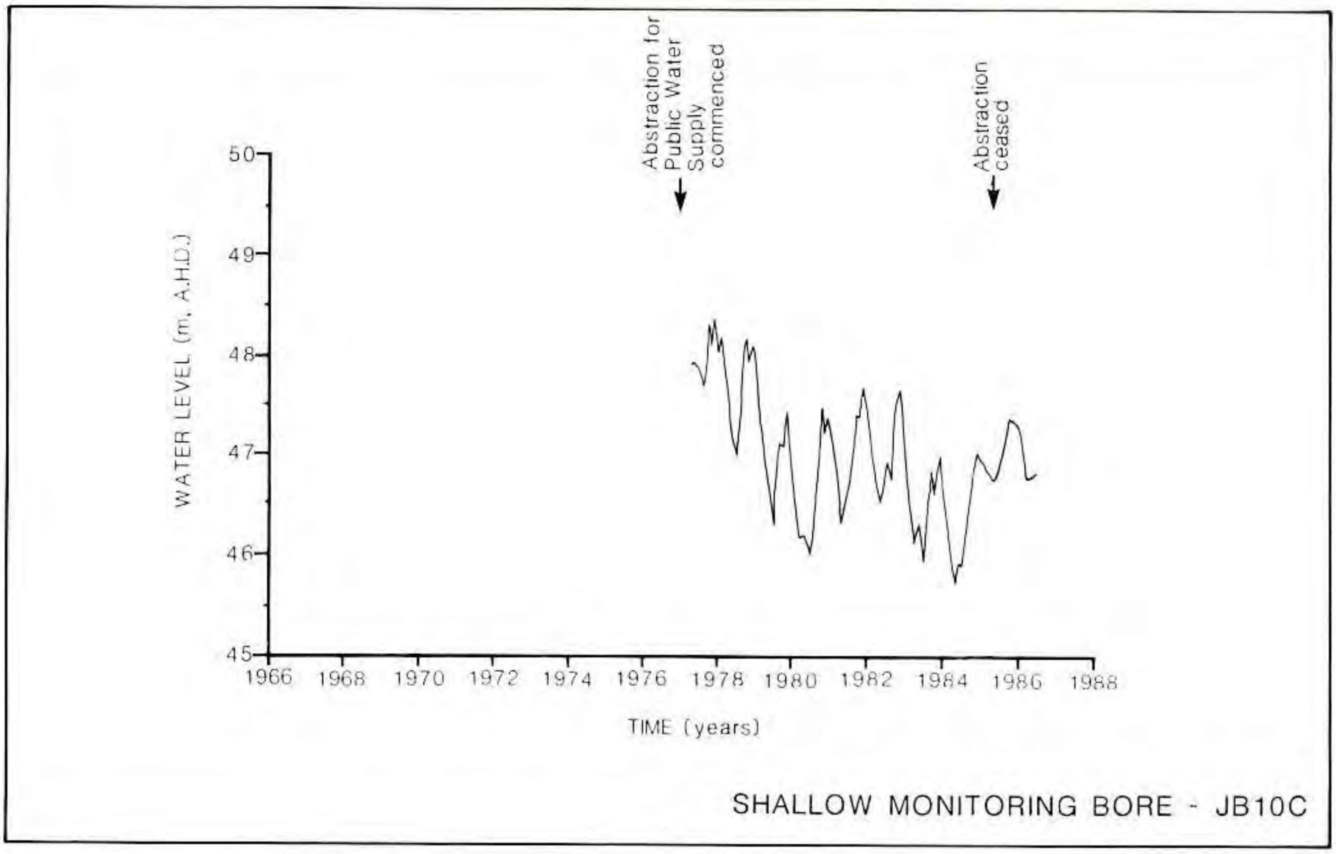
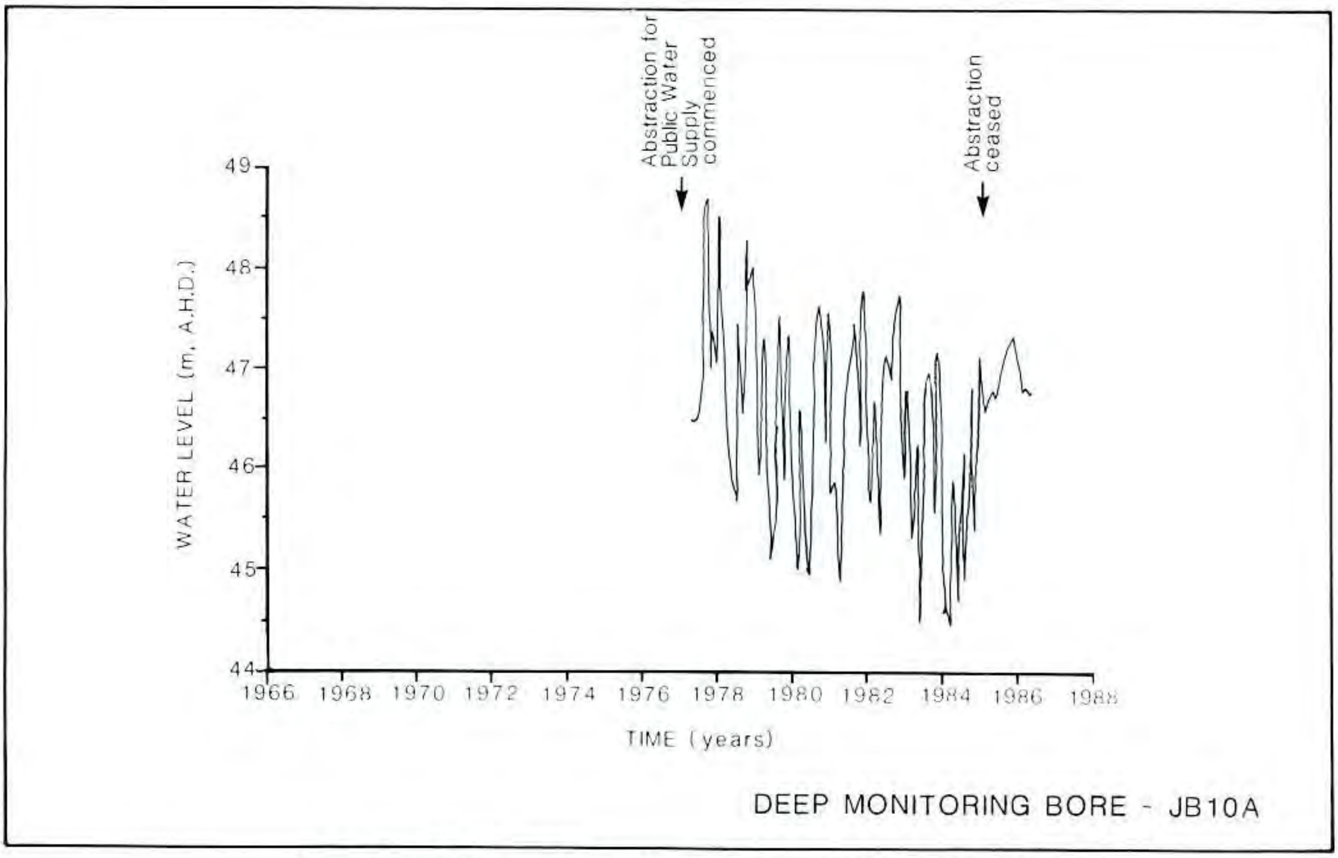


Figure 29 – WATER LEVEL TRENDS DUE TO CLIMATE WITH UNCHANGED LAND USE

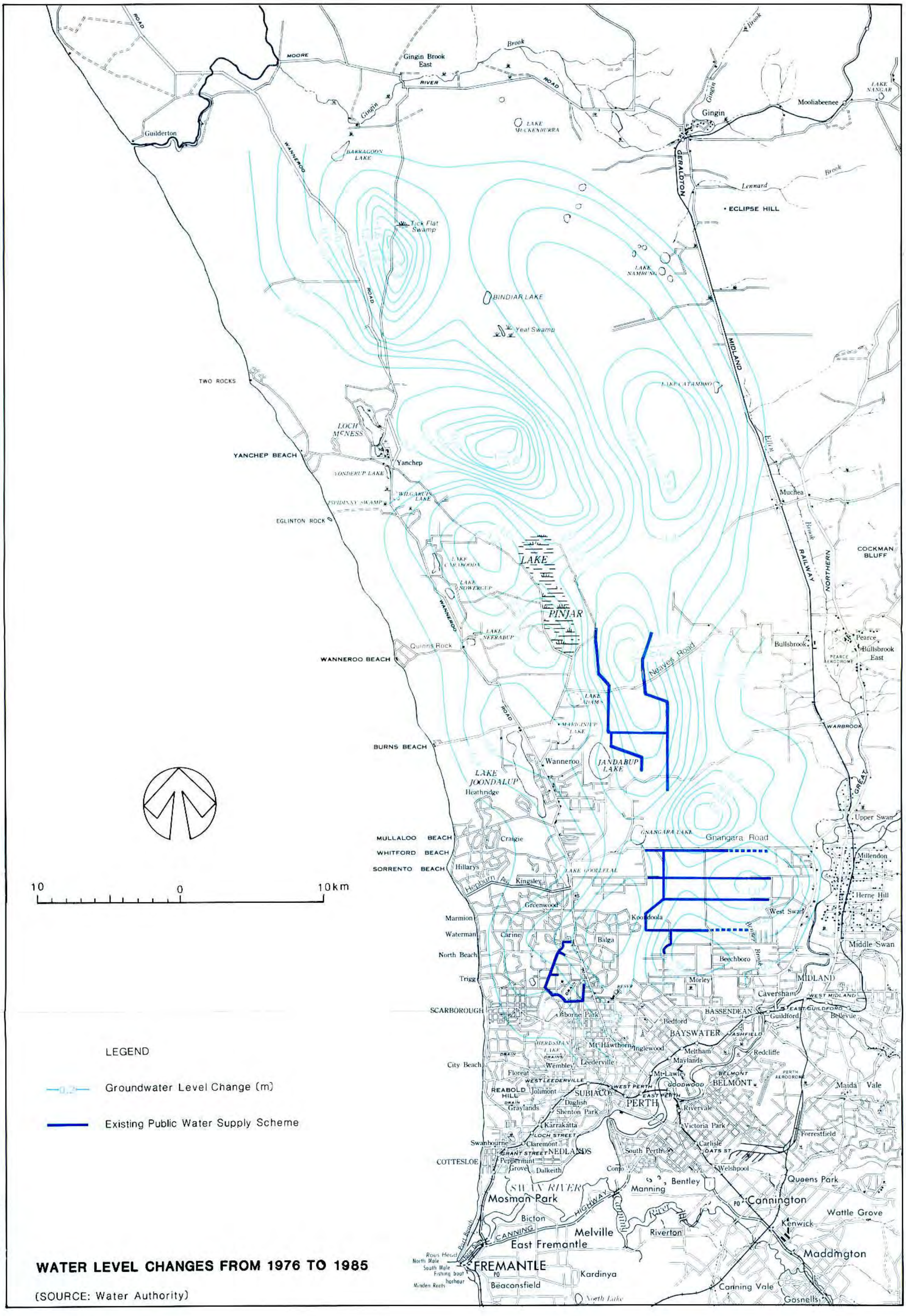




WATER LEVEL TRENDS DUE TO ABSTRACTION (DUAL MONITORING BORE LOCATED 600m FROM WATER AUTHORITY PRODUCTION WELL)

(SOURCE: Water Authority)

Figure 30
Dames & Moore



WATER LEVEL CHANGES FROM 1976 TO 1985

(SOURCE: Water Authority)

Figure 31
Dames & Moore

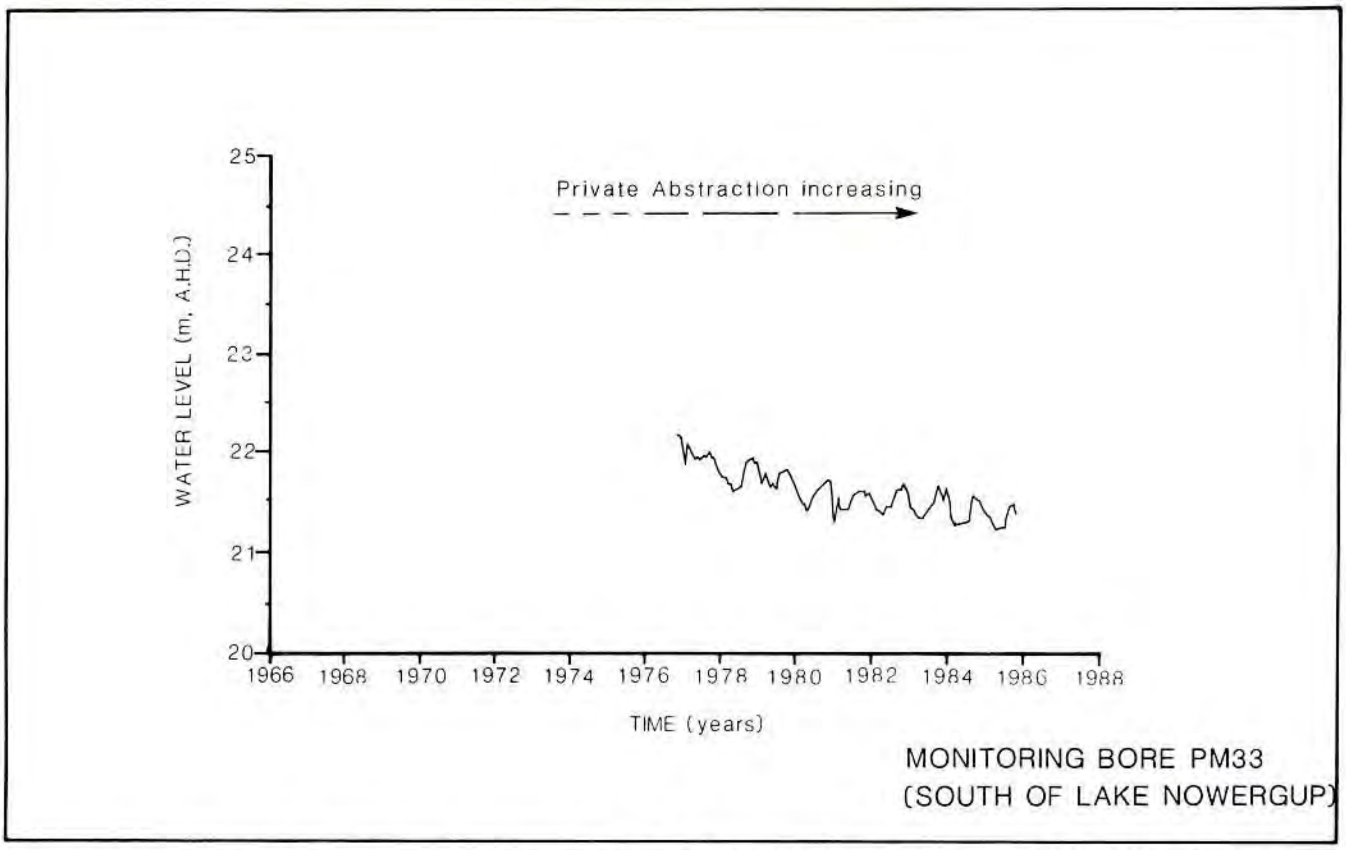


Figure 32 – WATER LEVEL TRENDS DUE TO PRIVATE ABSTRACTION AND CLIMATE

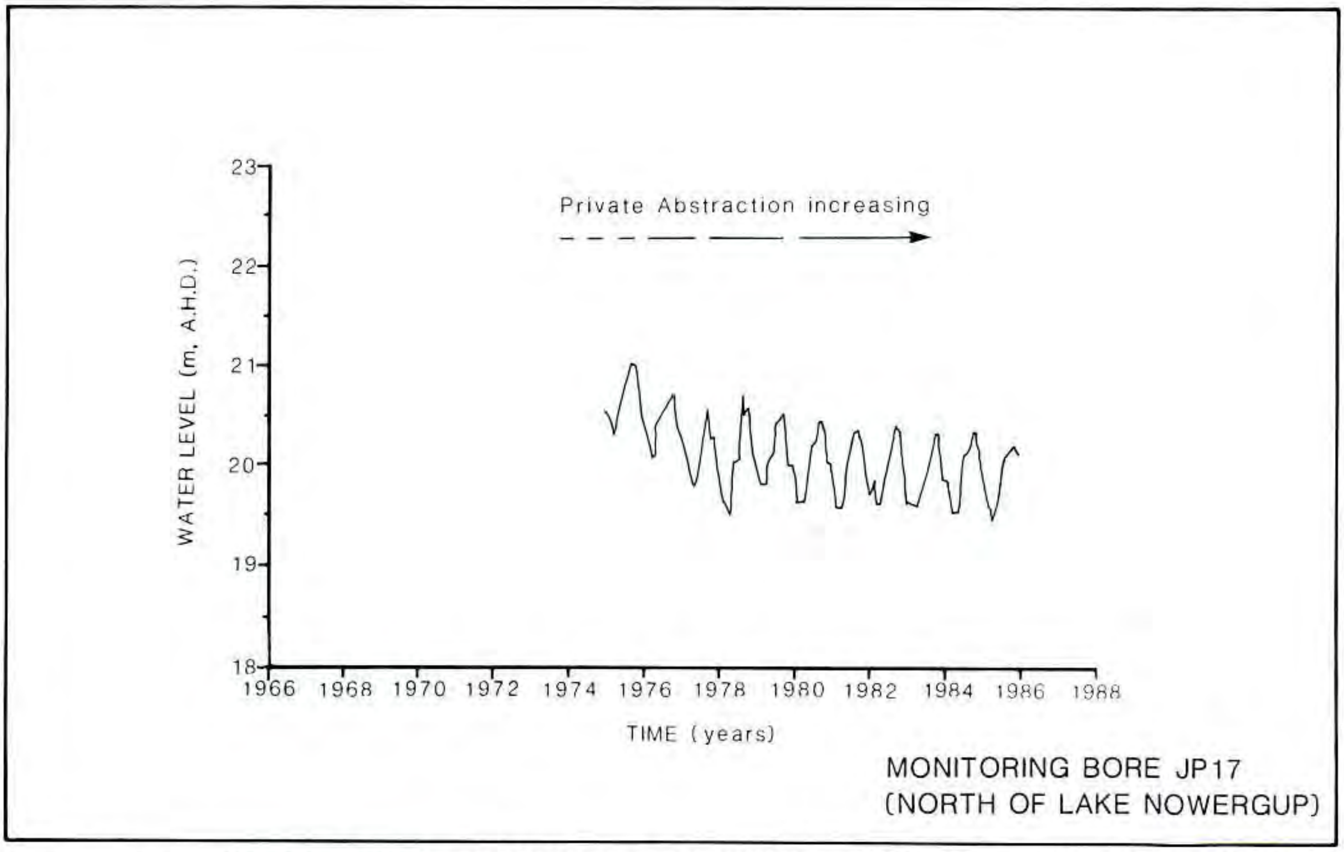


Figure 33 – WATER LEVEL TRENDS DUE TO PRIVATE ABSTRACTION AND CLIMATE

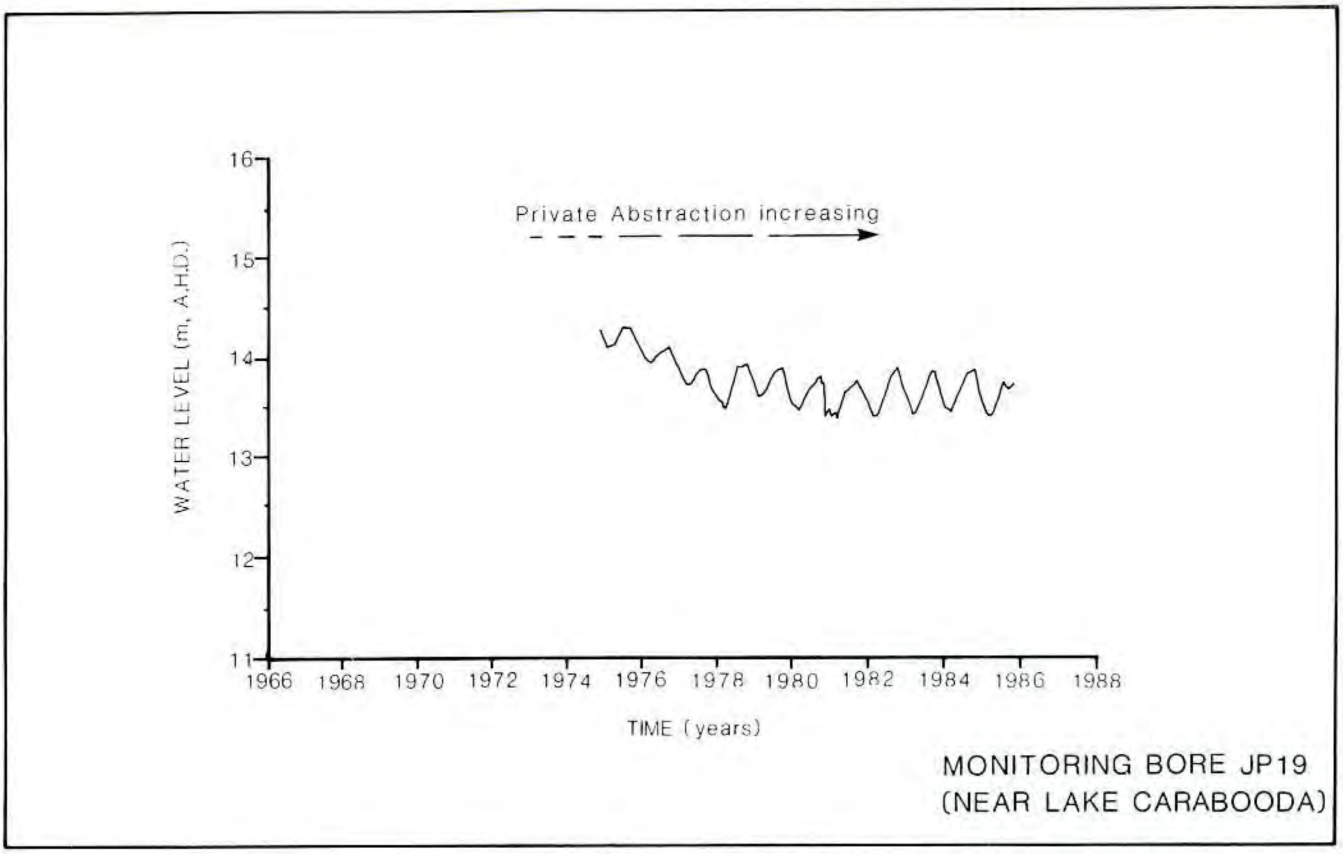


Figure 34 - WATER LEVEL TRENDS DUE TO CLIMATE WITH NO SIGNIFICANT EFFECT OF PRIVATE ABSTRACTION

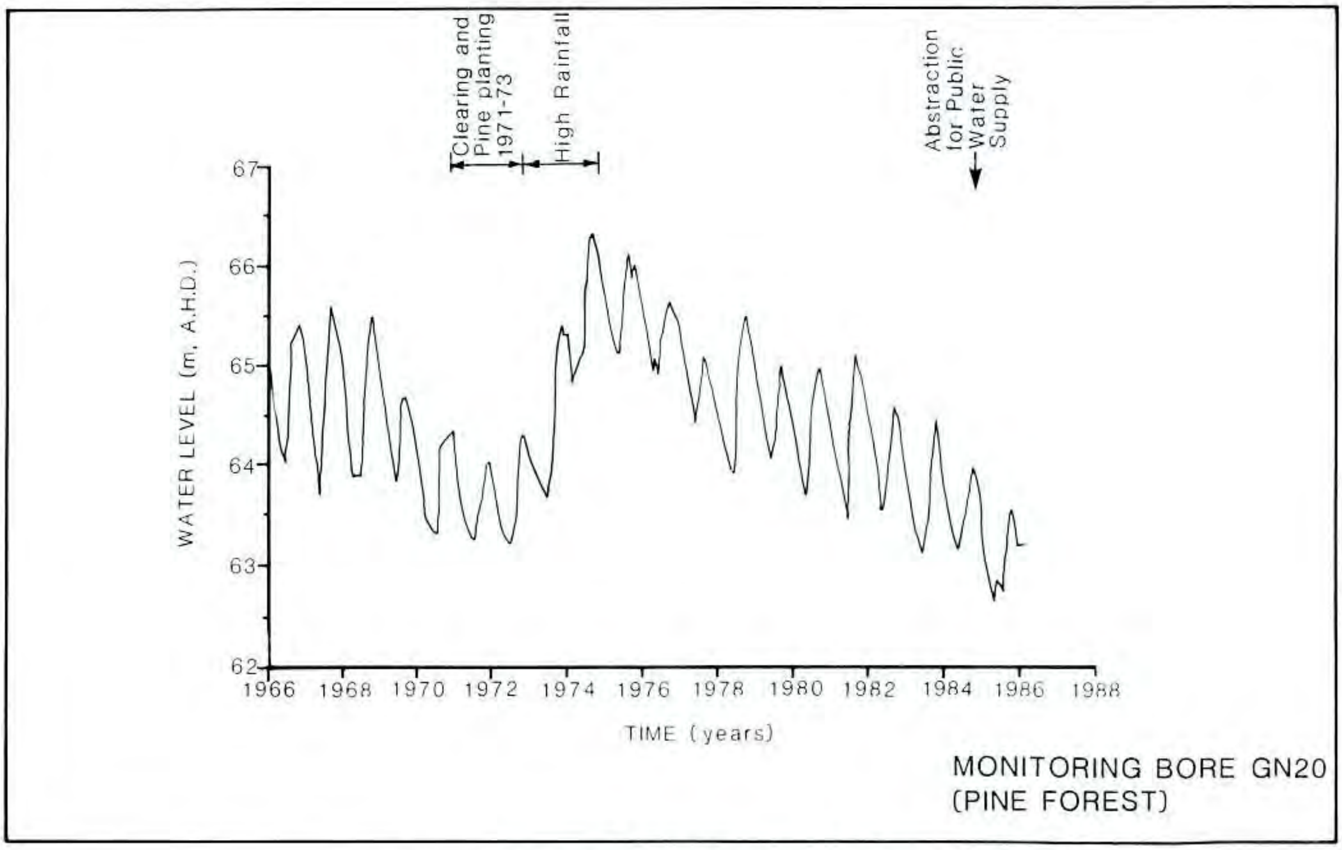


Figure 35 - WATER LEVEL TRENDS DUE TO CLEARING, REFORESTATION AND CLIMATE

(SOURCE: Water Authority)

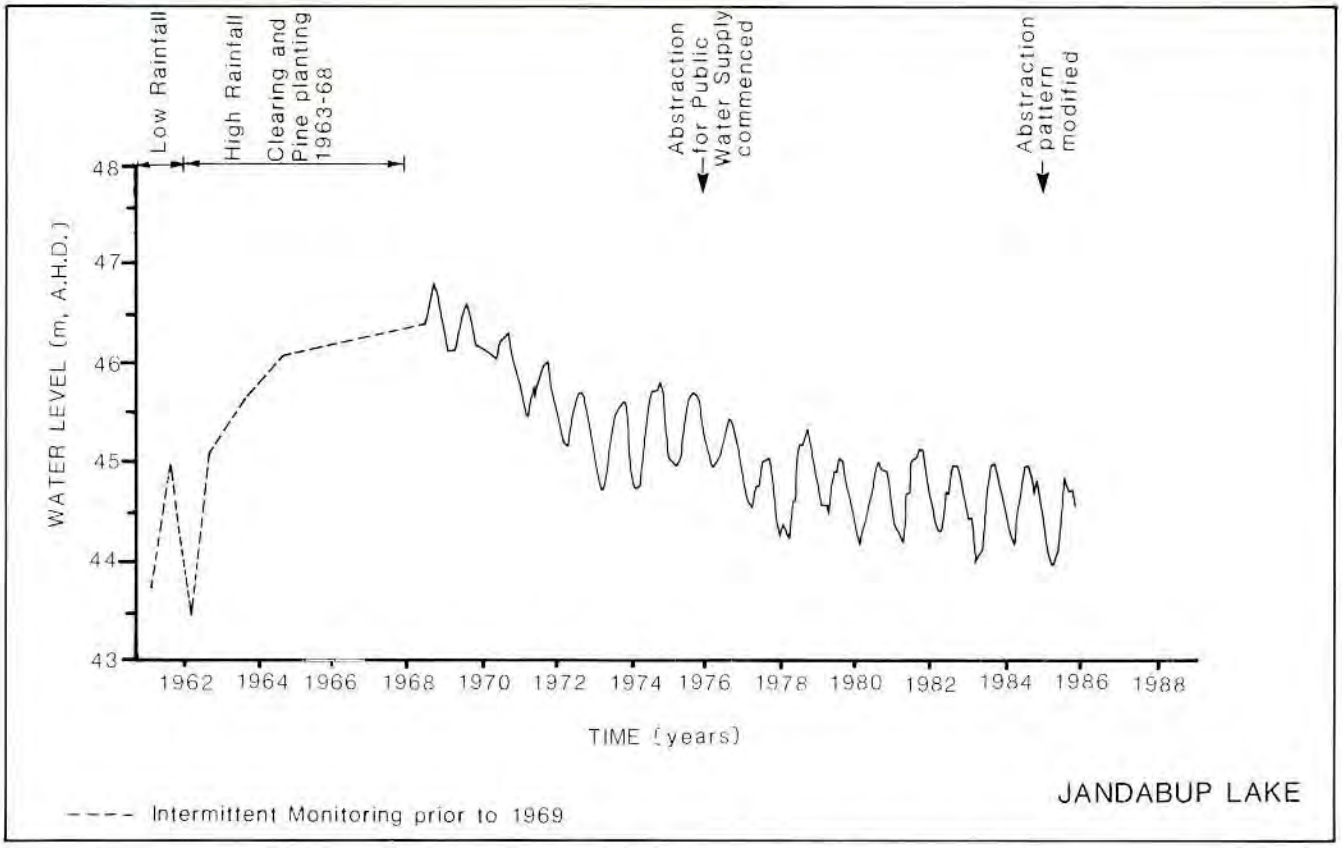


Figure 36 – WATER LEVEL TRENDS DUE TO CLEARING, REFORESTATION, GROUNDWATER ABSTRACTION AND CLIMATE

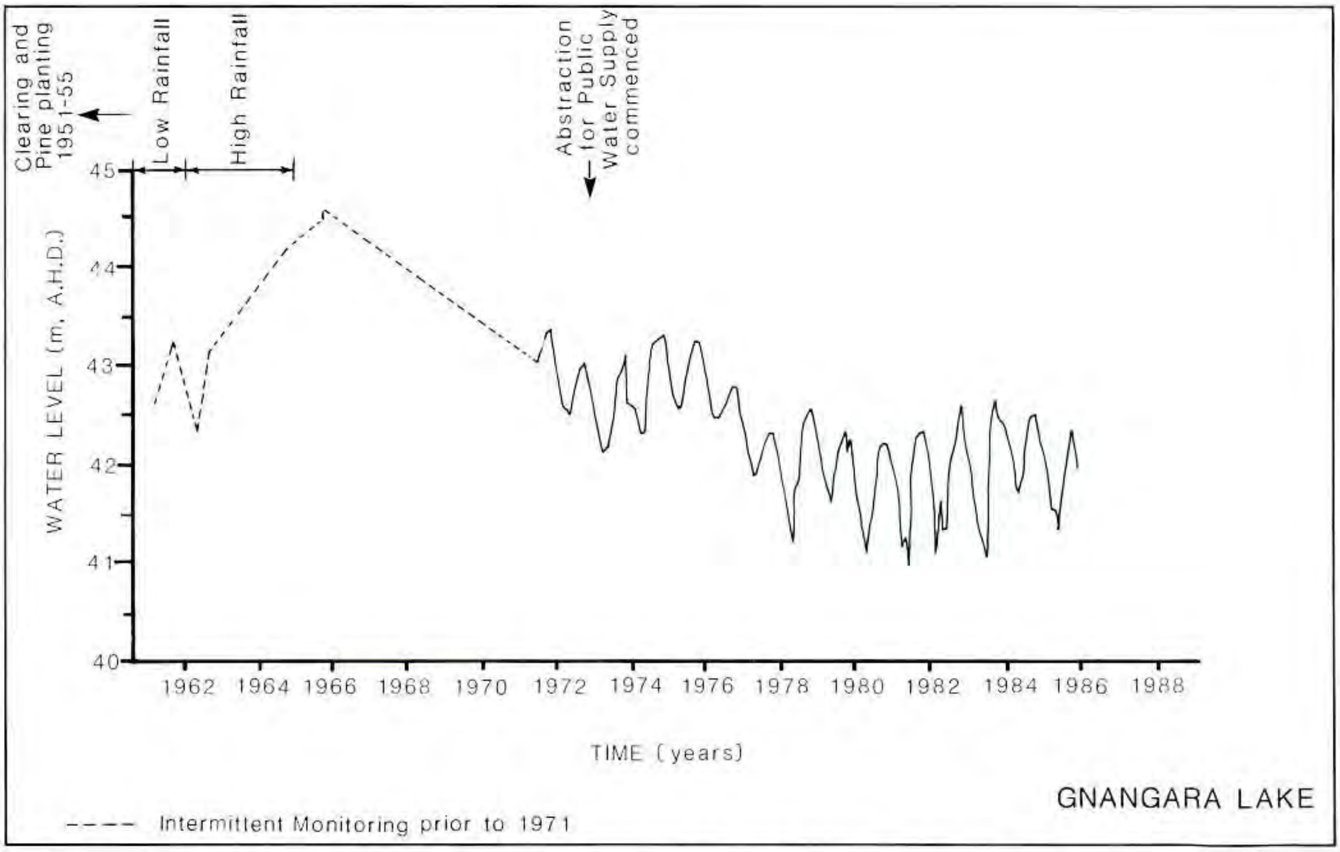


Figure 37 – WATER LEVEL TRENDS DUE TO CLEARING, REFORESTATION, GROUNDWATER ABSTRACTION AND CLIMATE

(SOURCE: Water Authority)

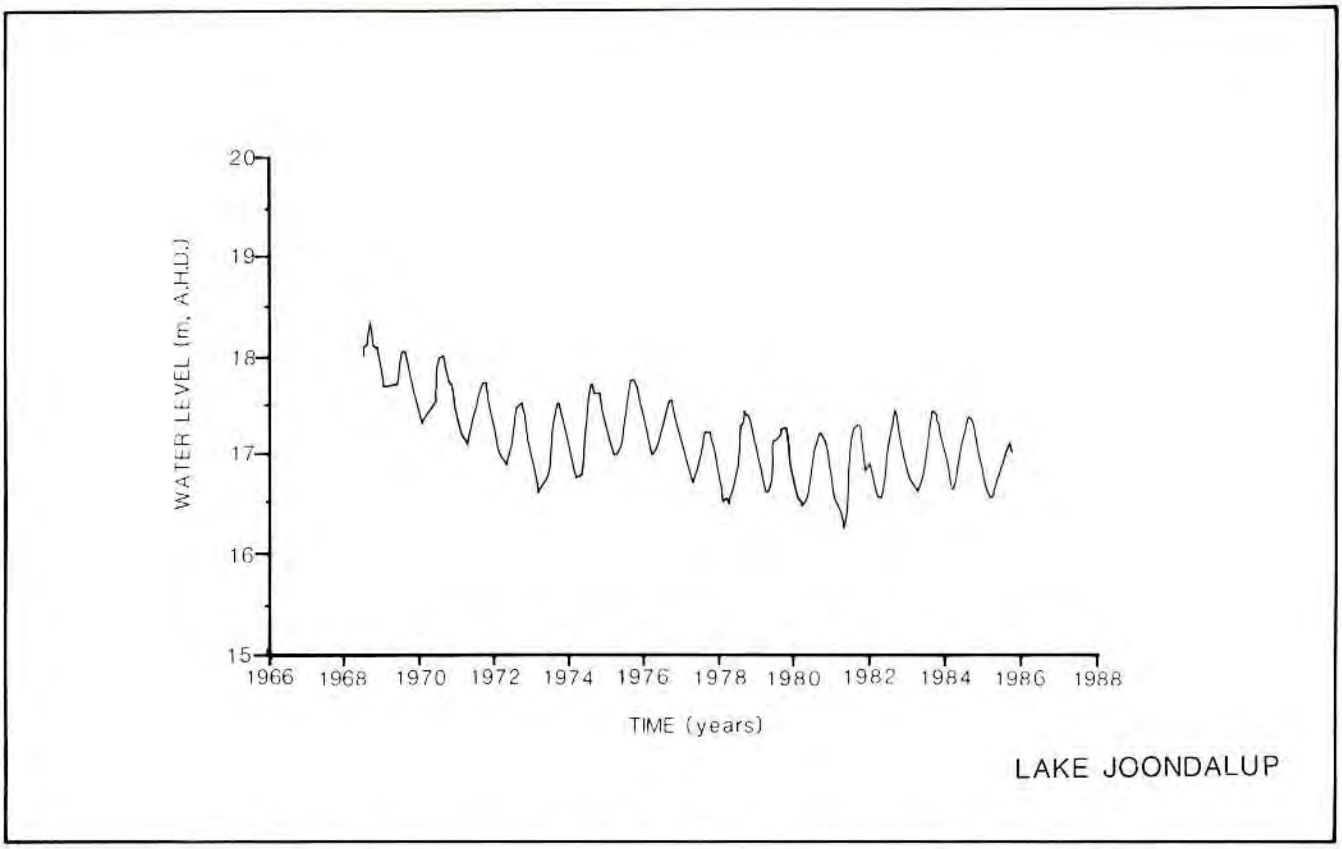


Figure 38 – WATER LEVEL TRENDS IN LAKE JOONDALUP

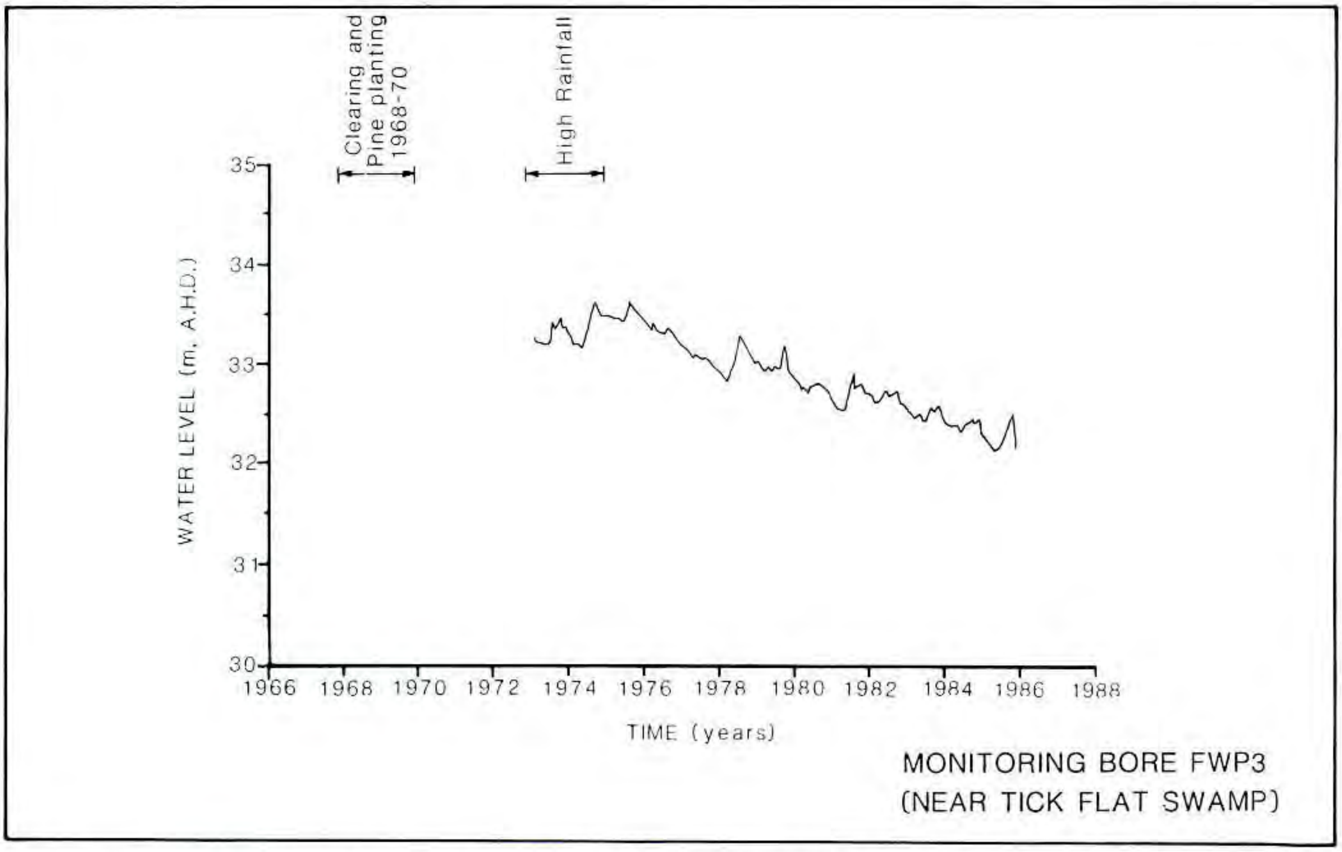
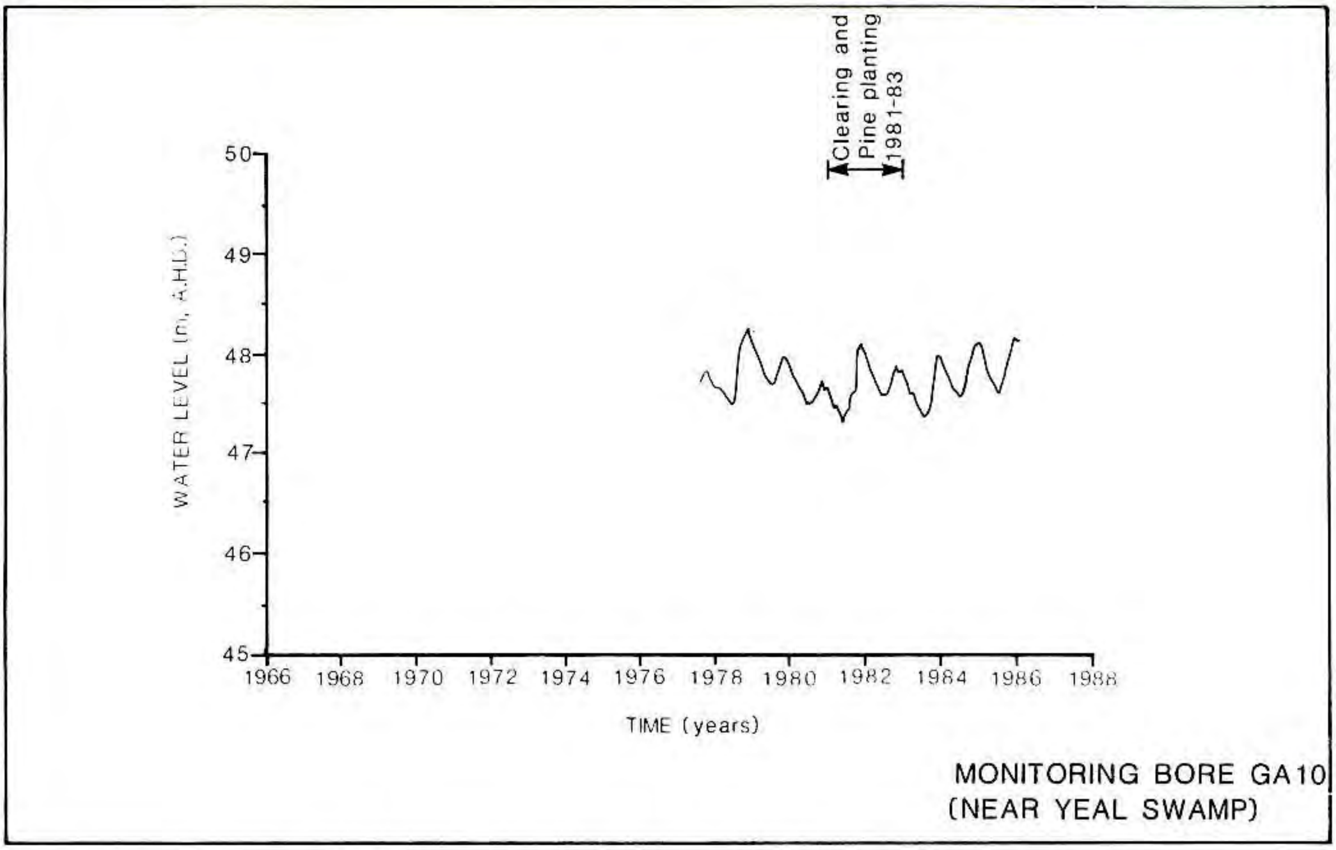


Figure 39 – WATER LEVEL TRENDS DUE TO REFORESTATION AND CLIMATE

(SOURCE: Water Authority)

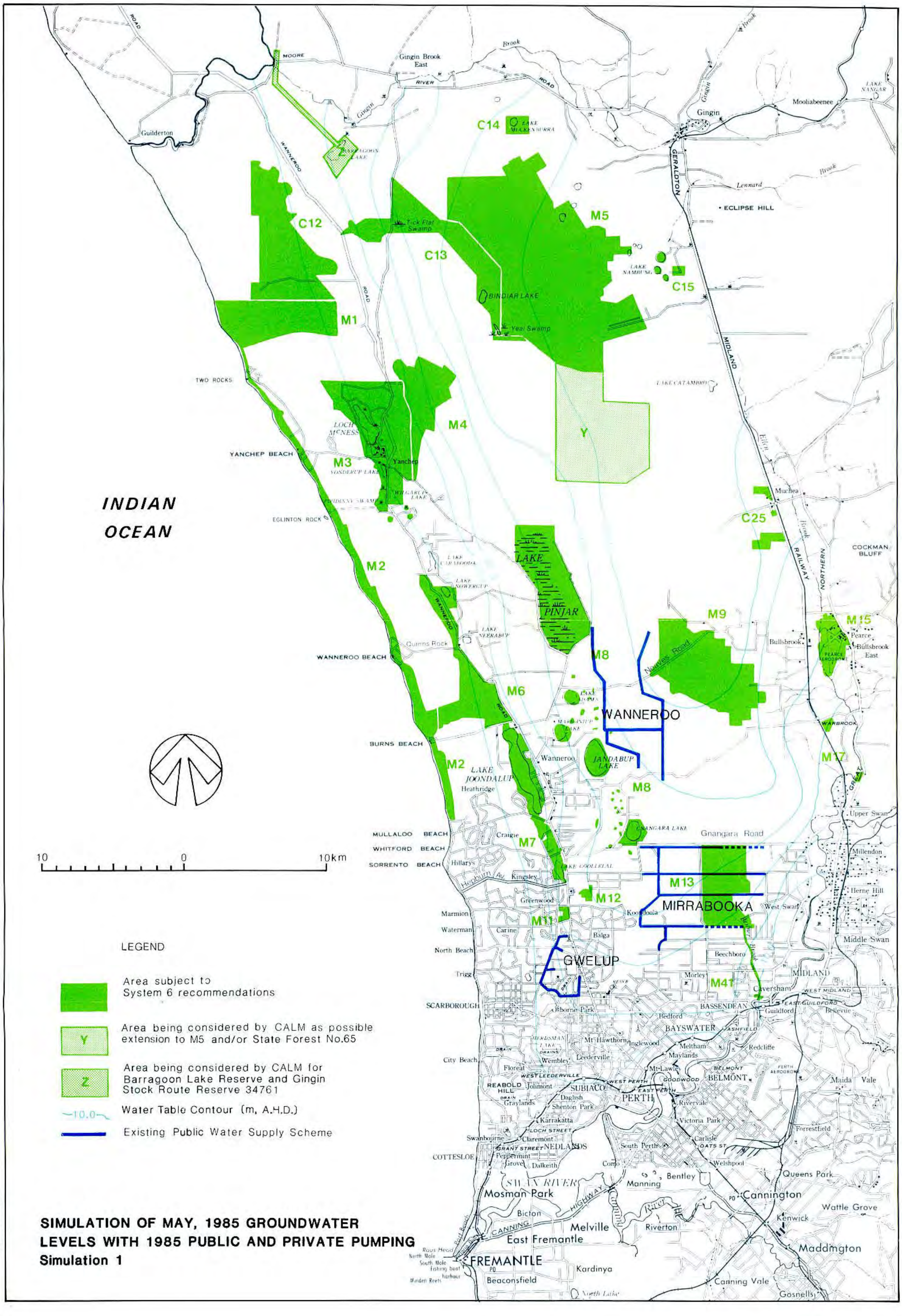


WATER LEVEL TRENDS DUE TO CLEARING AND CLIMATE

(SOURCE: Water Authority)

Figure 40

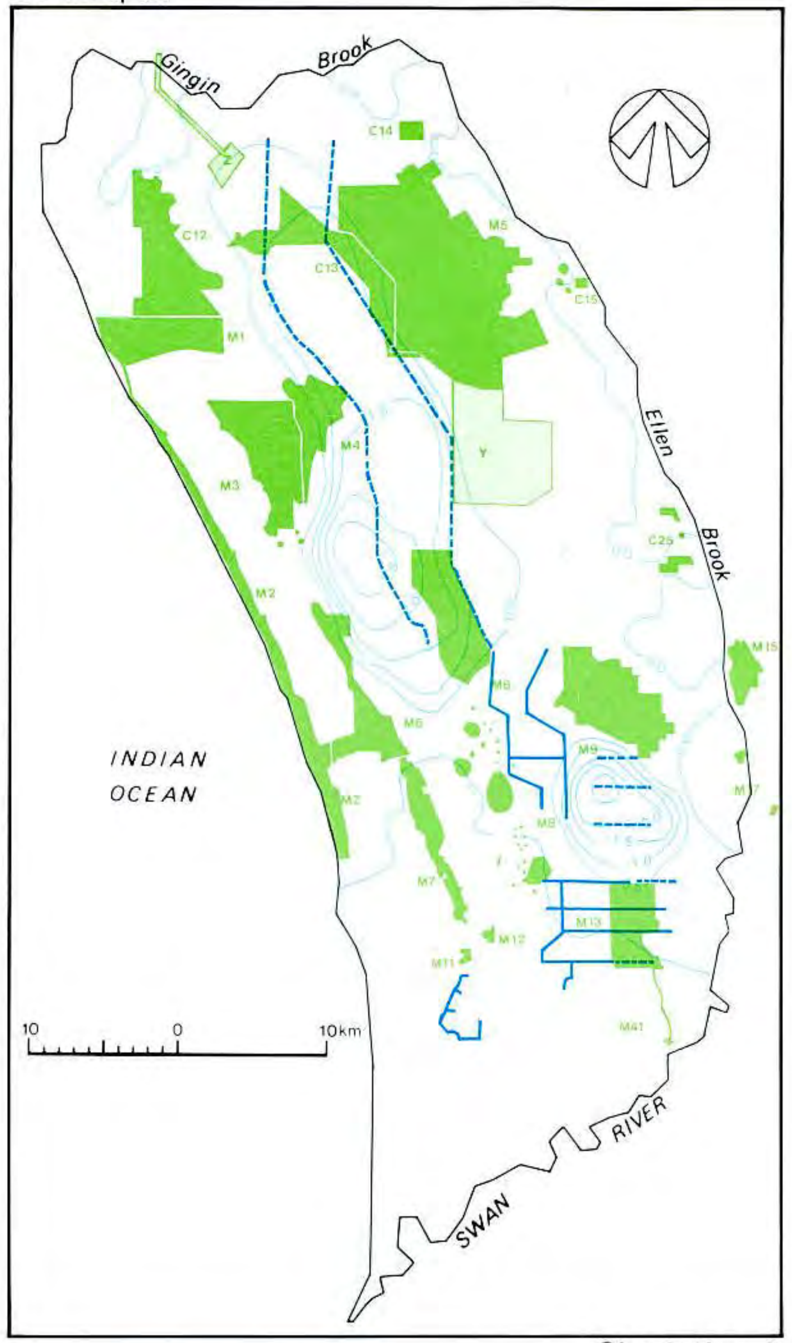
Dames & Moore



SIMULATION OF MAY, 1985 GROUNDWATER LEVELS WITH 1985 PUBLIC AND PRIVATE PUMPING
Simulation 1

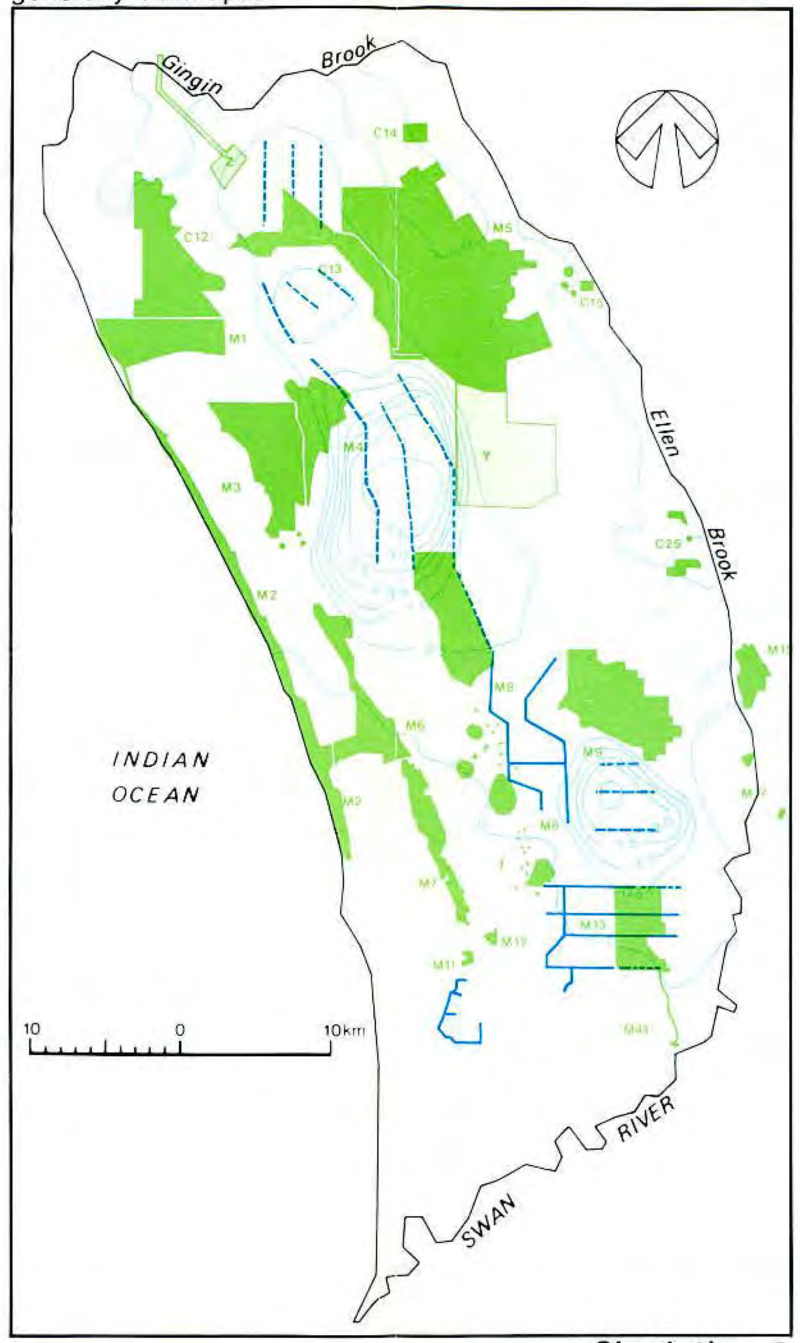
Figure 41
Dames & Moore

Two continuous lines of wells
2-3 km apart



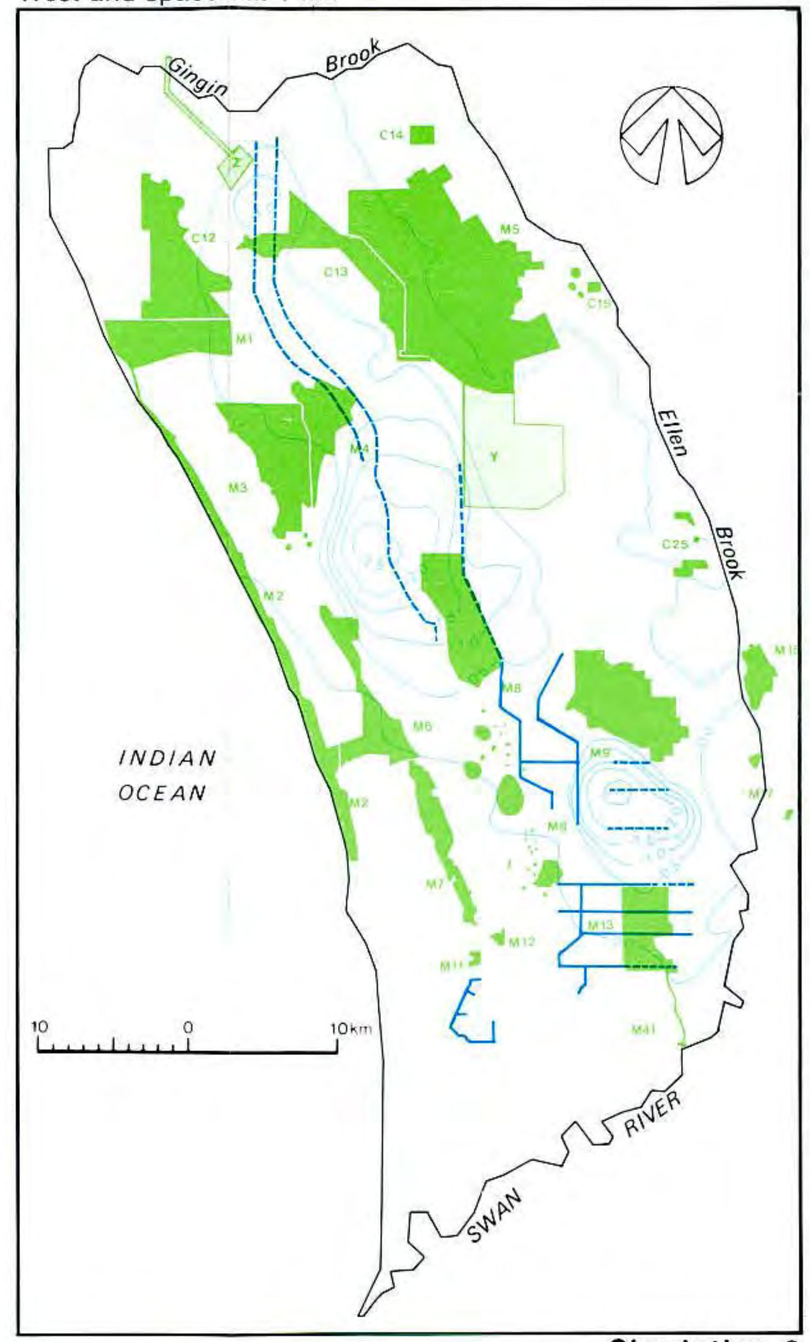
Simulation 6

Three discontinuous lines of wells
generally 1 km apart



Simulation 8

Northern Wellfields shifted to
West and spaced at 1 km



Simulation 9

LEGEND

Area subject to System 6 recommendations

Y — Area being considered by CALM as possible extension to M5 and/or State Forest No. 65

Z — Area being considered by CALM for Barragoon Lake Reserve and Gingin Stock Route Reserve 34761

Groundwater Level Change (m)

Existing Public Water Supply Scheme

Proposed Public Water Supply Scheme

SIMULATION OF GROUNDWATER LEVEL CHANGES DUE TO PUMPING FROM DIFFERENT WELLFIELD CONFIGURATIONS

Figure 42

Dames & Moore

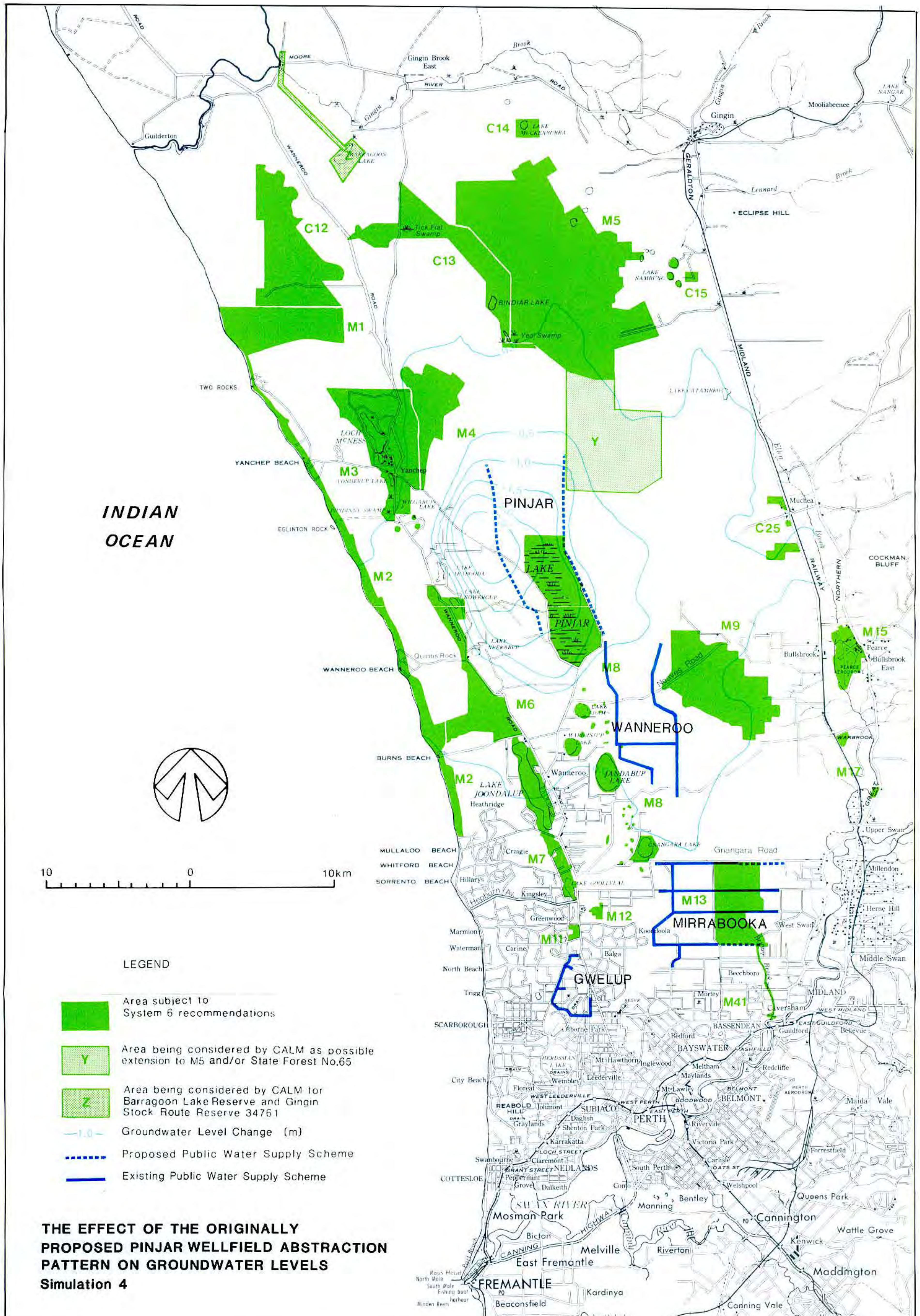
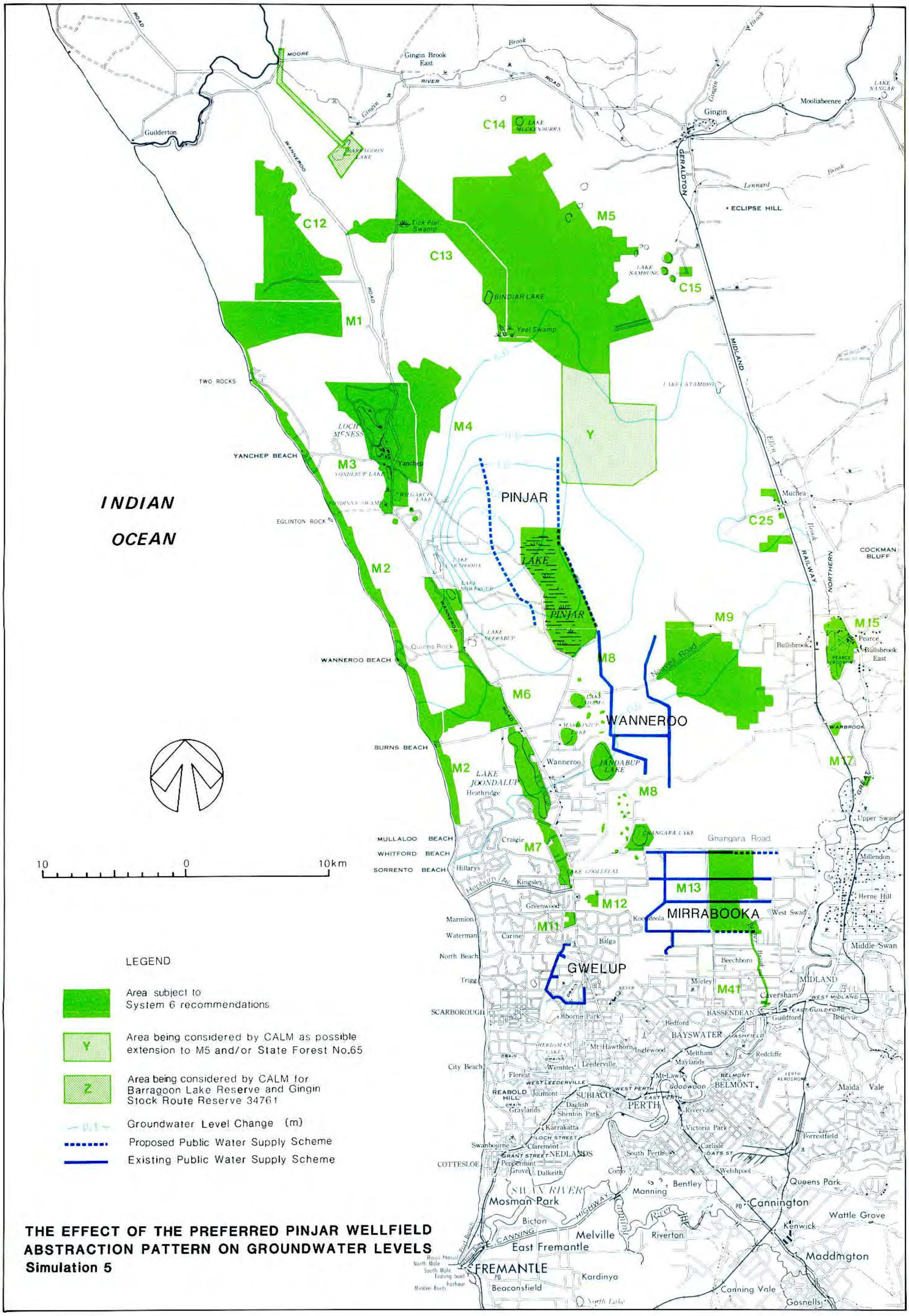


Figure 43
Dames & Moore

THE EFFECT OF THE ORIGINALLY PROPOSED PINJAR WELLFIELD ABSTRACTION PATTERN ON GROUNDWATER LEVELS
Simulation 4

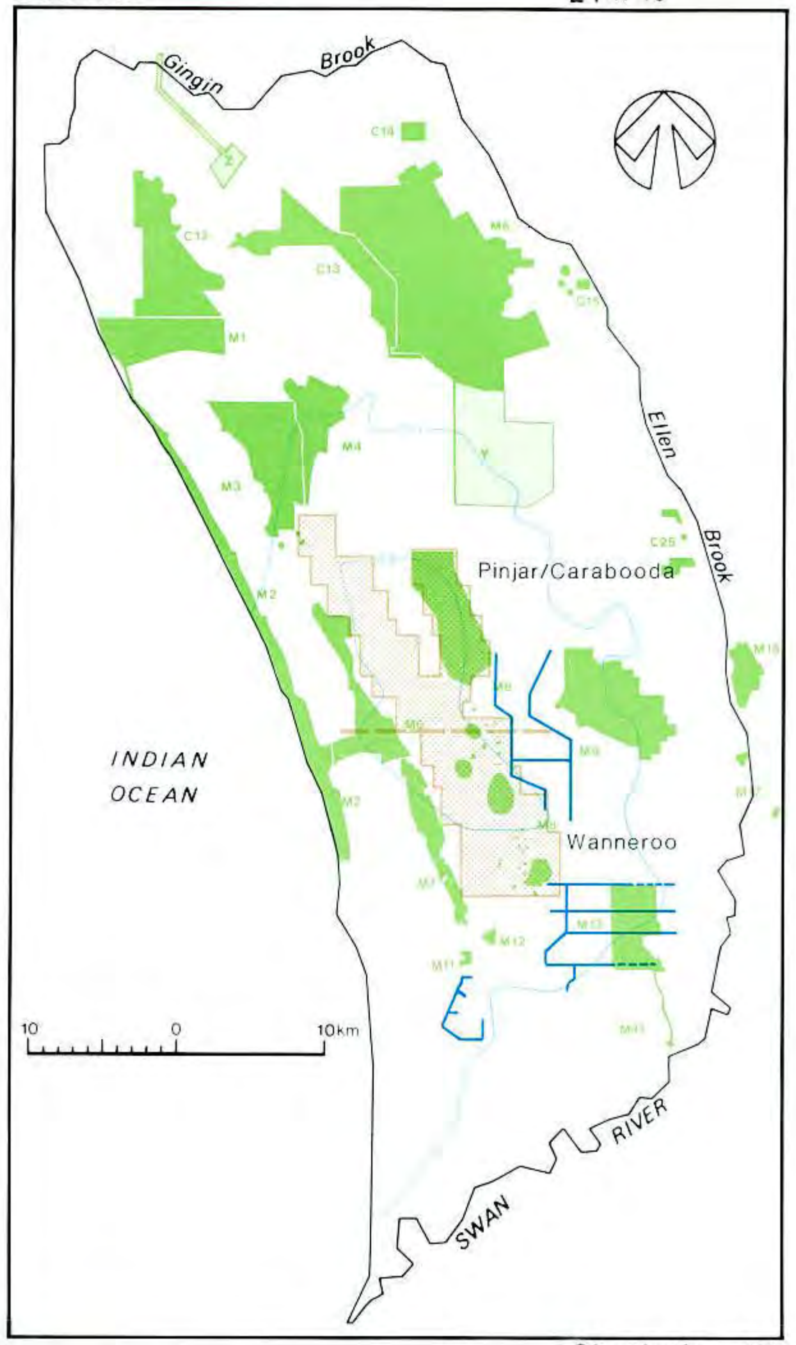


THE EFFECT OF THE PREFERRED PINJAR WELLFIELD ABSTRACTION PATTERN ON GROUNDWATER LEVELS
Simulation 5

Figure 44
Dames & Moore

MEDIUM
Simulated Pumping Volumes (cubic metres per year)

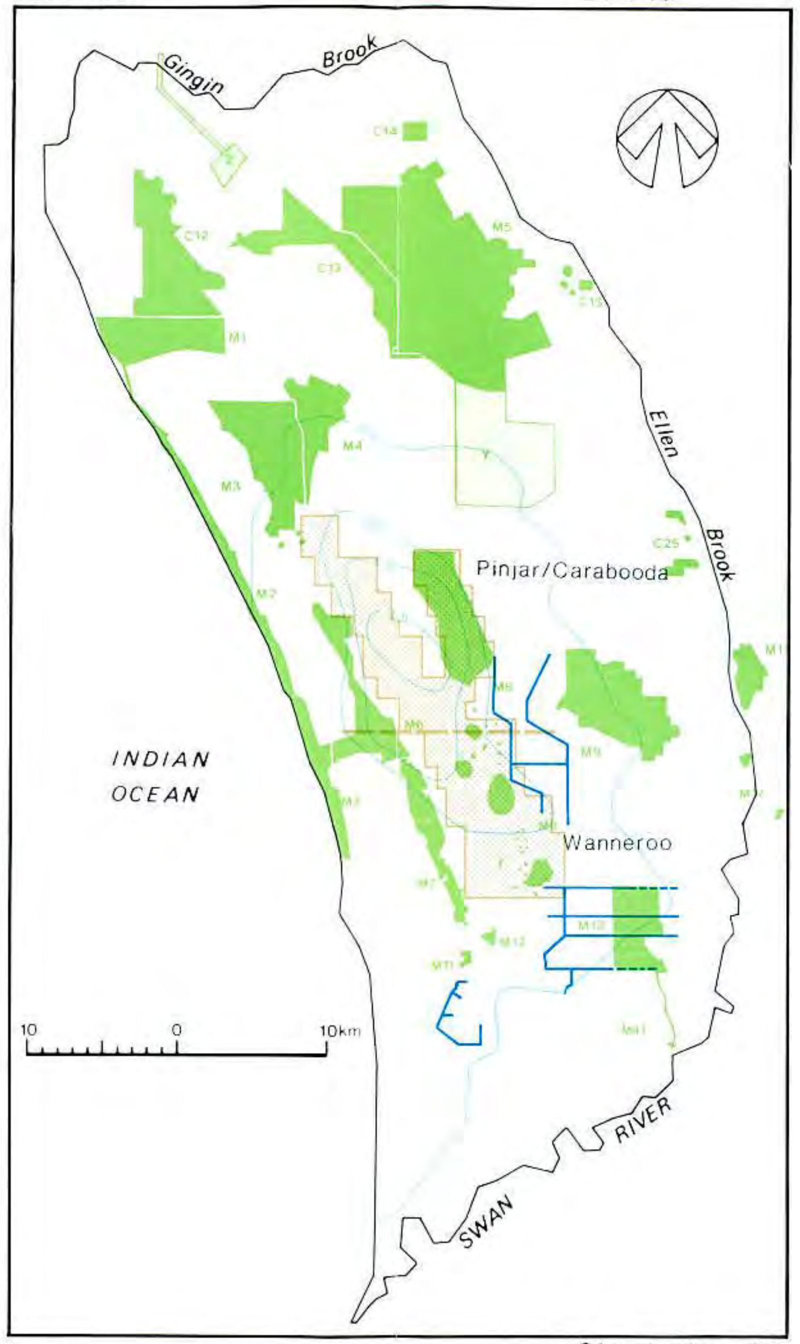
Pinjar/Carabooda	15×10^6
Wanneroo	21×10^6



Simulation 12

HIGH
Simulated Pumping Volumes (cubic metres per year)

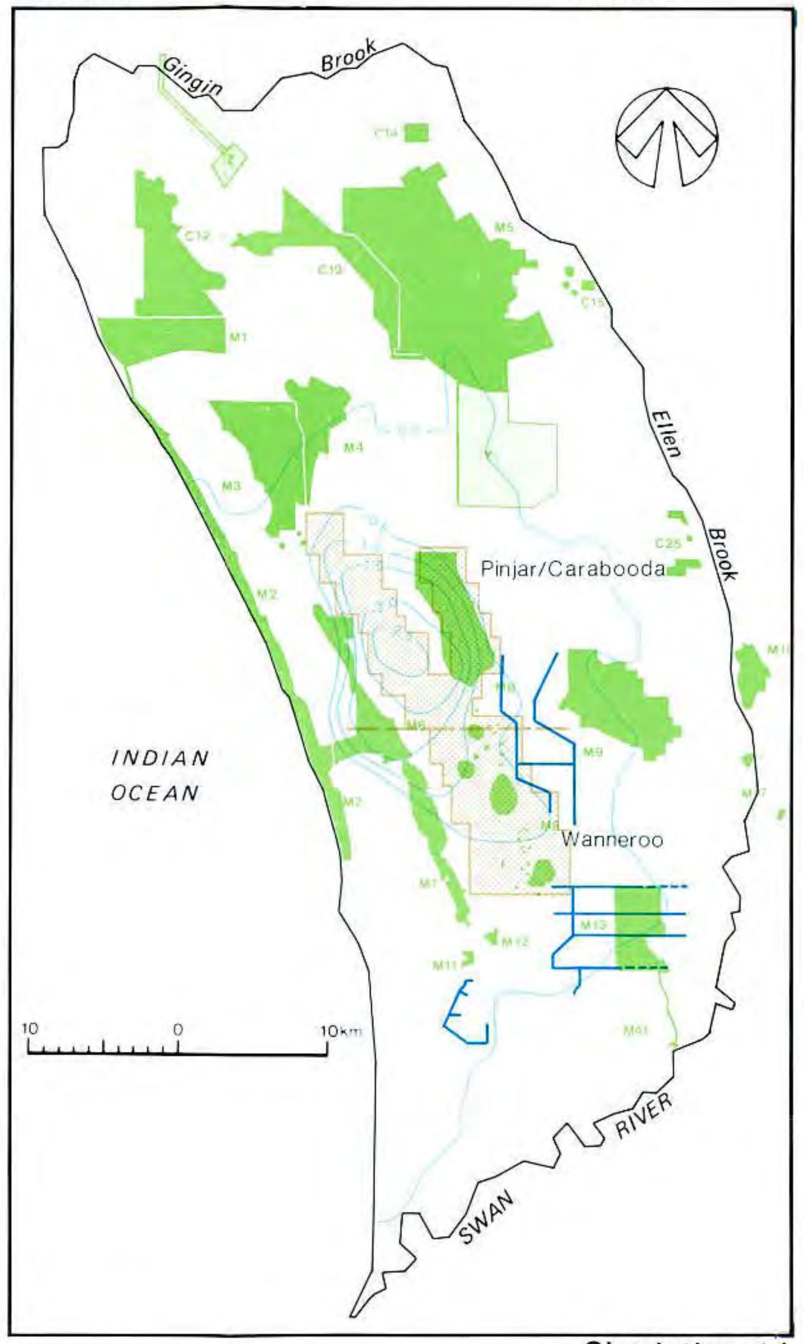
Pinjar/Carabooda	21×10^6
Wanneroo	21×10^6



Simulation 13

VERY HIGH
Simulated Pumping Volumes (cubic metres per year)

Pinjar/Carabooda	29×10^6
Wanneroo	21×10^6



Simulation 14

LEGEND

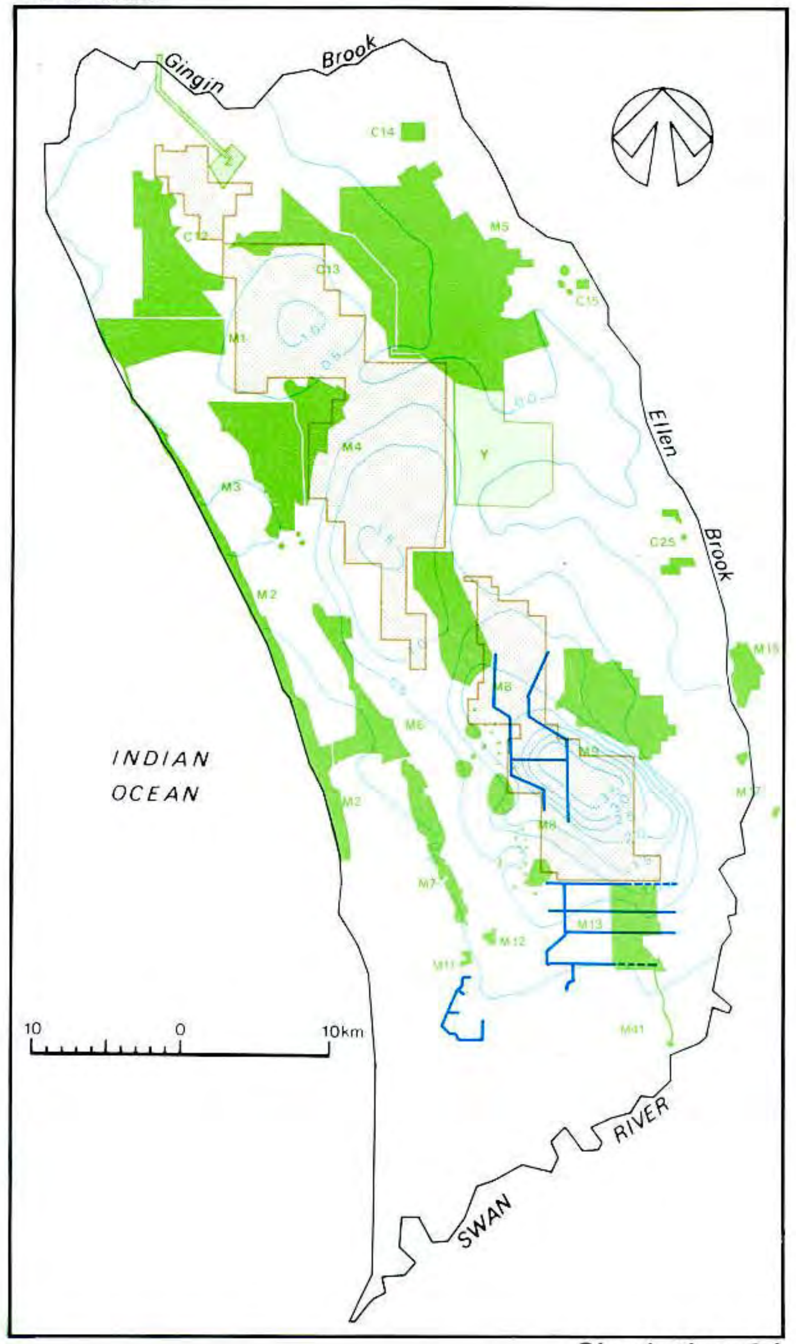
- Area subject to System 6 recommendations
- Y — Area being considered by CALM as possible extension to M5 and/or State Forest No. 65
- Z — Area being considered by CALM for Barragoon Lake Reserve and Gingin Stock Route Reserve 34761
- Groundwater Level Change (m)
- Existing Public Water Supply Scheme
- Rural areas suitable for horticulture

SIMULATION OF GROUNDWATER LEVEL CHANGES DUE TO INCREASES IN PRIVATE ABSTRACTION

Figure 45

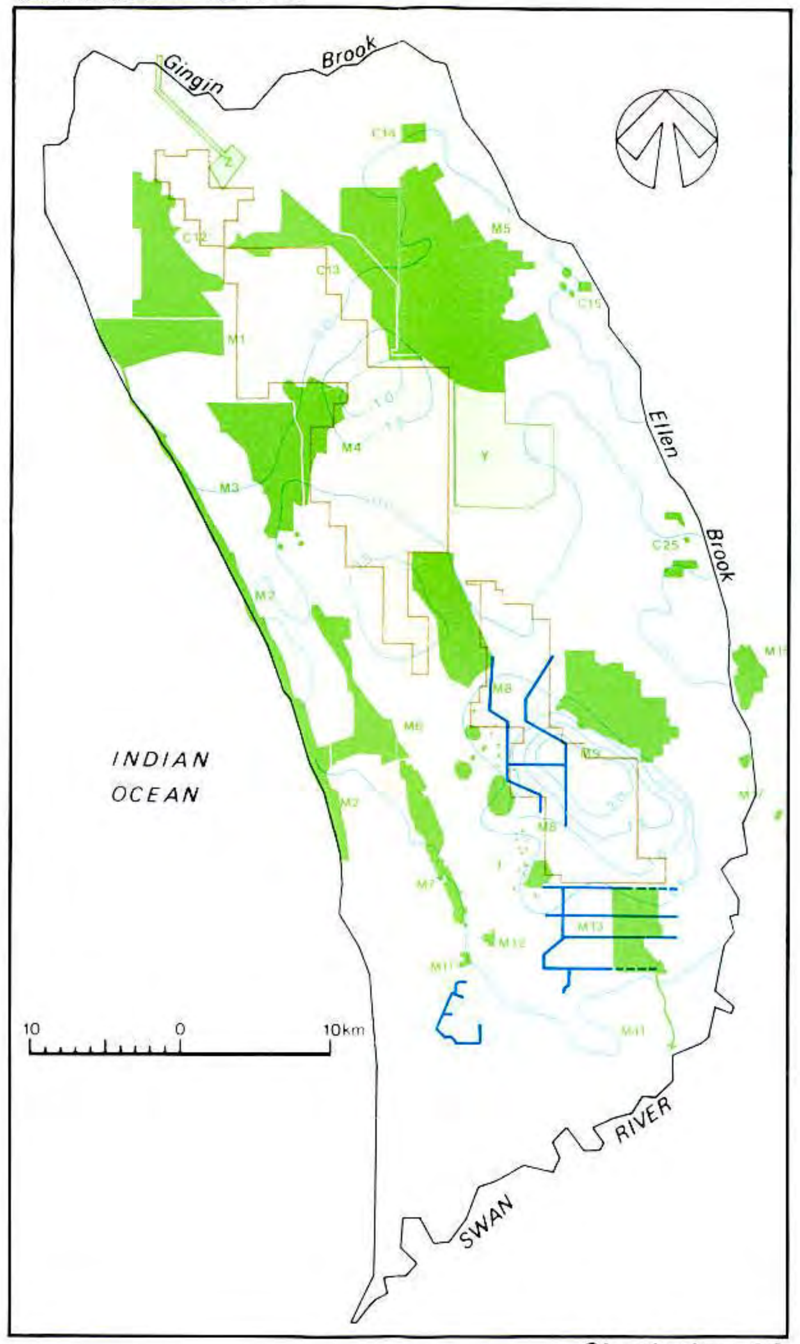
Dames & Moore

Canopy cover changed from existing to equivalent of native forest



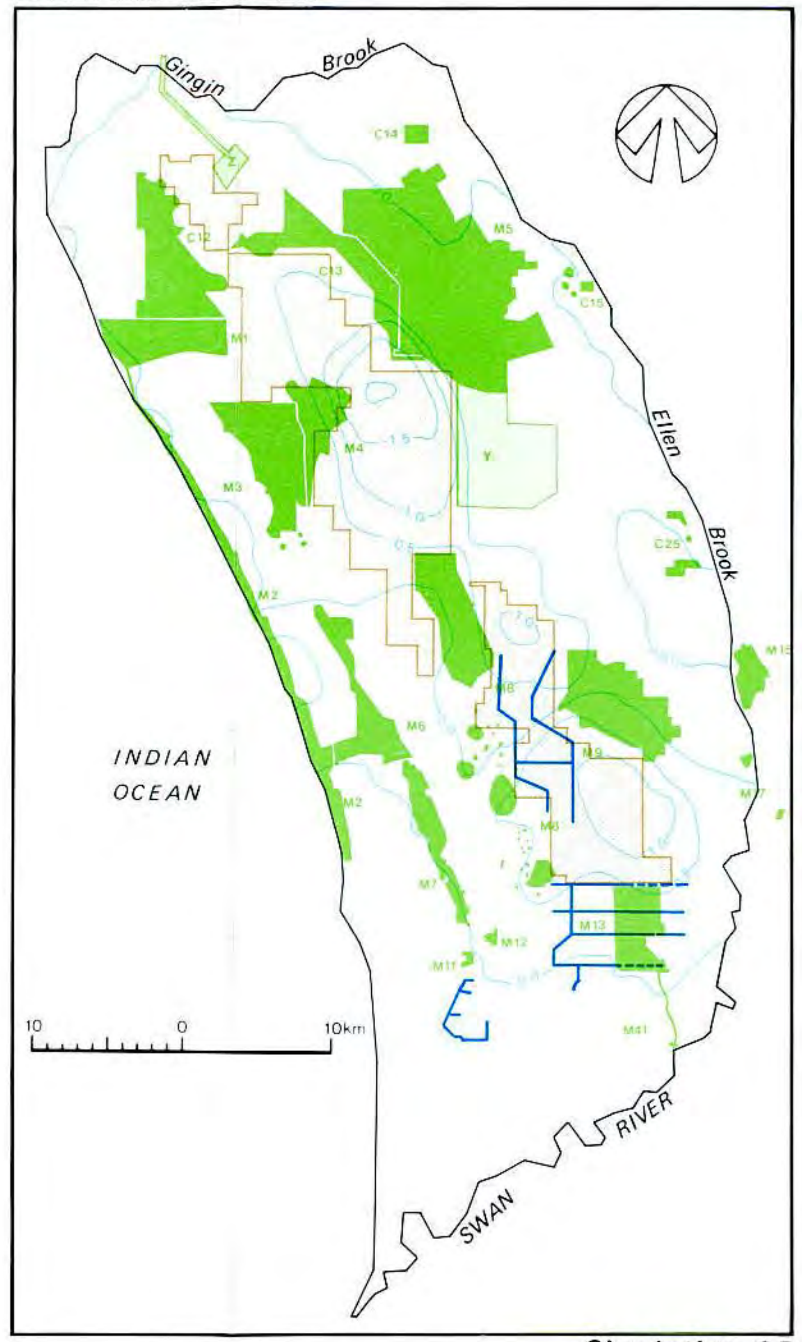
Simulation 24

Canopy cover changed from existing to equivalent of basal area of 7-15m²/ha



Simulation 23

Canopy cover changed from existing to equivalent of basal area of 15-20m²/ha



Simulation 25

LEGEND

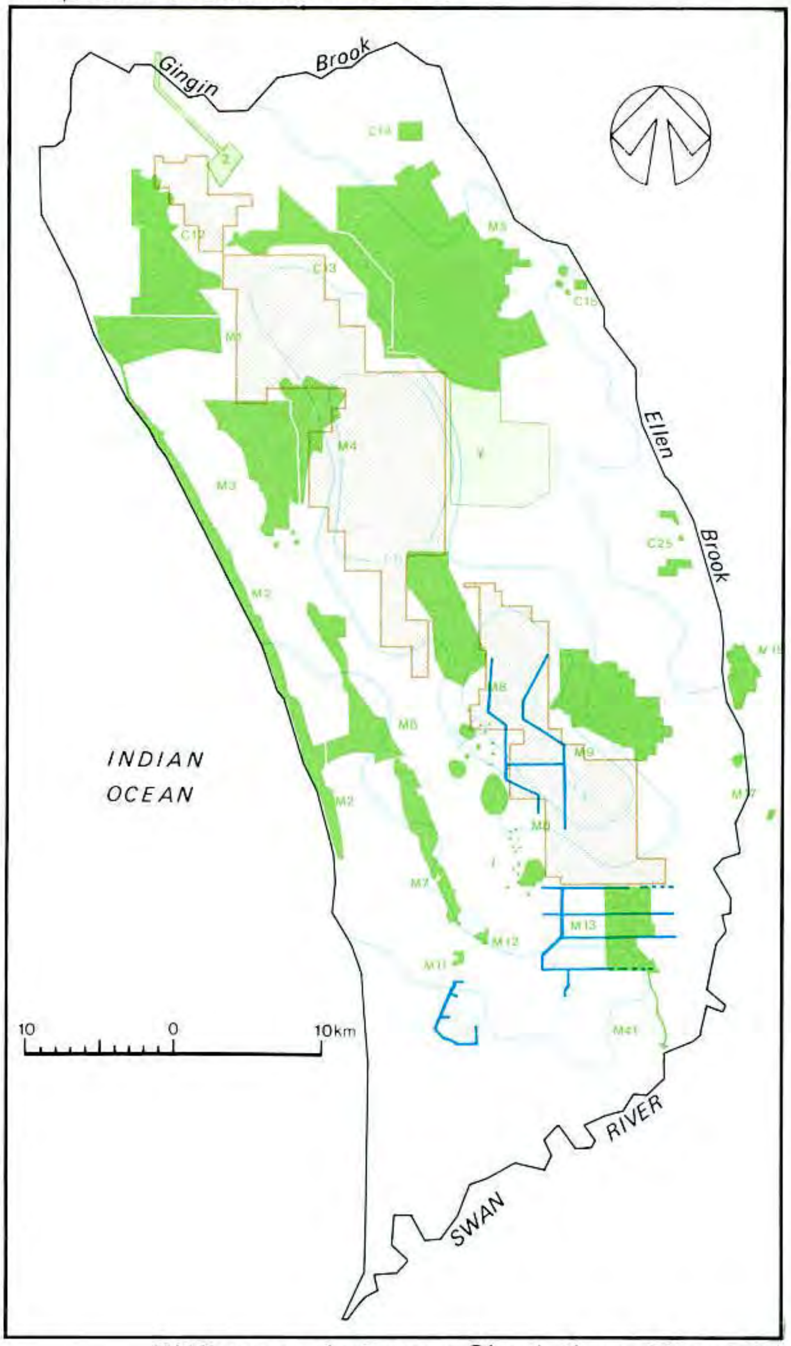
- Area subject to System 6 recommendations
- Y Area being considered by CALM as possible extension to M5 and/or State Forest No. 65
- Z Area being considered by CALM for Barragoon Lake Reserve and Gingin Stock Route Reserve 34761
- Groundwater Level Change (m)
- Existing Public Water Supply Scheme
- State Forest No. 65 Plantation Area

SIMULATION OF GROUNDWATER LEVEL CHANGES DUE TO EFFECTS OF DIFFERENT FOREST CANOPY COVERS

Figure 46

Dames & Moore

Canopy cover changed from equivalent of native forest to equivalent of basal area 7-15m²/ha



Difference between Simulations 23and 24

LEGEND

Area subject to System 6 recommendations

Y Area being considered by CALM as possible extension to M5 and/or State Forest No. 65

Z Area being considered by CALM for Barragoon Lake Reserve and Gingin Stock Route Reserve 34761

Groundwater Level Change (m)

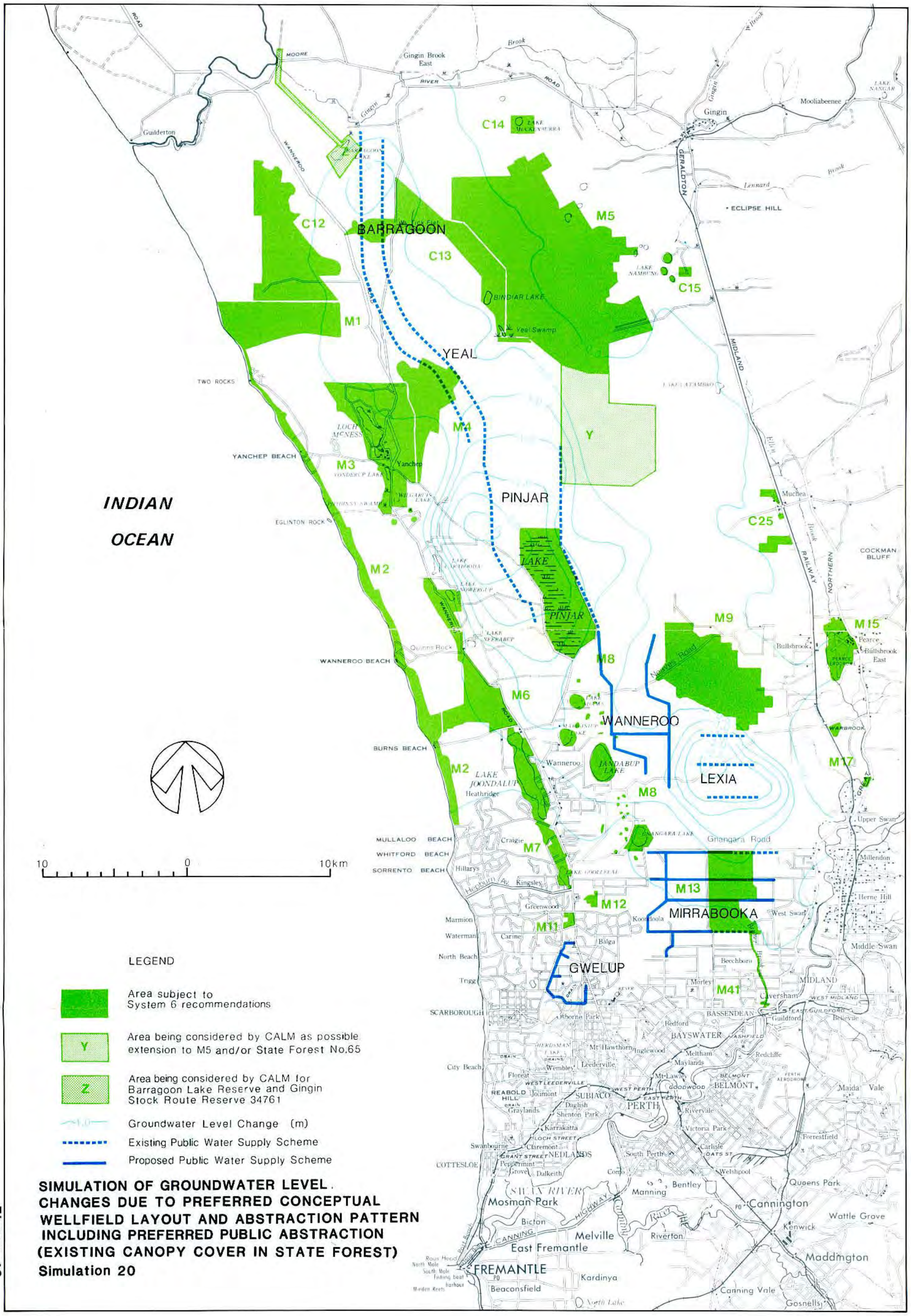
Existing Public Water Supply Scheme

State Forest No. 65 Plantation Area

SIMULATION OF GROUNDWATER LEVEL CHANGES DUE TO CHANGING CANOPY COVER FROM EQUIVALENT OF NATIVE FOREST TO EQUIVALENT OF PINE FOREST BASAL AREA OF 7-15m²/ha

Figure 47

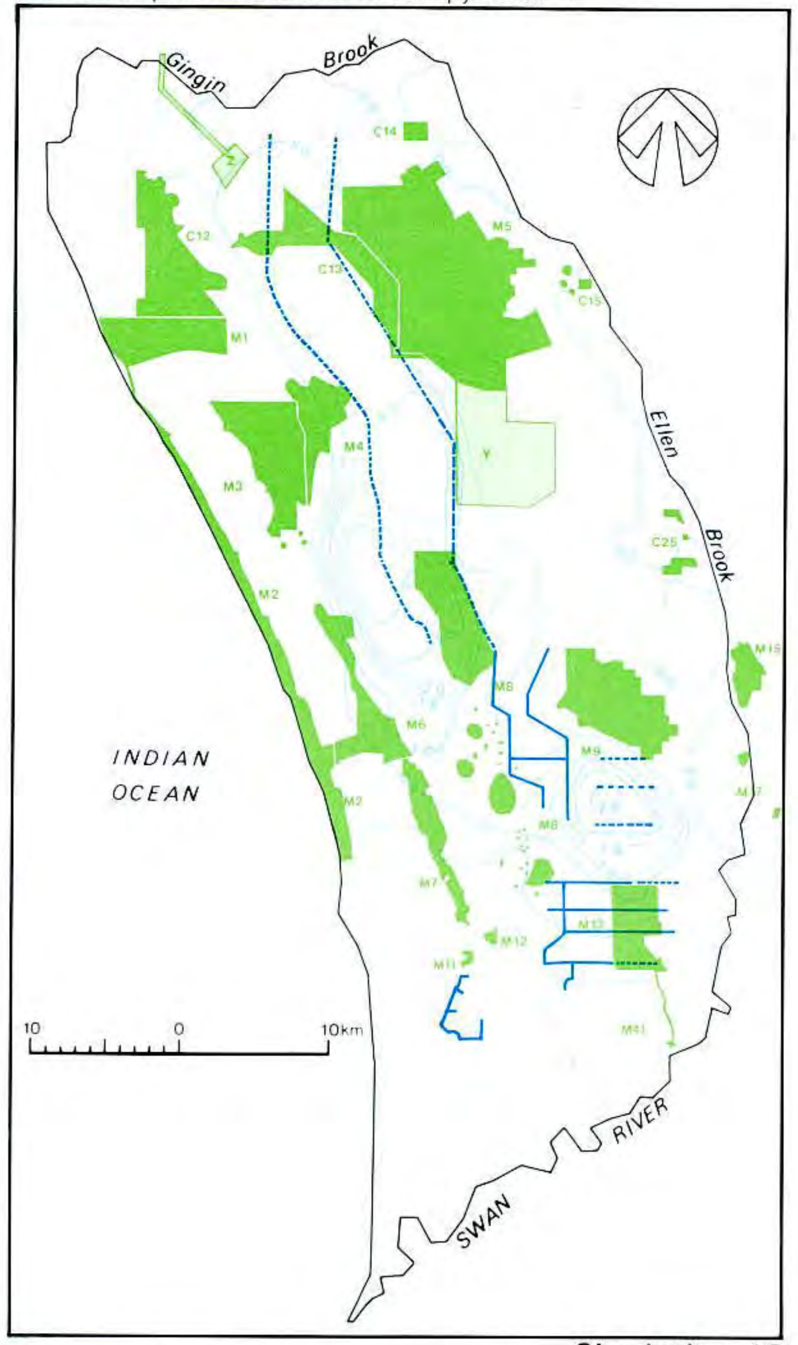
Dames & Moore



SIMULATION OF GROUNDWATER LEVEL CHANGES DUE TO PREFERRED CONCEPTUAL WELLFIELD LAYOUT AND ABSTRACTION PATTERN INCLUDING PREFERRED PUBLIC ABSTRACTION (EXISTING CANOPY COVER IN STATE FOREST)
Simulation 20

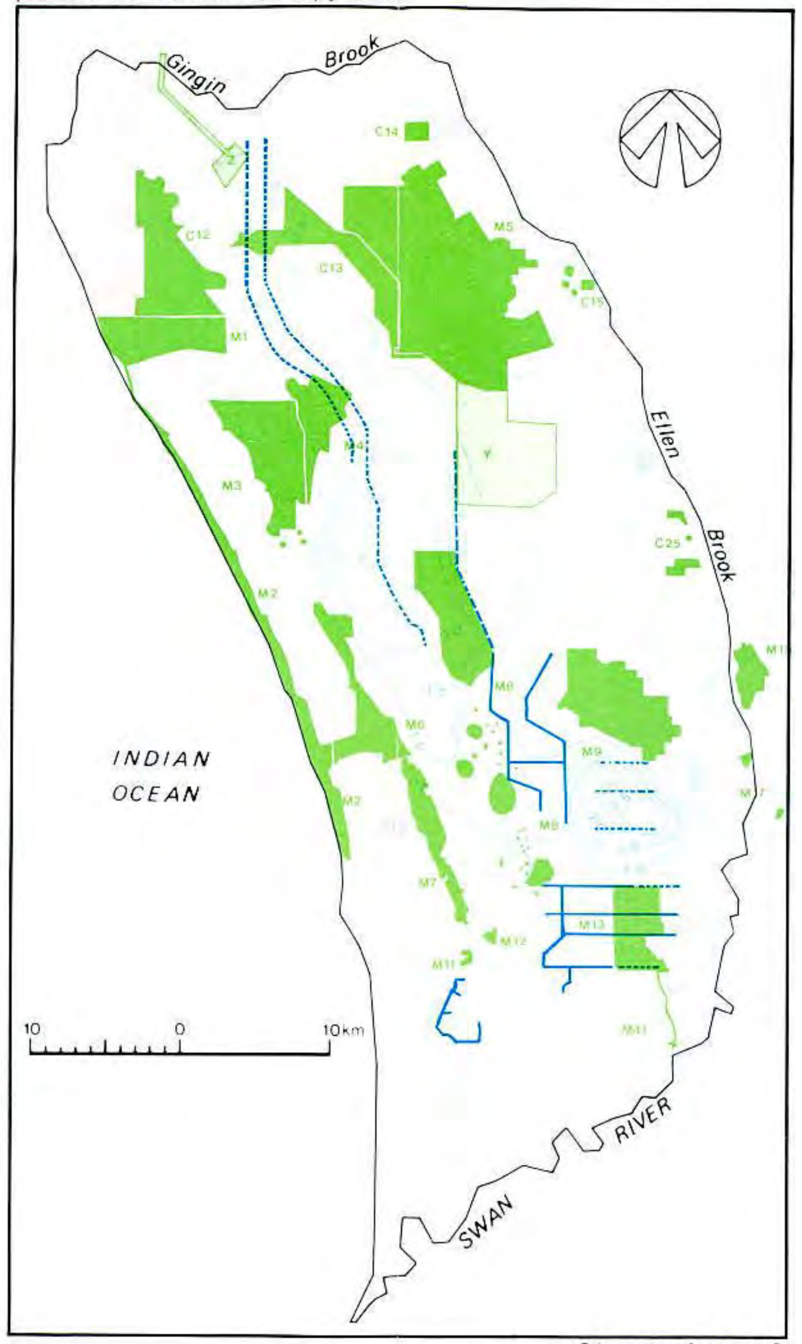
Figure 48
Dames & Moore

Originally Proposed Wellfield layout and abstraction pattern with current canopy cover



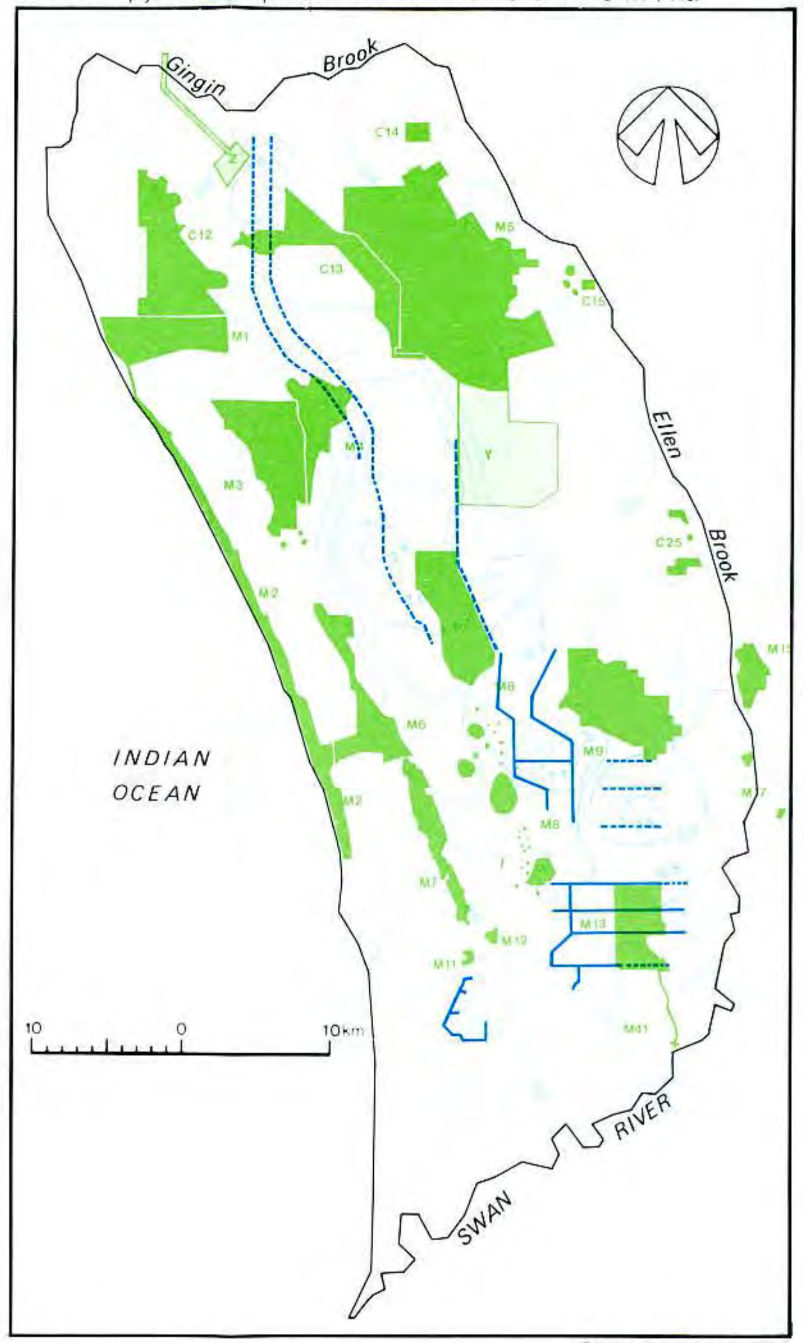
Simulation 15

Modified Wellfield layout and abstraction pattern with current canopy cover



Simulation 20

Modified Wellfield layout and abstraction pattern with canopy cover equivalent to basal area of 7-15 m^2/ha



Simulation 23

LEGEND

Area subject to System 6 recommendations

Y Area being considered by CALM as possible extension to M5 and/or State Forest No. 65

Z Area being considered by CALM for Barragoon Lake Reserve and Gingin Stock Route Reserve 34761

Groundwater Level Change (m)

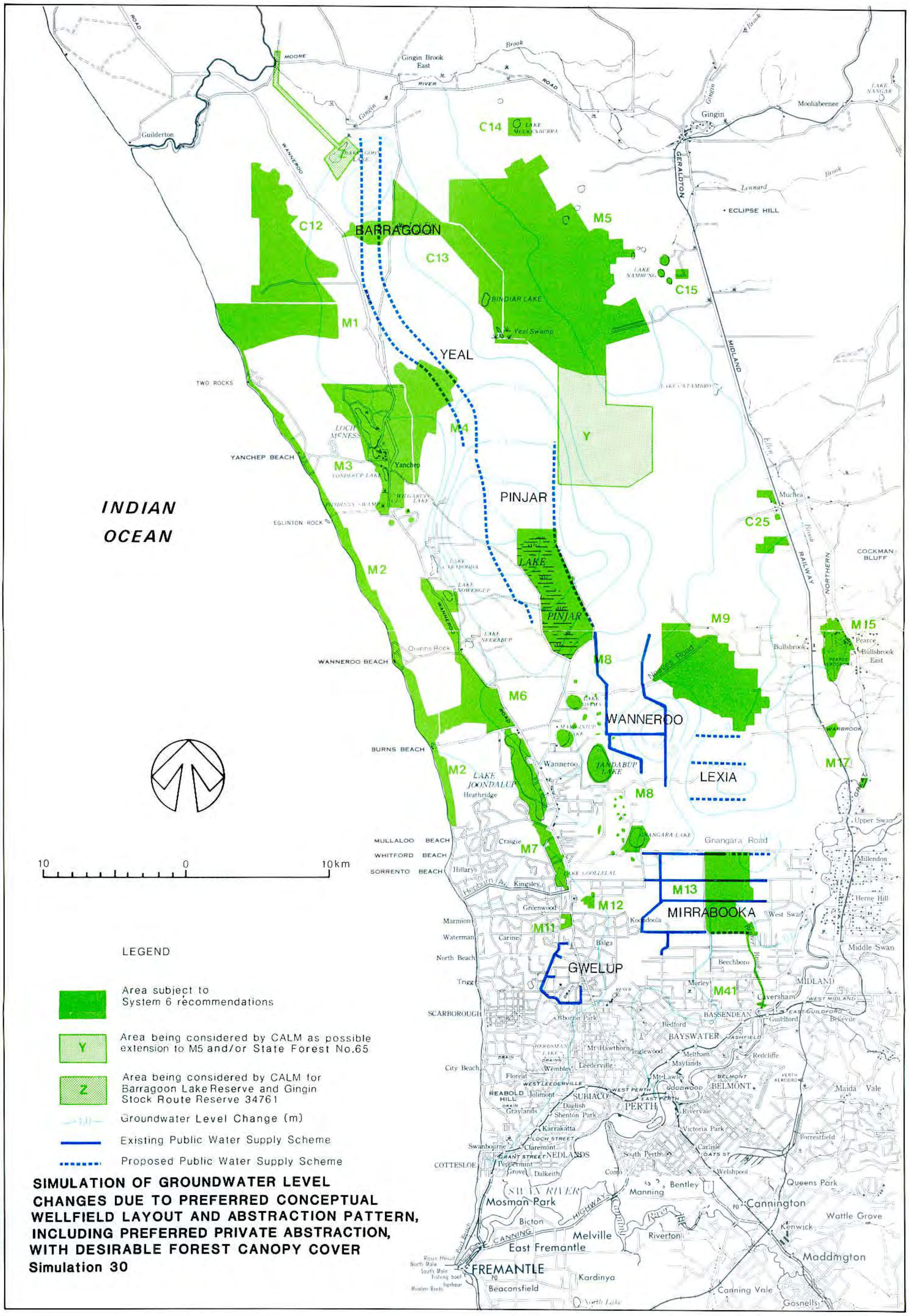
Existing Public Water Supply Scheme

Proposed Public Water Supply Scheme

SIMULATION OF GROUNDWATER LEVEL CHANGES DUE TO DIFFERENT WELLFIELD LAYOUTS, ABSTRACTION PATTERNS AND FOREST CANOPY COVERS INCLUDING PREFERRED PRIVATE ABSTRACTION

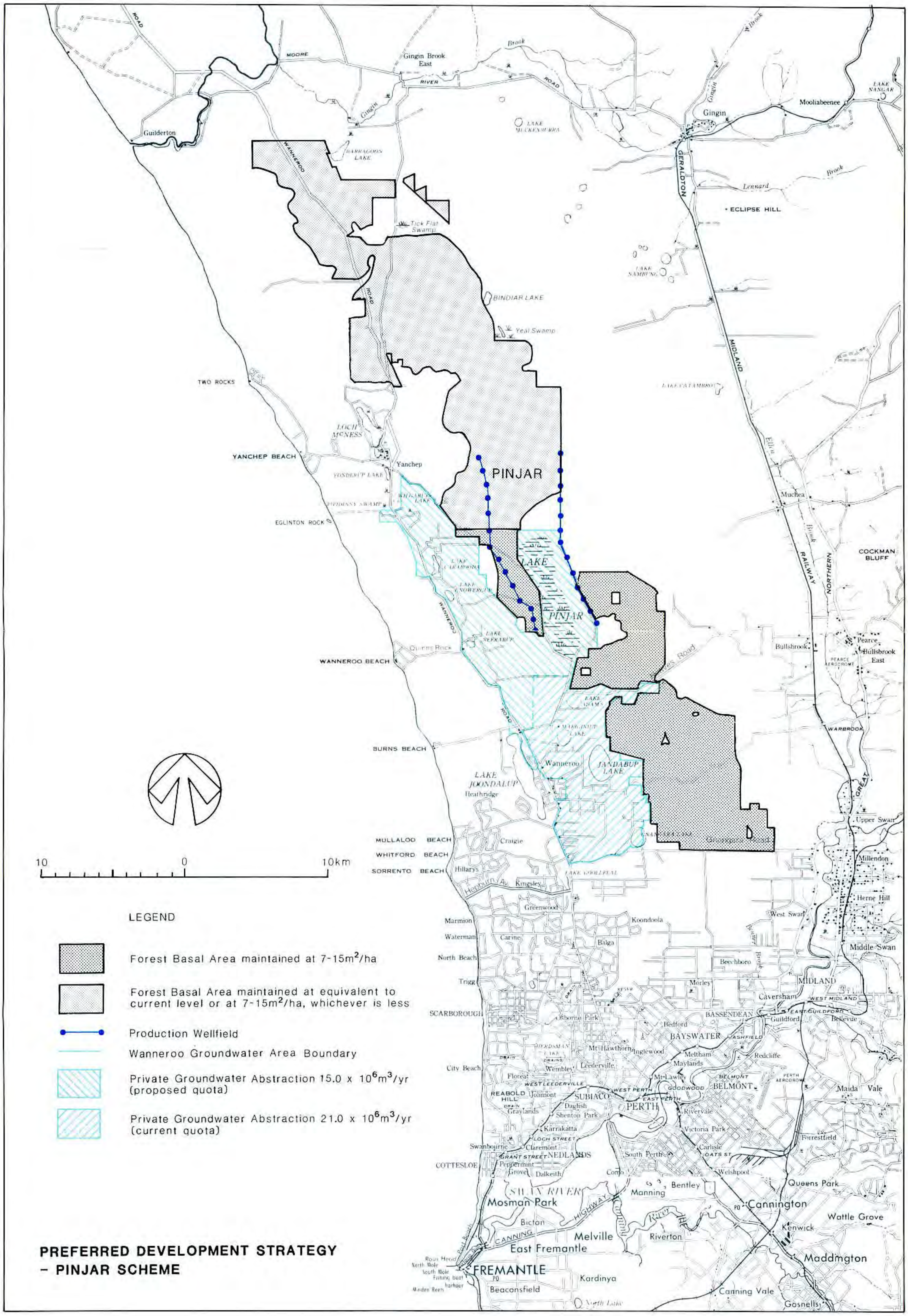
Figure 49

Dames & Moore



SIMULATION OF GROUNDWATER LEVEL CHANGES DUE TO PREFERRED CONCEPTUAL WELLFIELD LAYOUT AND ABSTRACTION PATTERN, INCLUDING PREFERRED PRIVATE ABSTRACTION, WITH DESIRABLE FOREST CANOPY COVER
Simulation 30

Figure 50
Dames & Moore



PREFERRED DEVELOPMENT STRATEGY - PINJAR SCHEME

Figure 51
Dames & Moore